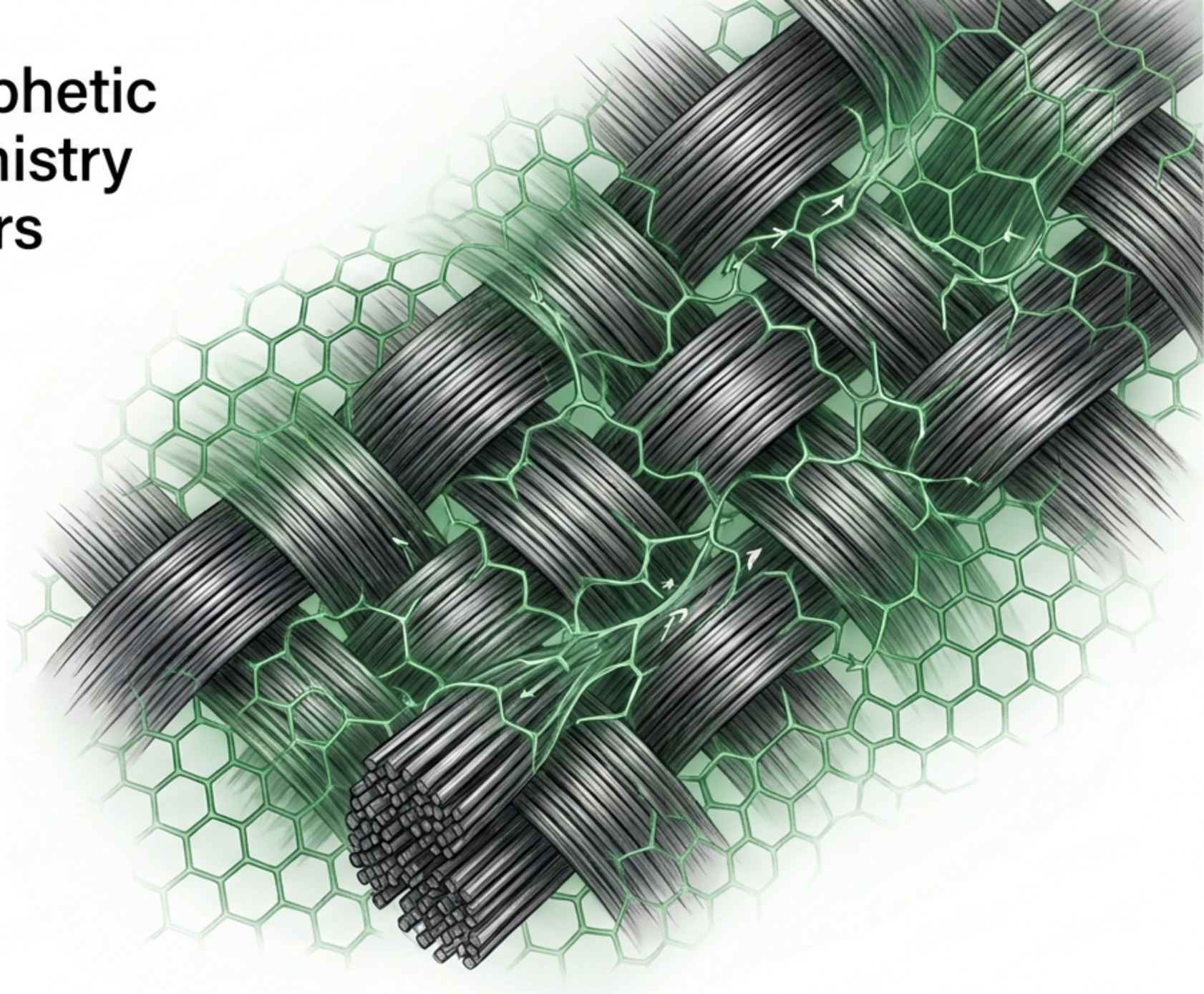
Hempoxies: The Prophetic Green Organic Chemistry of Bio-Epoxy Vitrimers

