

Hempoxies: The 99% Hemp-Derived Programmable Materials Platform

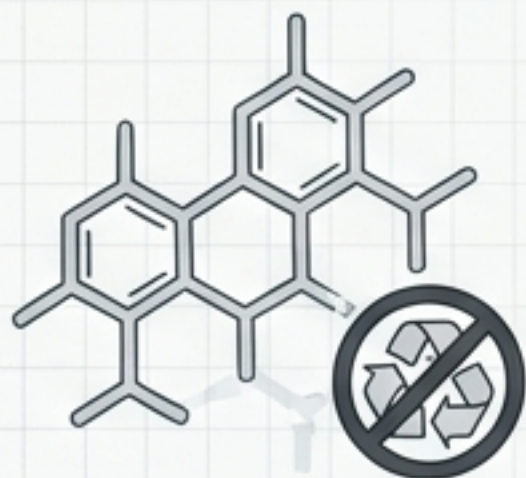
Complete Formulation, Hierarchical Processing, and Vitrimer Network Criteria



The materials industry is trapped in a binary compromise between strength and circularity.

Traditional Thermosets

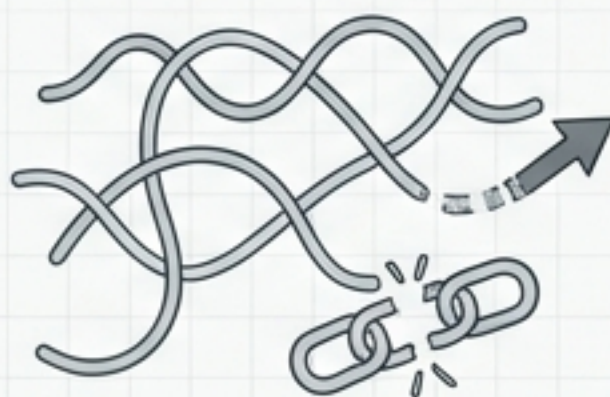
(e.g., standard epoxy).
High mechanical strength,
rigid cross-linking.



Fatal flaw:
Unrecyclable,
permanent bonds.

Thermoplastics

(e.g., ABS).
Recyclable,
melt-processable.



Fatal flaw: Weak
structural integrity,
susceptible to creep.

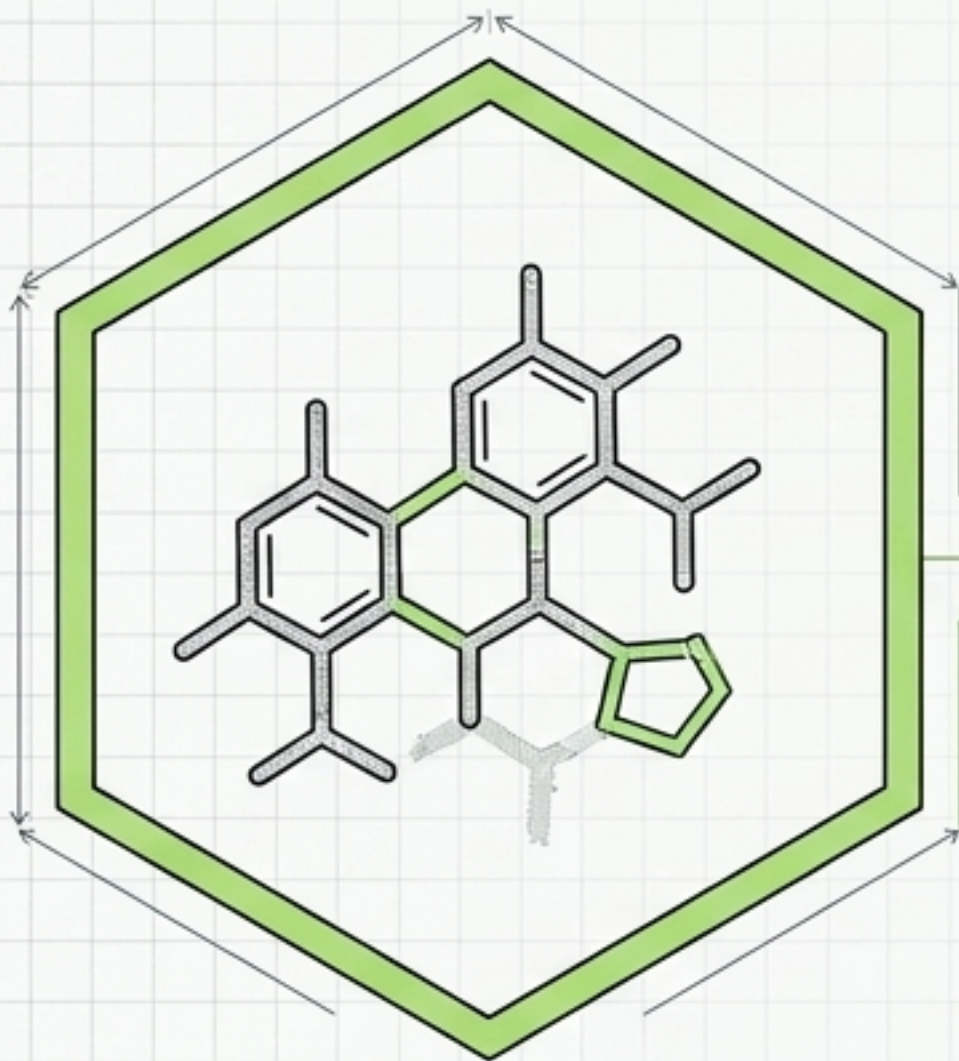
Hemp Vitrimers

High strength covalent
networks + dynamic
reprocessability.



The Advantage: The
Goldilocks solution,
>99% bio-based.

Vitrimer chemistry bridges the performance gap, and *Cannabis sativa* L. provides the complete structural blueprint.



The Matrix: Epoxidized and Maleinized Hempseed Oil (EHO + MHO) form the covalently cross-linked base.

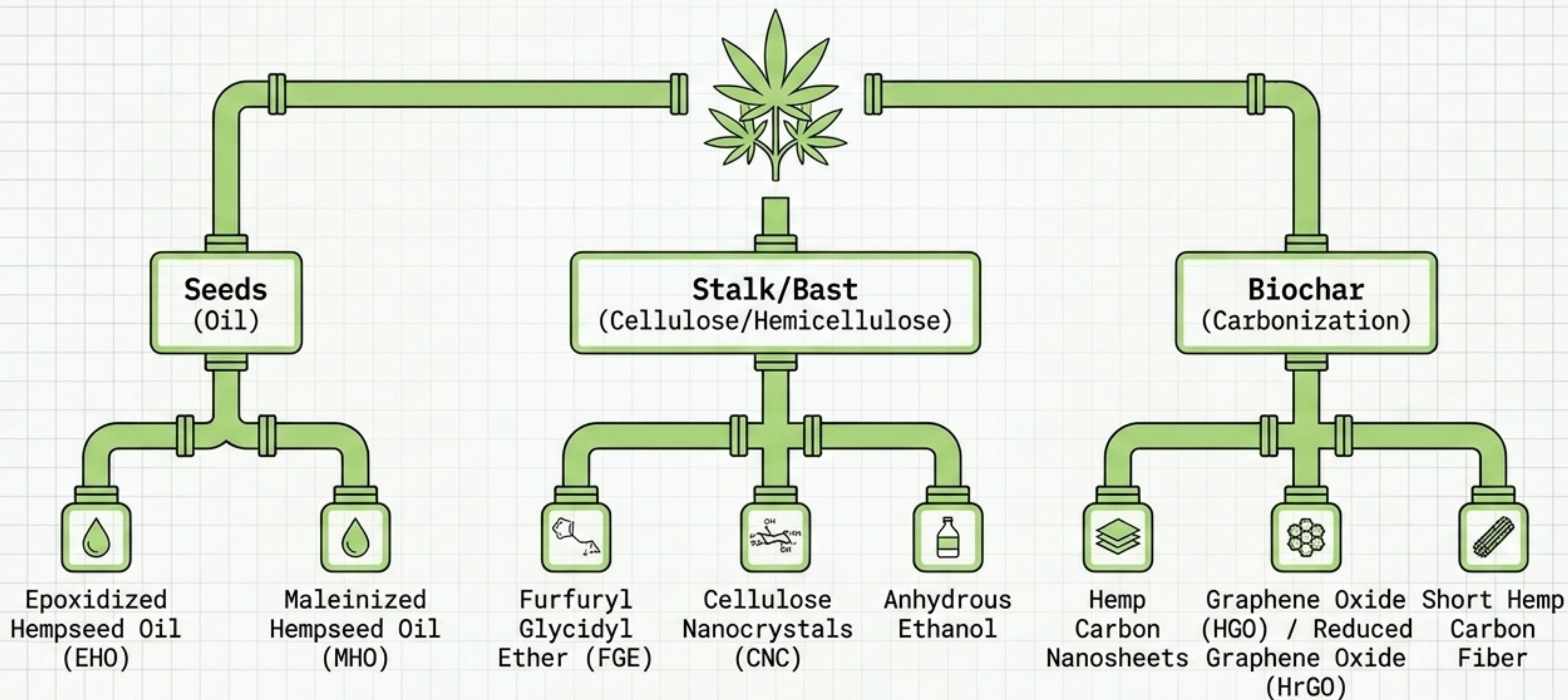


The Catalyst: Zinc acetylacetonate enables beta-hydroxy ester dynamic exchange under heat.



The Reinforcement: Hemp-derived multiscale architectures prevent mechanical failure across five dimensional scales.

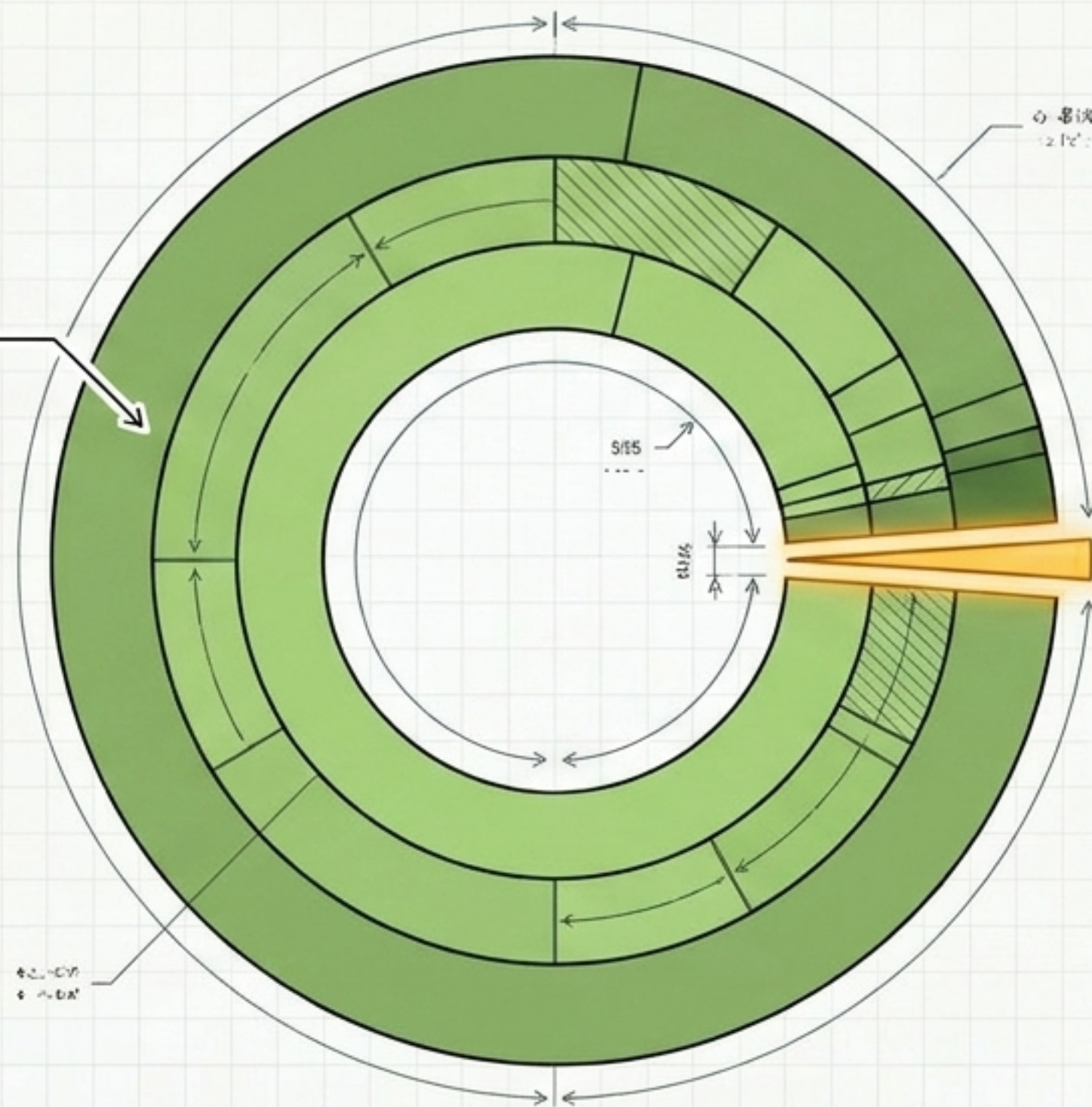
A single monoculture crop cascades into eight discrete chemical and structural components.



The >99% bio-based claim relies on isolating the minimal non-hemp catalytic fraction.

98.5% total mass.

100% renewable carbon
via ASTM D6866 / ISO 16620
radiocarbon analysis.



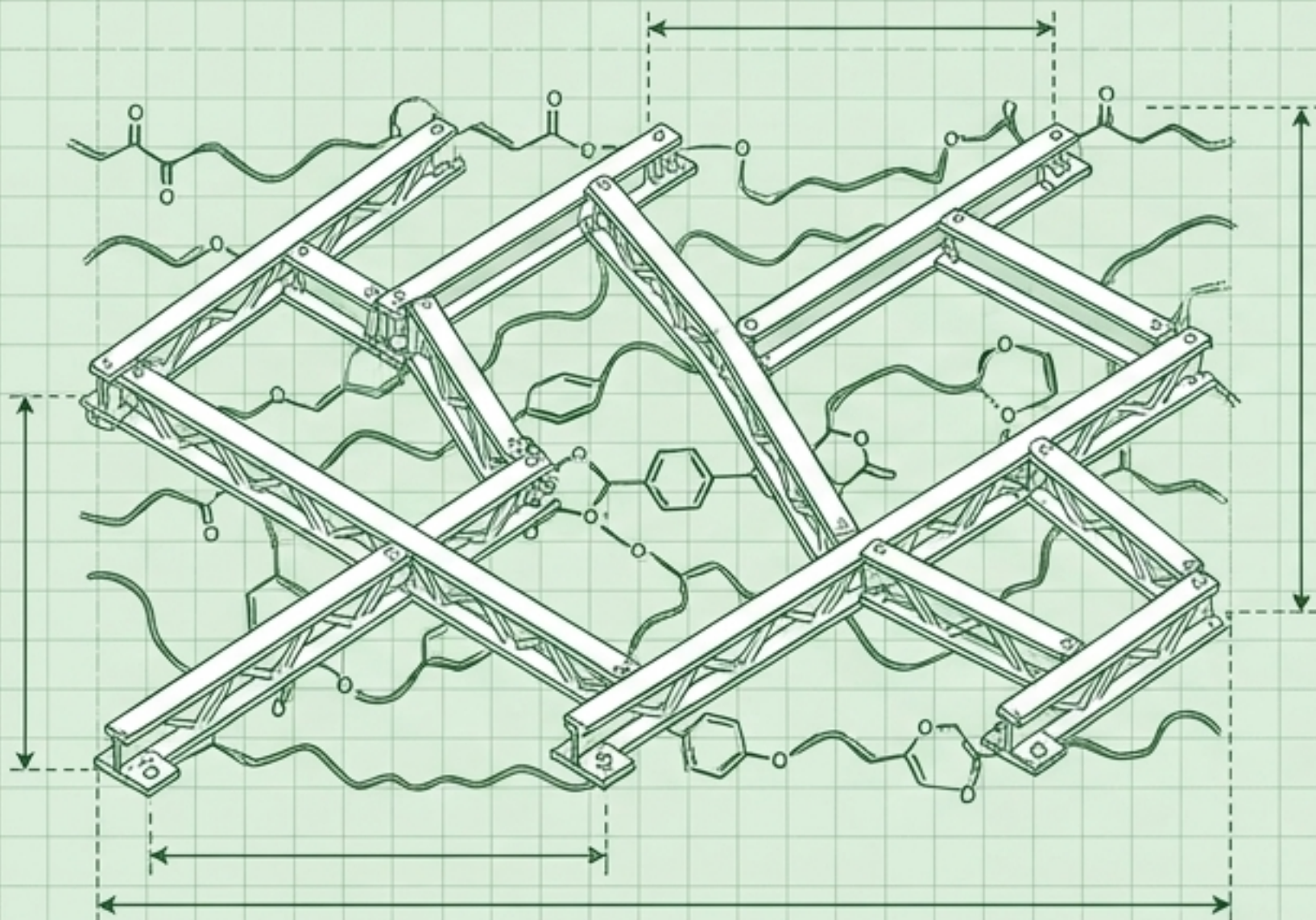
1.5% total mass.