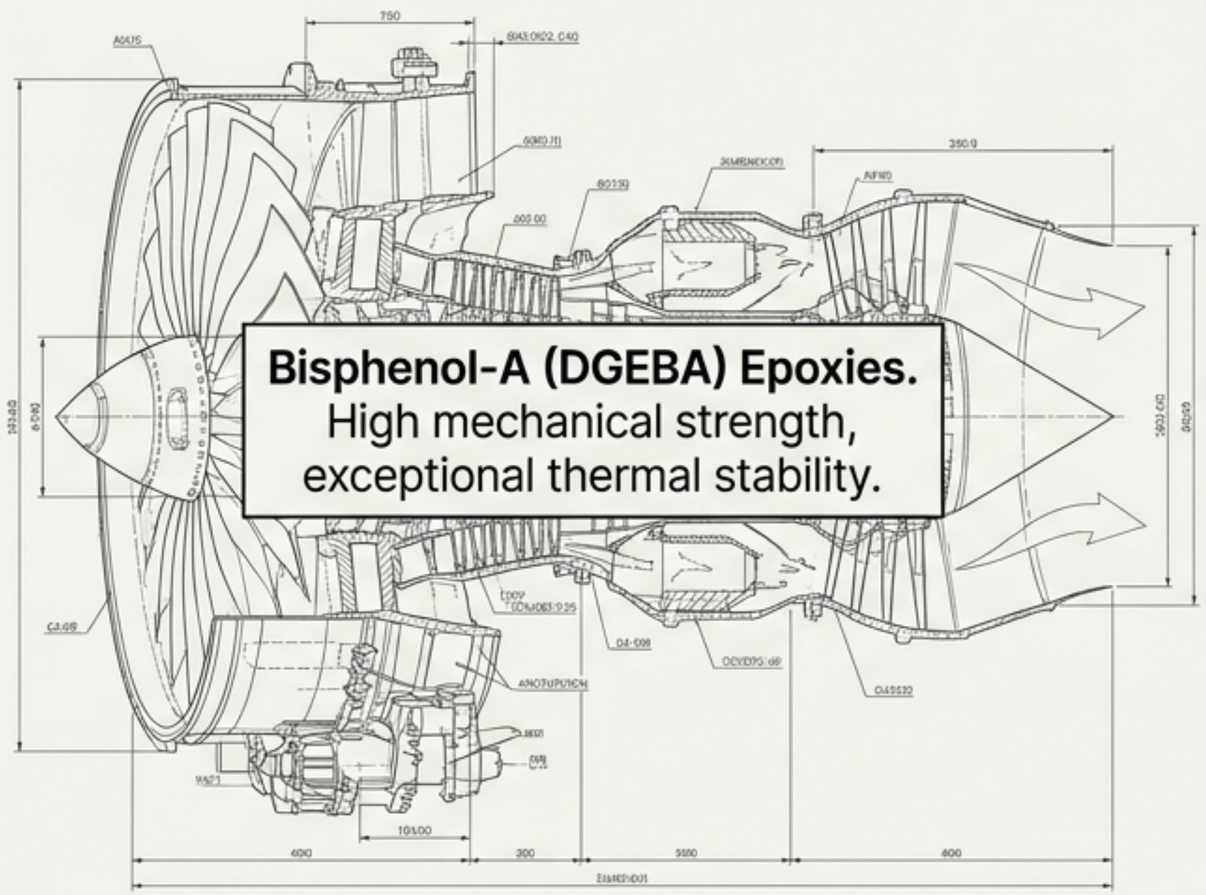
A fully bio-based, self-healing nanocomposite architecture.