Zinc acetylacetonate
($\text{Zn}(\text{acac})_2$).

The non-negotiable cure
and transesterification
catalyst.

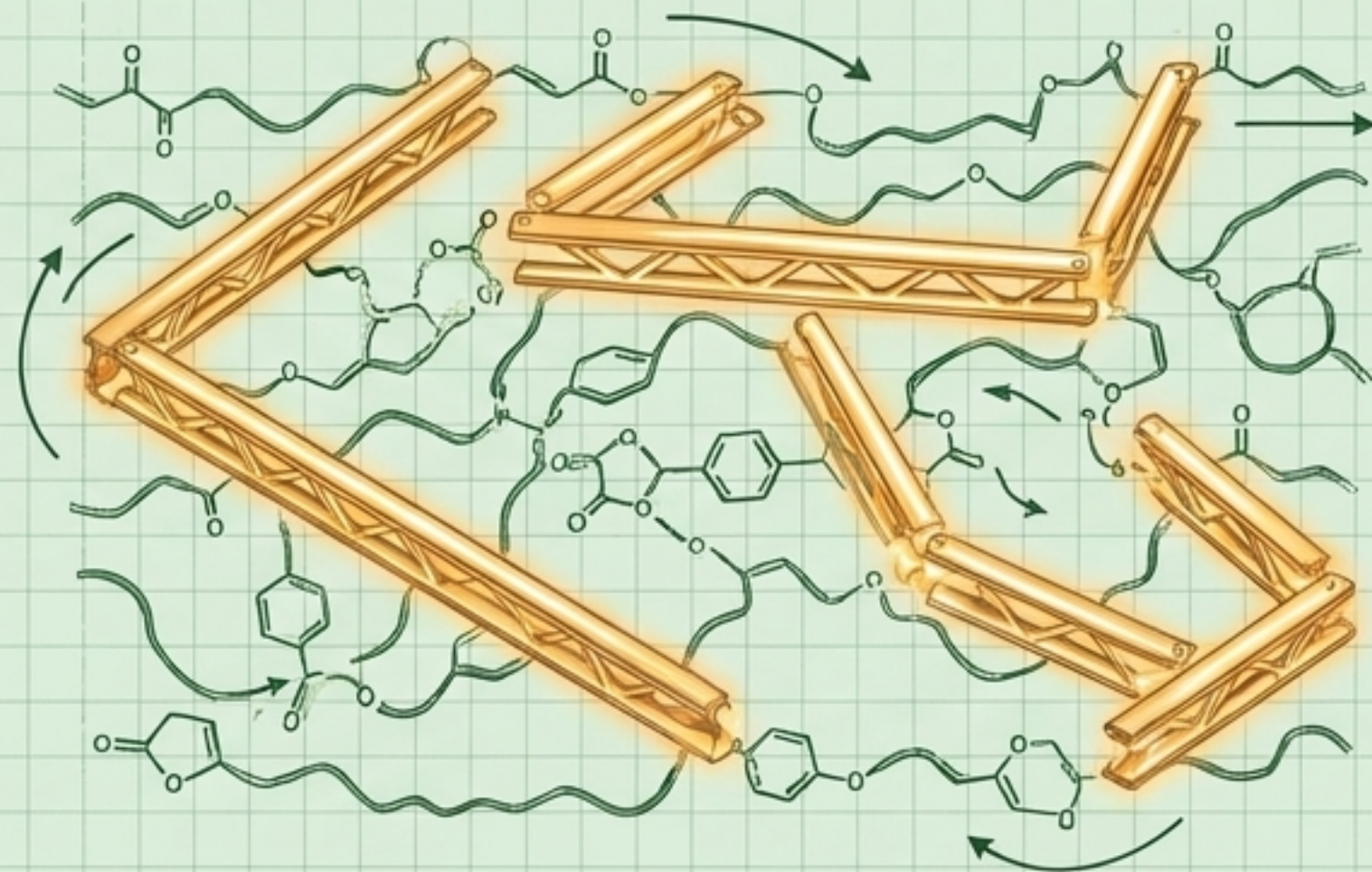
Beta-hydroxy ester linkages provide thermoset rigidity at room temperature and fluid reorganization under heat.

State 1 (Room Temp)



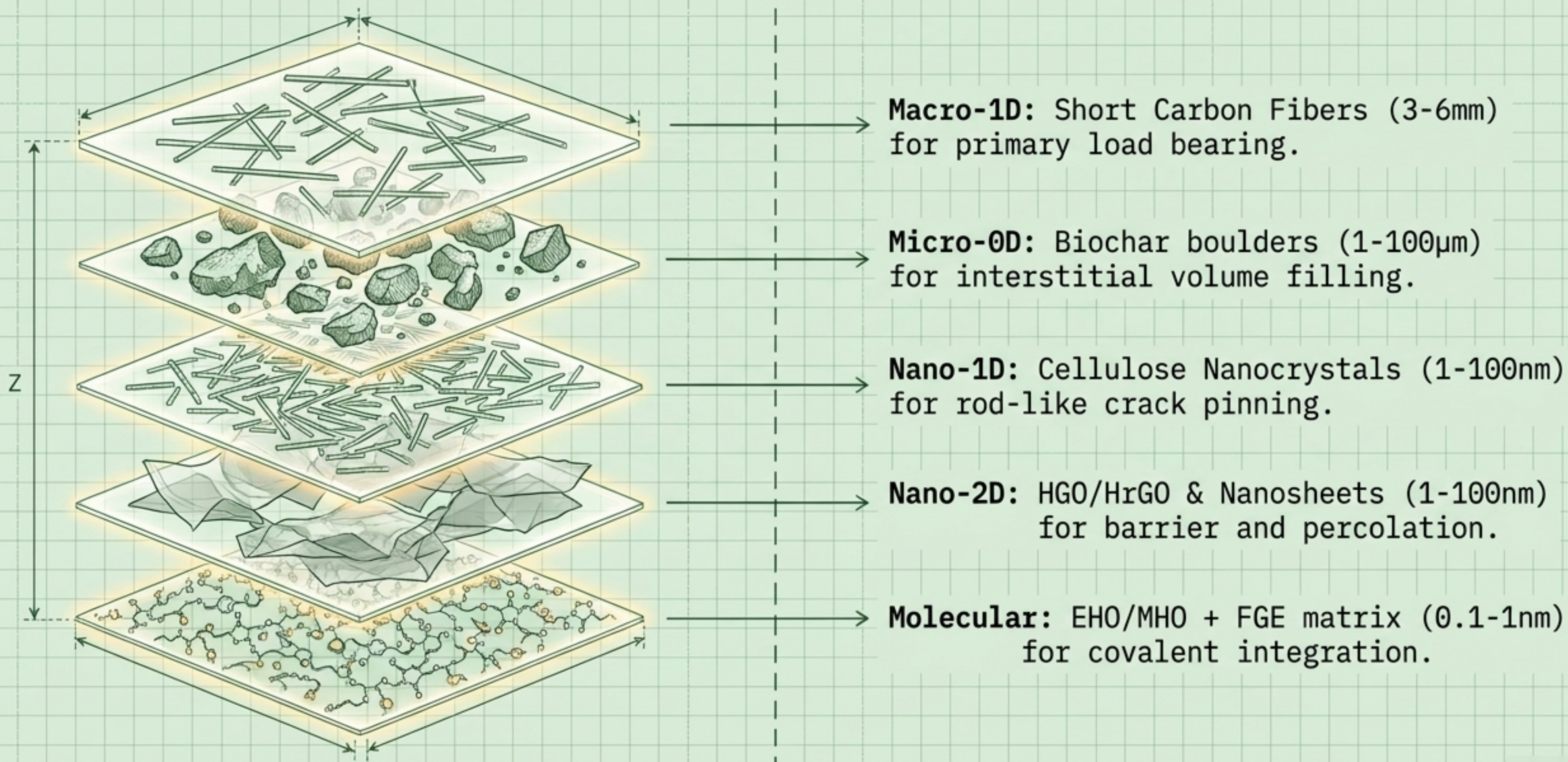
Solid state. Permanent cross-linked network.
High load-bearing capacity.