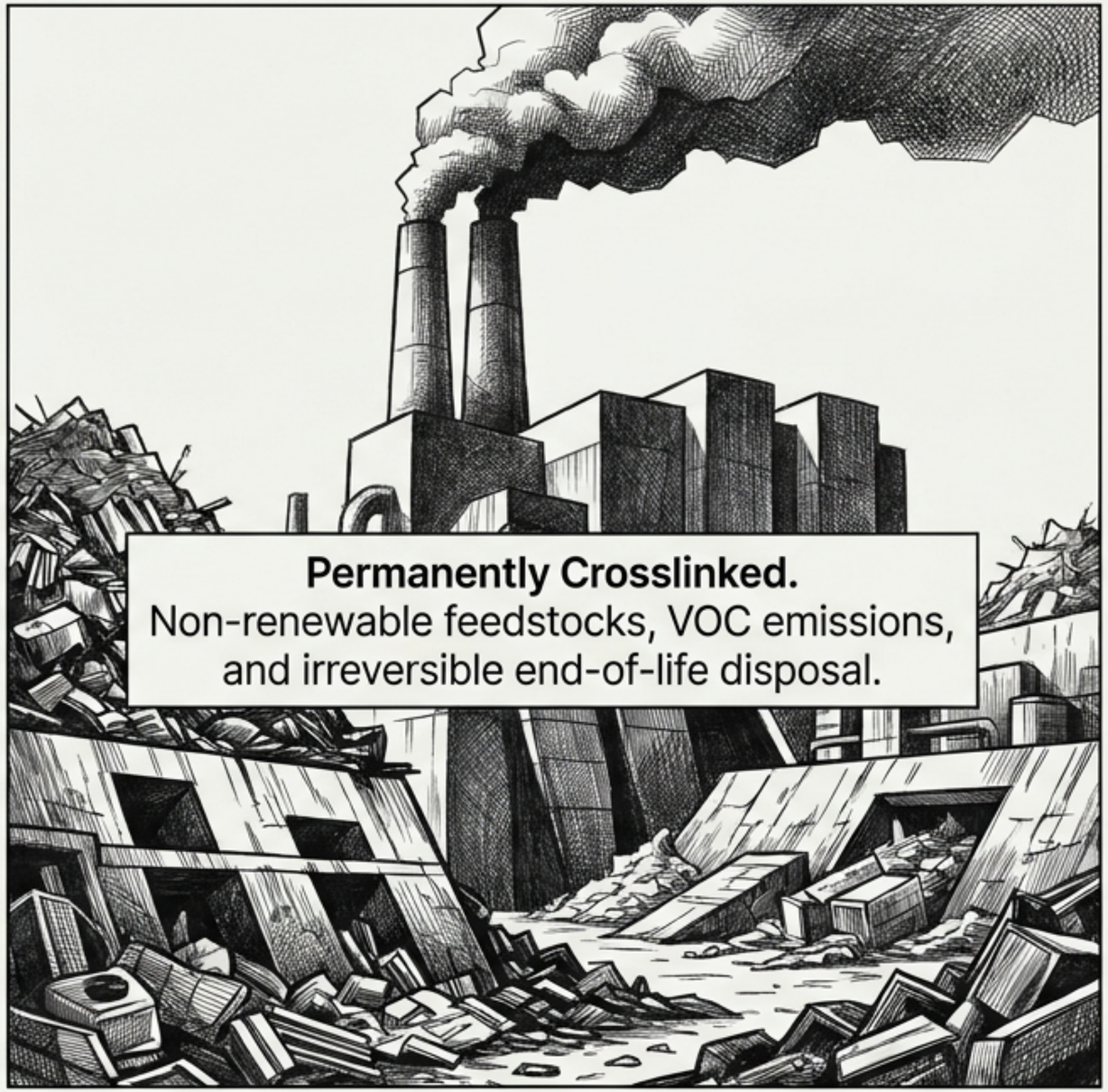
Conceptual Design by Marie-Soleil Seshat Landry / Landry Industries Inc.

Gemini Notebook

The 3.5-Million-Tonne Paradox of Conventional Epoxies



Bisphenol-A (DGEBA) Epoxies.
High mechanical strength, exceptional thermal stability.