State 2 (180°C + Zinc Catalyst)

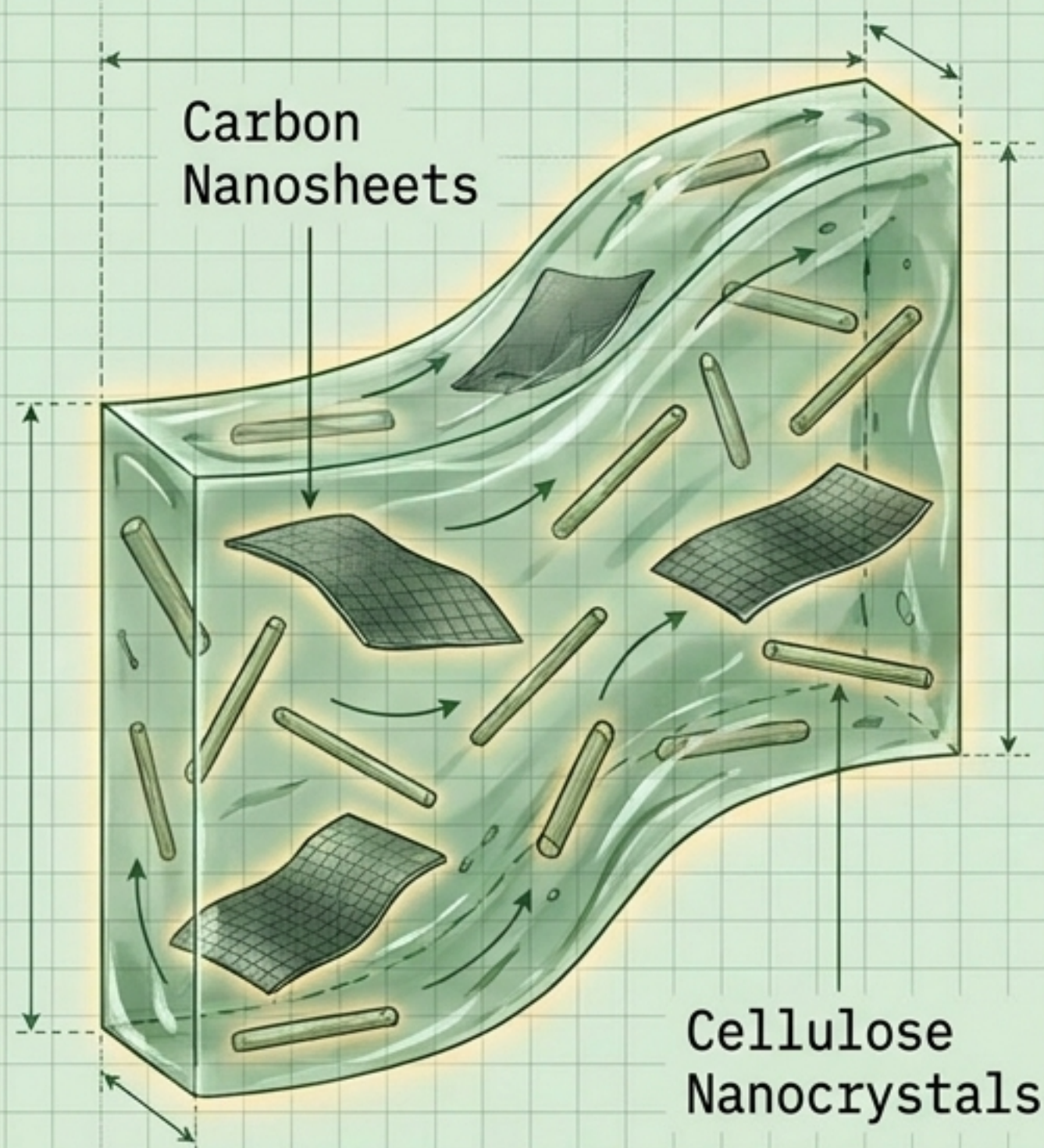


Thermally activated transesterification exchange.
Characteristic relaxation time (τ^*) < 300 s at 180°C.
Enables self-healing, thermal reprocessing, and welding.

Preventing mechanical failure requires occupying every dimensional niche from the macro to the molecular scale.



Carbon and cellulose nanofillers operate below a strict 2.5 phr ceiling to govern interfacial and barrier properties.



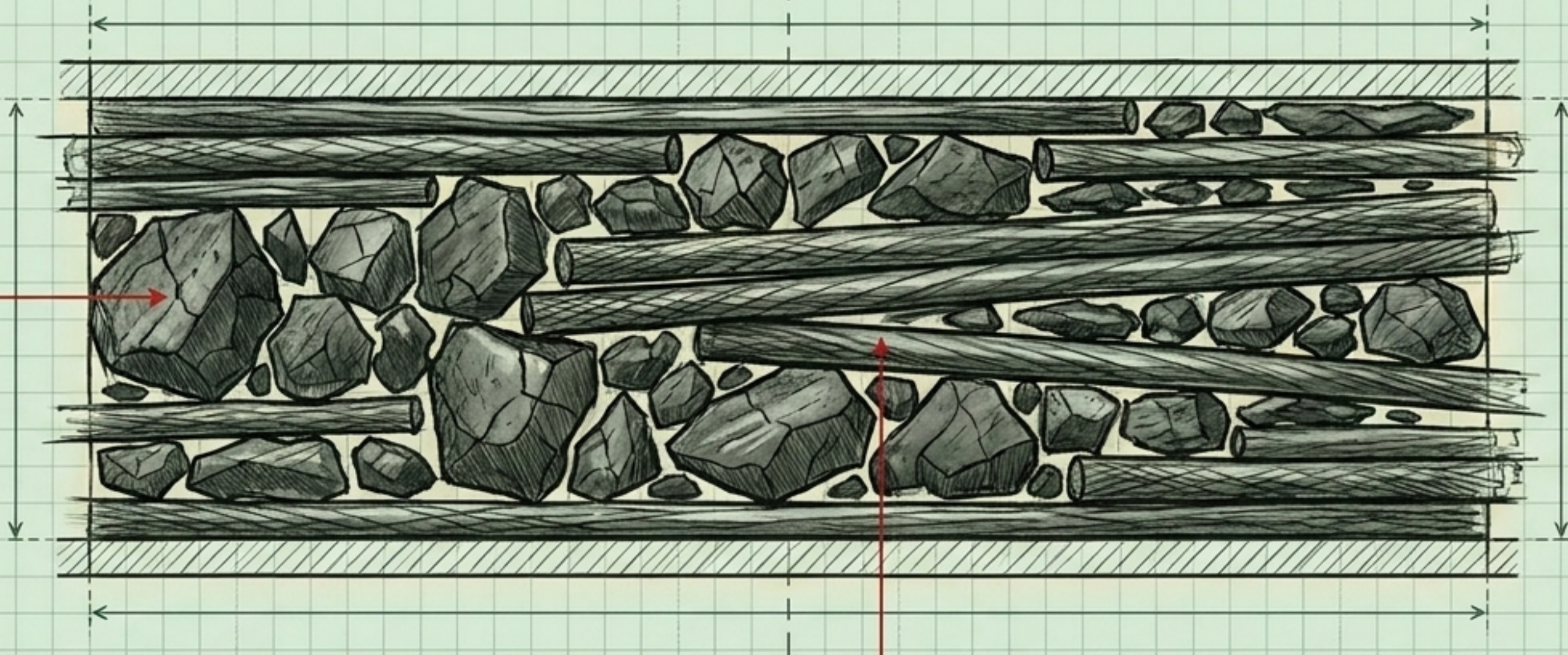
FGE (8-12 phr)

Lowers uncured viscosity by 30-50% while furan rings enable π - π stacking.

⚠ The 2.5 phr Ceiling

Exceeding this combined nano-filler threshold exponentially spikes viscosity, prevents fiber wet-out, and starves the transesterification network by adsorbing the zinc catalyst.

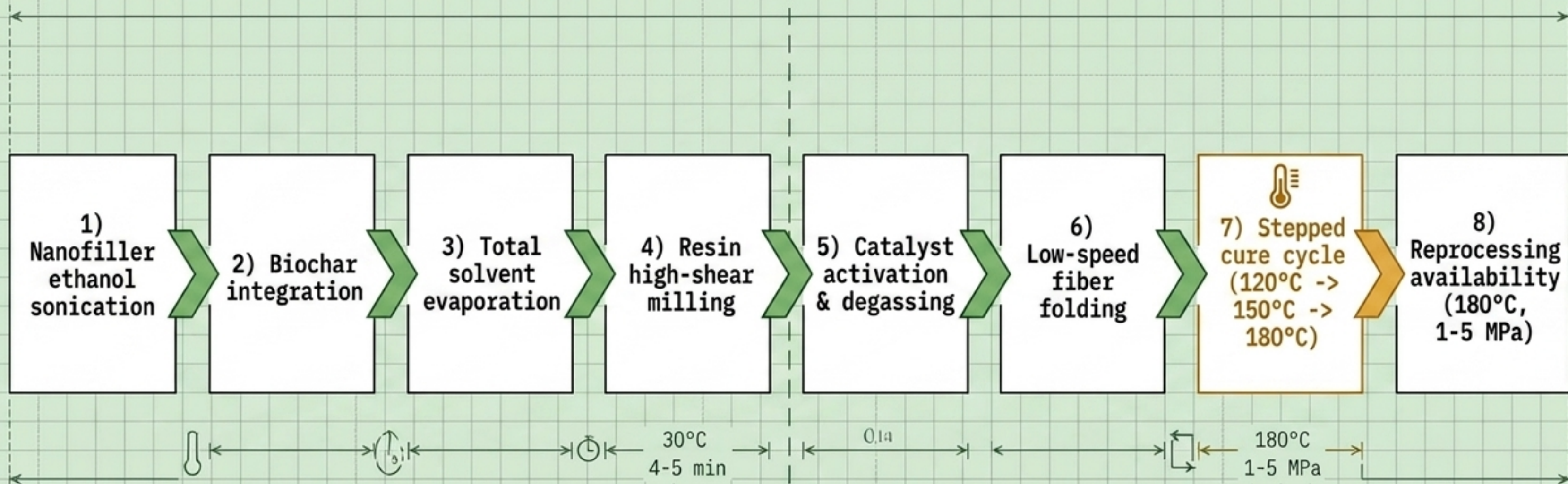
Short carbon fibers bear the primary mechanical load while biochar fills the interstitial volumes.



Biochar (3-5 phr): Improves compressive modulus by 10-15% and reduces coefficient of thermal expansion (CTE) by filling resin-rich pockets without severe viscosity penalties.

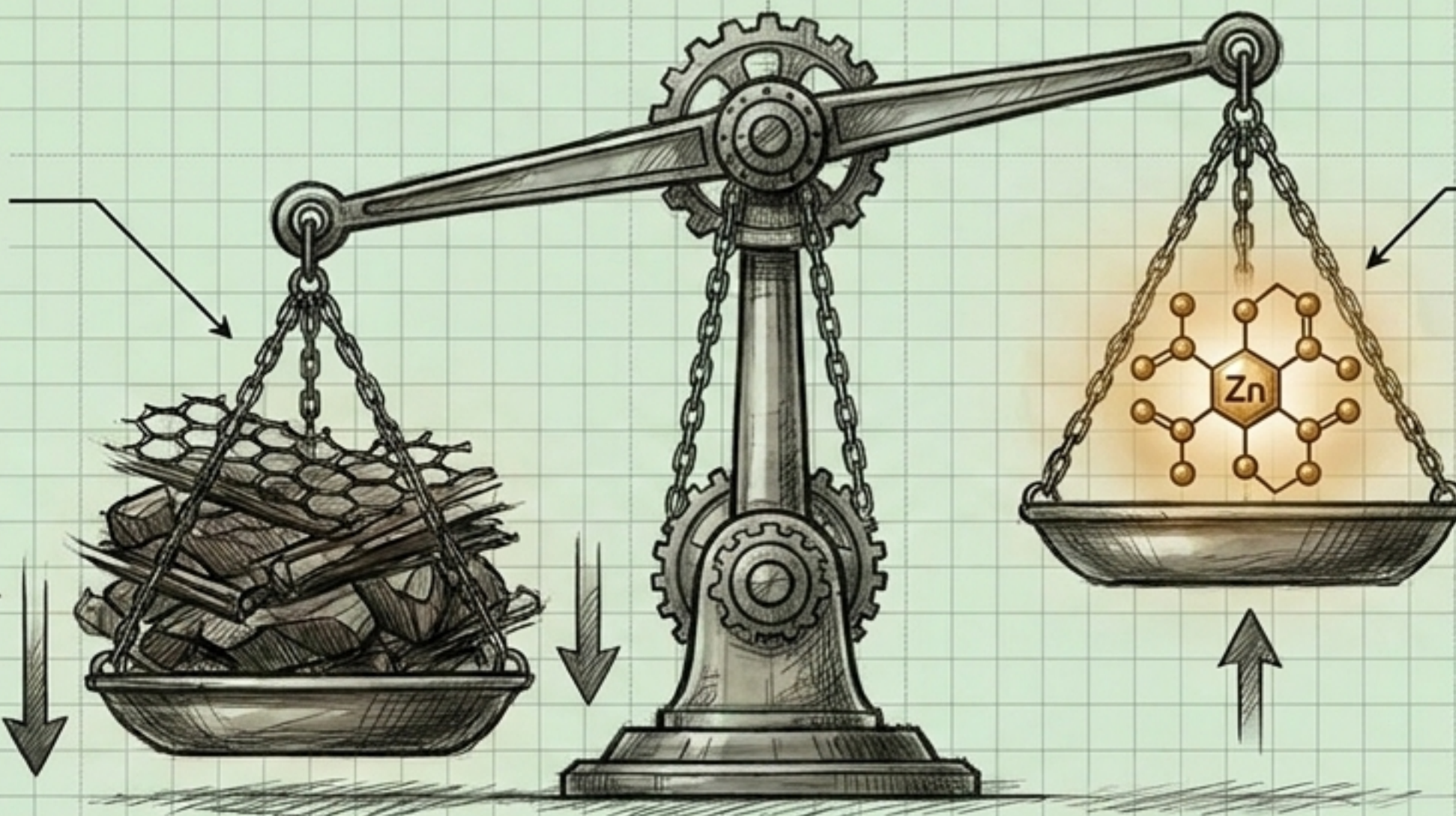
Short Carbon Fiber (15-20 phr): The primary mechanical driver. Increases tensile modulus by up to 120% and flexural strength by 90% before fiber-fiber contact creates voids.