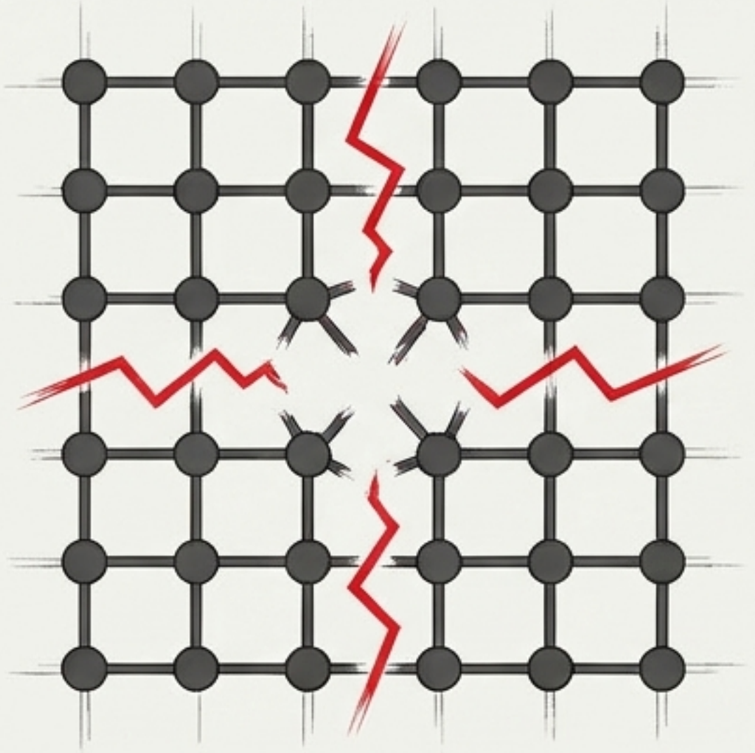


Permanently Crosslinked.
Non-renewable feedstocks, VOC emissions, and irreversible end-of-life disposal.

The global production of synthetic thermoset resins exceeds 3.5 million tonnes annually.
We are trading long-term ecological viability for short-term mechanical permanence.