Hierarchical compounding ensures flawless dispersion before initiating the vitrimer cure cycle.



High filler loadings restrict chain mobility, necessitating precise catalyst compensation to maintain dynamic reprocessability.

High Filler Loading



Catalyst Compensation

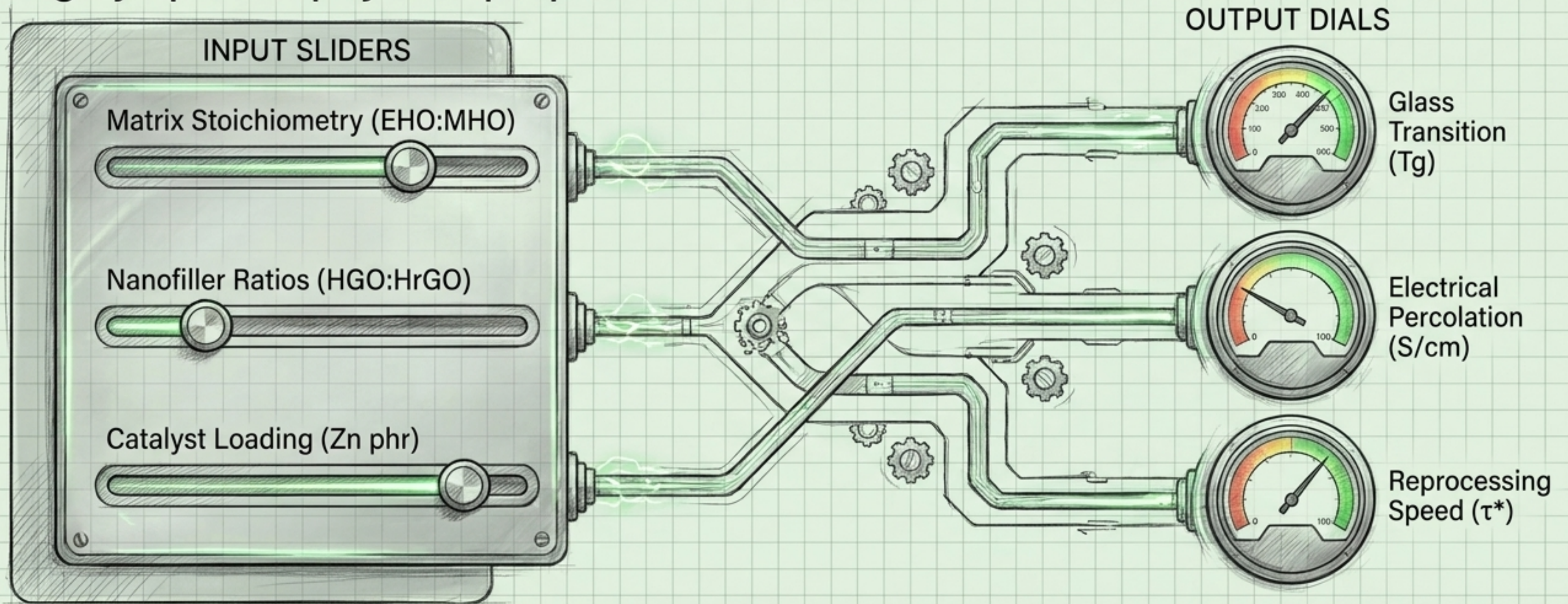
The Problem:

Graphene oxide surfaces adsorb the $\text{Zn}(\text{acac})_2$ catalyst, starving the matrix of the chemical engine needed for bond exchange.

The Solution: The Catalyst Tax

Any nano-filler loading >2 phr requires increasing the catalyst baseline from 2.0 phr to 2.5–3.0 phr to ensure stress relaxation τ^* remains < 300 s.

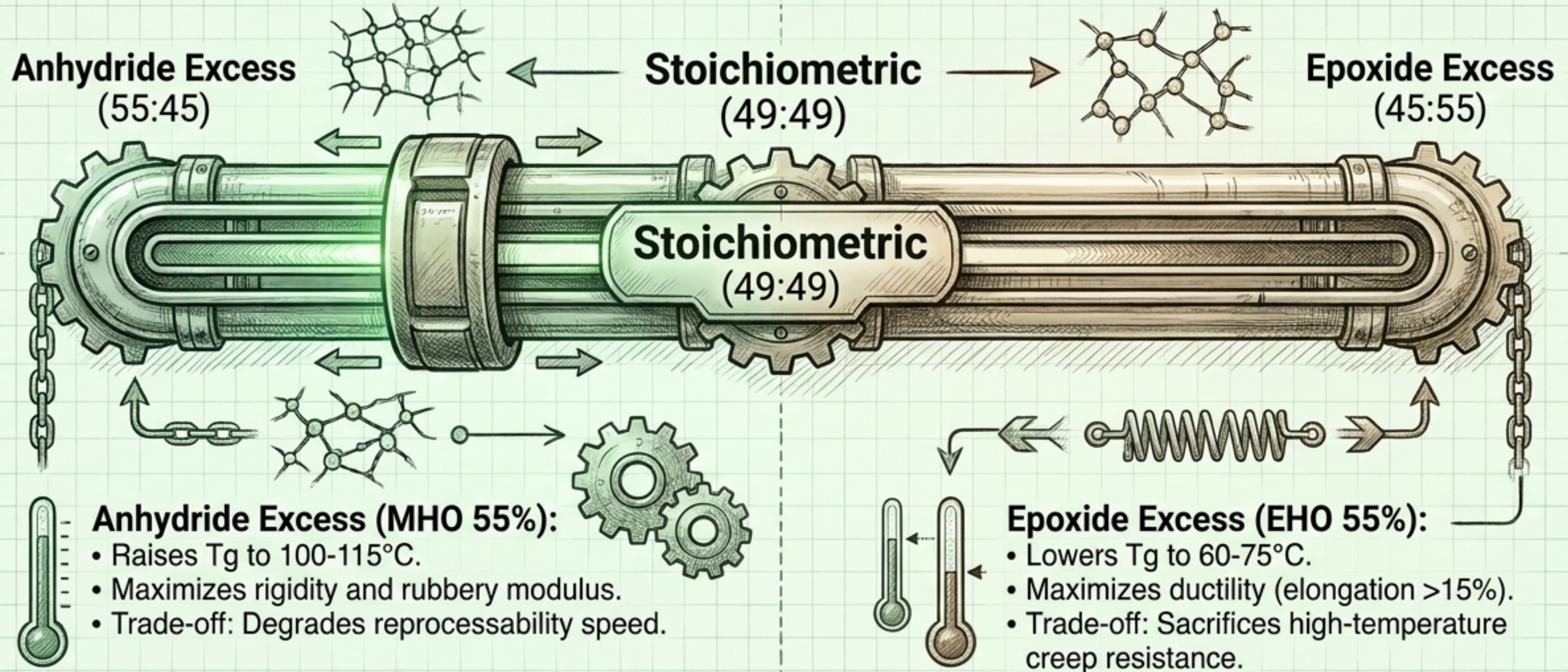
The formulation variables function as programmable software, outputting highly specific physical properties on demand.



By independently tuning seven compositional variables, the composite adapts to entirely distinct industrial use-cases without changing the biological feedstock.

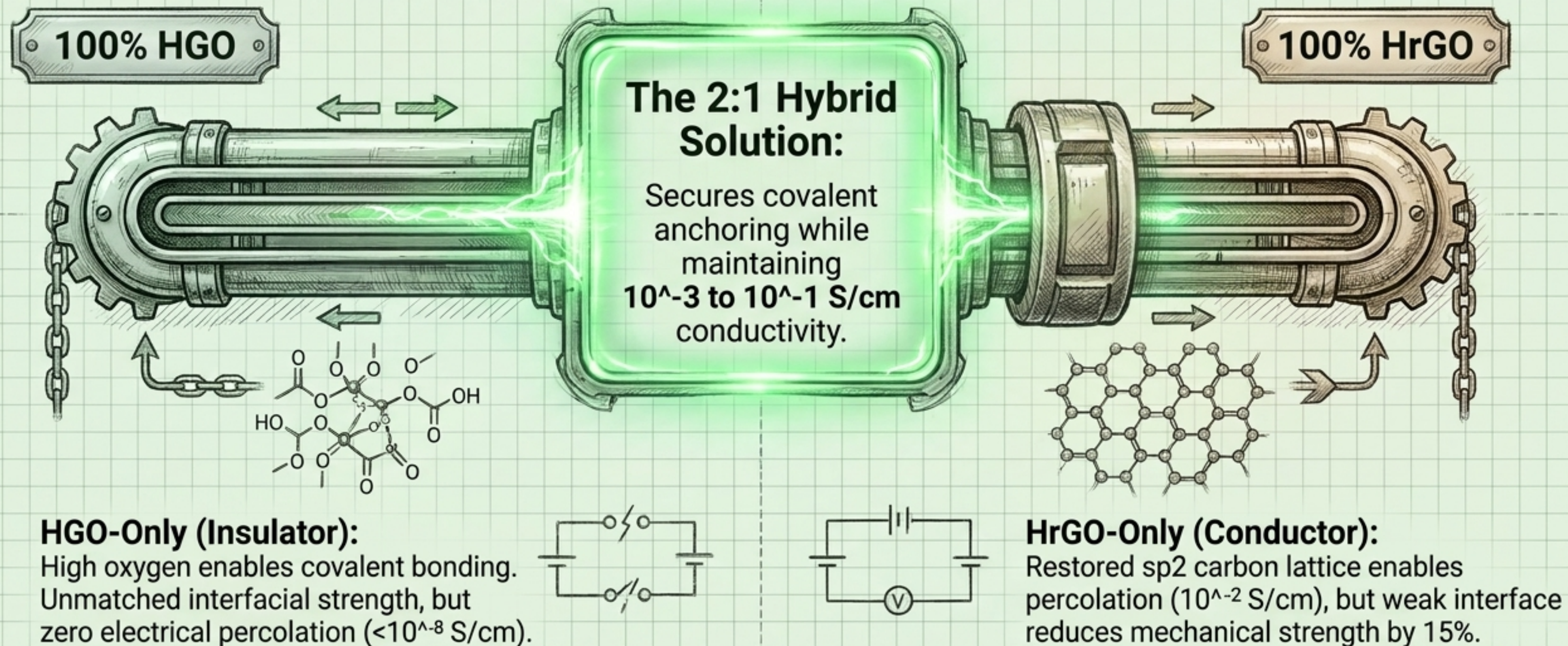
Sustainable Schematic

Tuning the EHO to MH0 ratio strictly controls cross-link density, rigidity, and the glass transition temperature.

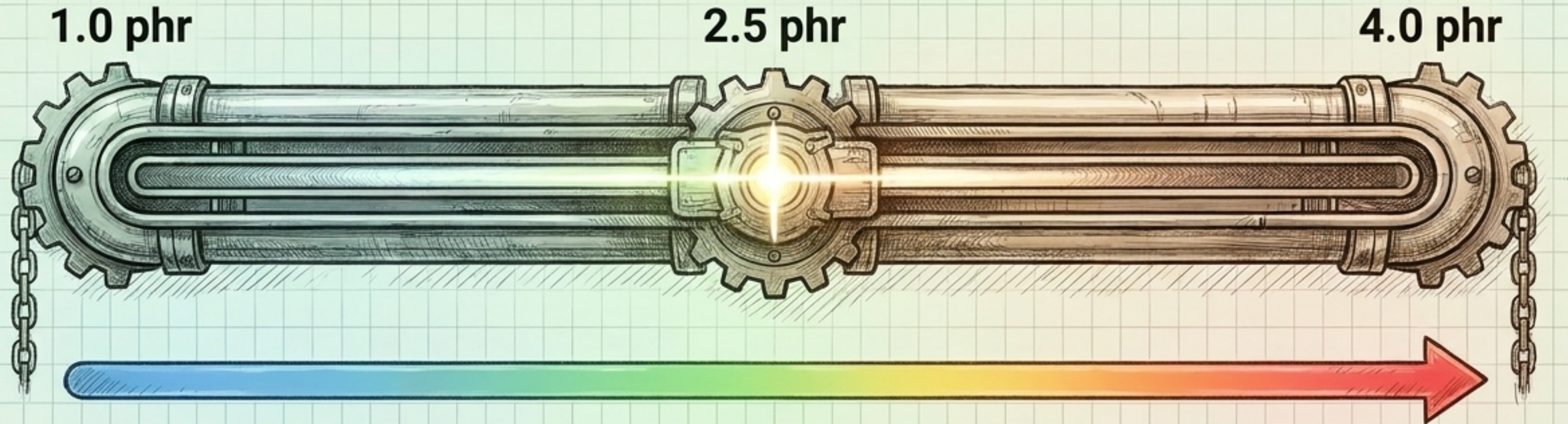


Sustainable Schematic

The **HGO to HrGO** ratio tunes electrical conductivity across eight orders of magnitude without altering total component mass.

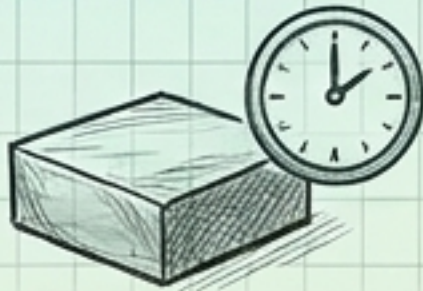


Zinc acetylacetonate acts as the primary dial for the dynamic temperature window and reprocessing speed.



Low:

Behaves like a standard thermoset. High service temp, but reprocessability is sluggish ($\tau^* > 1000$ s).



Optimal:

The general-purpose vitrimer window. Full cure in 4 hours, thermal reprocessing in 10-30 minutes ($\tau^* = 100-300$ s).