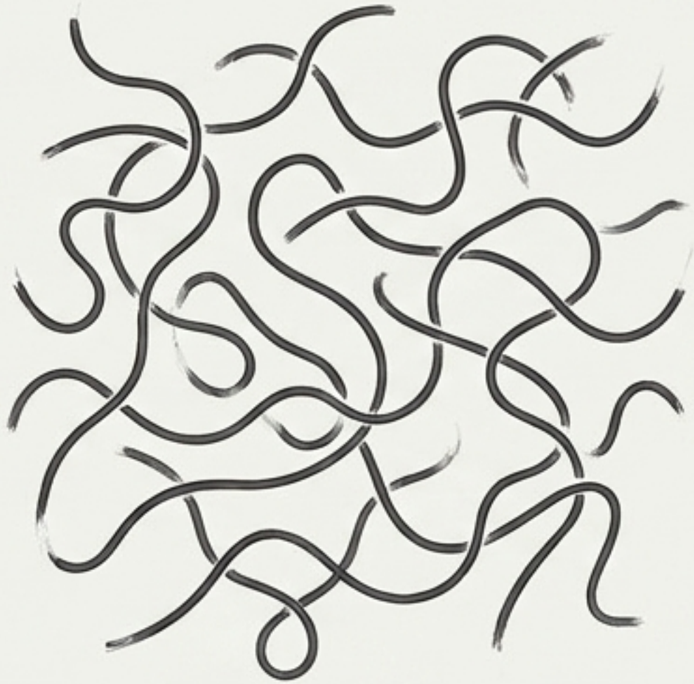
Gemini Notebook

The Vitrimer Paradigm: Covalent Adaptable Networks



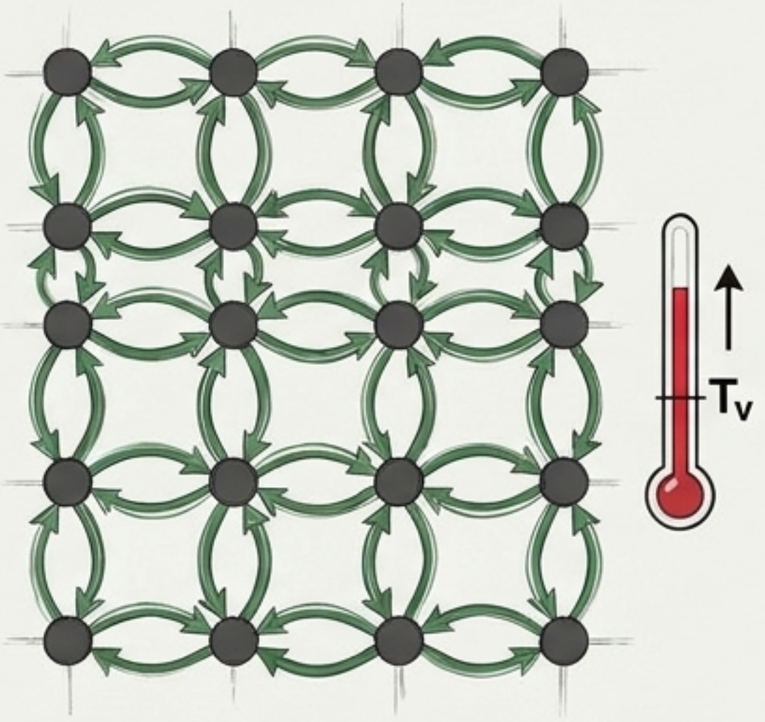
Thermoset (Permanently Locked)

Bonds sever completely under stress. Cannot be reshaped or healed.



Thermoplastic (Melting)

Loses structural integrity and network density when heated.



Vitrimer (Dynamic Exchange)

Through transesterification, bonds “swap partners” above the Topology Freezing Temperature (Tv). Enables melt reprocessing while retaining crosslink density.

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Synthesizing the 100% Bio-Based Vision

Seed

Epoxidized Hempseed Oil (EHO)

Primary Matrix

Processing Residue

Epoxidized Kraft Lignin

Interfacial Compatibilizer



Hurd (Shiv)

Pyrolytic Biochar

Thermal/Micro-Reinforcement

Bast Fiber

Cellulose Nanocrystals (CNCs) & CFNs

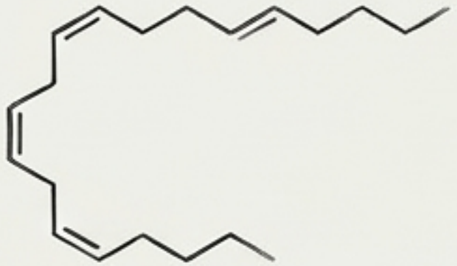
Nano-Reinforcement

Data Point: Achieving 95-100% bio-based carbon content (ASTM D6866), contrasting with the near-zero bio-content of DGEBA systems.

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Matrix Engineering: Swern-Type In Situ Epoxidation

Step 1



Hempseed oil lipid chain (55-60% linoleic, 15-20% alpha-linolenic acid).

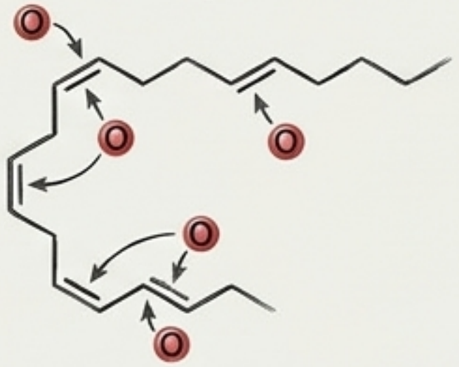
Step 2

Formic Acid + H_2O_2

50 C controlled

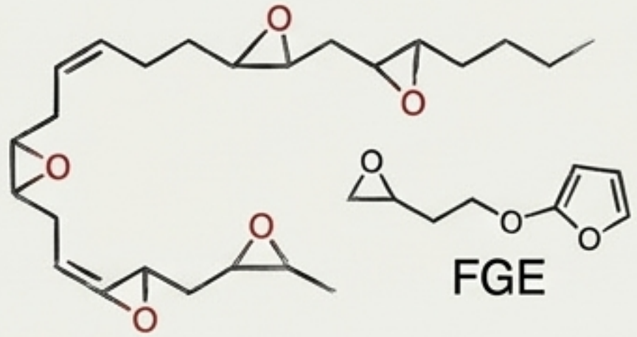
In situ peroxyformic acid generation.