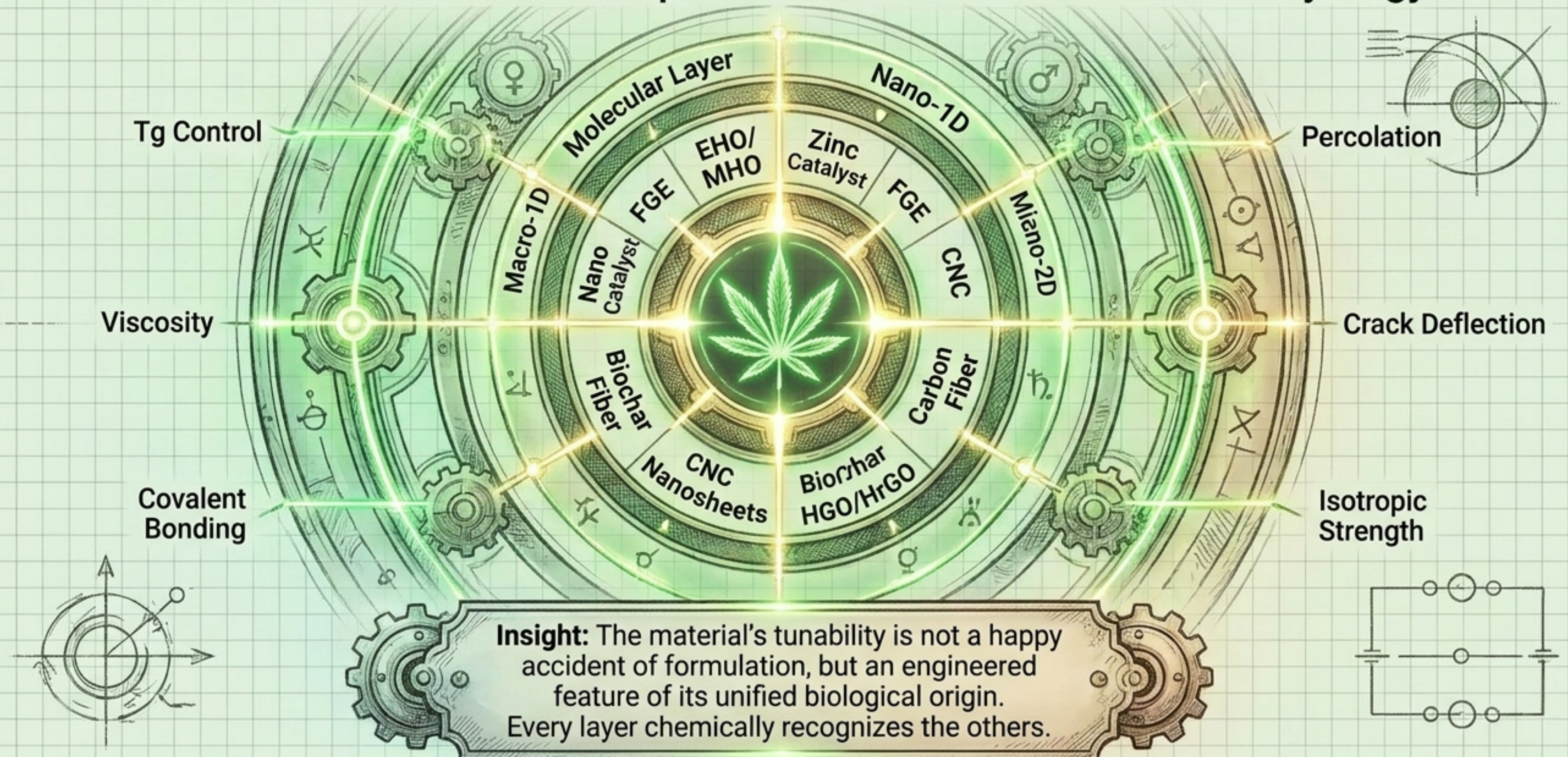


High:

Rapid reprocessability (< 10 mins). **Danger:** Compresses the flow temperature window, risking hydrolysis and dimensional instability in service.



Because every component shares a unified monoculture origin, their tunable interactions achieve perfect covalent and mechanical synergy.



The ultimate proof of a programmable materials platform lies in its ability to assassinate incumbent monoliths.



By loading specific formulation protocols ('Variants'), the Hempoxy platform can match or exceed the specific structural metrics of petroleum-based and metallic legacy materials.

HEMP-AL and HEMP-TITAN configurations utilize maximized carbon fiber loads and anhydride-rich matrices to beat metal specific moduli.

HEMP-AL vs. Aluminum 6061-T6

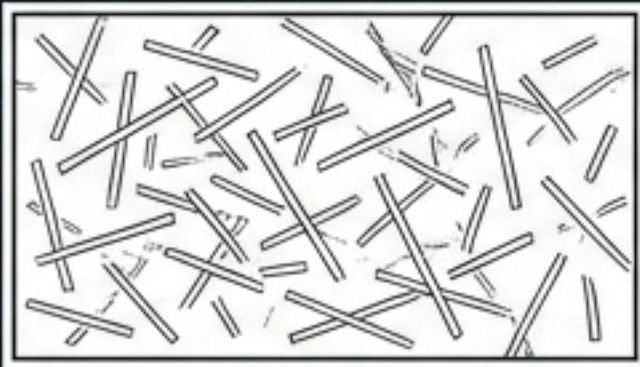
- Anhydride matrix (45:55)
- 25 phr aligned fiber
- Result: +9.8% Specific Modulus, +80% Specific Strength, 50% lighter than Al.

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

- High nano-filler loading (3.6 phr)
- 28 phr aligned fiber
- Result: +18% Specific Modulus, 69% lighter than Titanium.

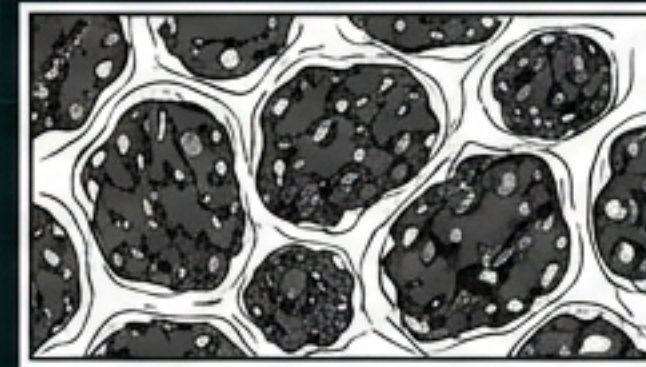
HEMP-STEEL and HEMP-CRETE prioritize omnidirectional toughness and particulate aggregates to outperform heavy heavy industry staples.

HEMP-STEEL vs. Mild Steel



Random-in-plane fiber orientation (22 phr). Trades modulus for omnidirectional strength. Result: +193% Specific Strength, 83% lighter than steel.

HEMP-CRETE vs. C30 Concrete



Massive biochar aggregate loading (45 phr total) + hydrophobic vitrimer matrix. Result: +83% Compressive Strength, +1067% Tensile Strength, eliminates freeze-thaw degradation.

Extreme formulation tunability enables direct competition with commercial plastics, legacy epoxies, and aramid fibers.

HEMP-PLAST vs. ABS

Epoxide-rich matrix + high cheap biochar (8 phr). Yields +113% tensile strength and +89% specific strength over commodity plastic.

HEP-OXY vs. Standard Epoxy

The direct drop-in. 49:49 stoichiometric ratio yields +100% strength and +300% modulus over DGEBA, plus thermal reprocessability.

HEMP-KEV vs. Kevlar-49

Pushes fiber to 30 phr maximum limit. Approaches Kevlar's density with superior impact absorption in compression.

HEMP-GFRP vs. E-glass/Epoxy

20 phr random fiber yields comparable specific properties but is 28% lighter, fully bio-based, and ends wind-turbine blade landfilling.

The Hempoxy platform delivers superior specific performance across critical industrial sectors while ensuring 100% circularity.

Material Comparison	Key Performance Metric	Hempoxy Winning Data
HEMP-AL vs Al 6061-T6	28.1 GPa cm ³ /g	+10% sp. mod, -50% mass
HEMP-STEEL vs Mild Steel	167 MPa cm ³ /g	+193% sp. str, -83% mass
HEMP-PLAST vs ABS	4.66 GPa cm ³ /g	+89% sp. str, bio-based
HEMP-CRETE vs Concrete	35 MPa tensile	+1067% tensile, reprocessible
HEP-OXY vs DGEBA Epoxy	9.38 GPa cm ³ /g	+100% strength, reprocessible
HEMP-KEV vs Kevlar-49	36.6 GPa cm ³ /g	Impact tough, reprocessible
HEMP-TITAN vs Ti-6Al-4V	30.4 GPa cm ³ /g	+18% sp. mod, -69% mass
HEMP-GFRP vs E-Glass/Epoxy	20.0 GPa cm ³ /g	Reprocessible, -28% mass

Not a single material. A programmable, infinite materials platform.