Step 3

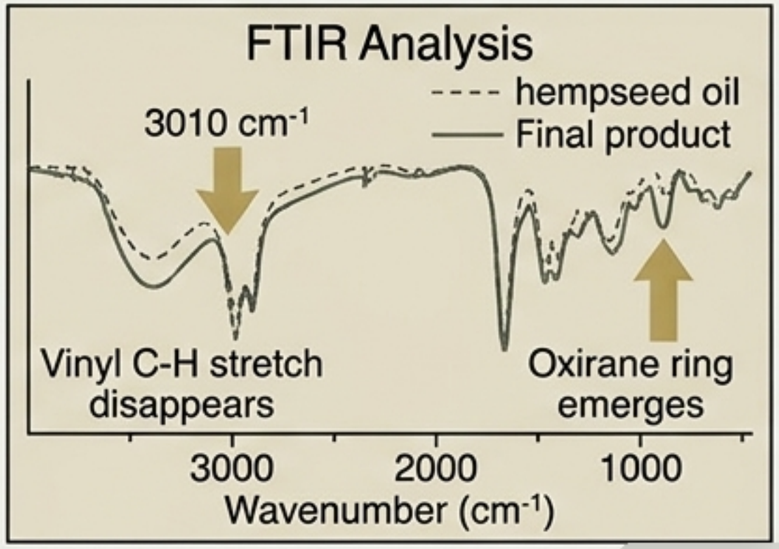


Electrophilic epoxidation of C=C double bonds.

Step 4



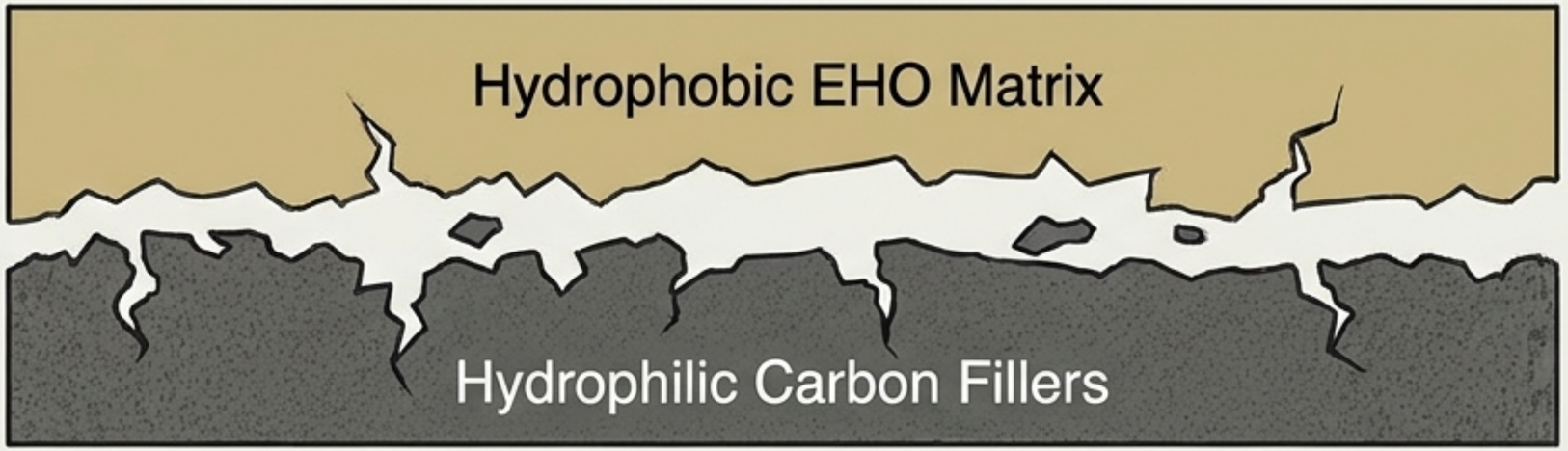
Final EHO structure with bio-compatible Furfuryl Glycidyl Ether (FGE) reactive diluent.



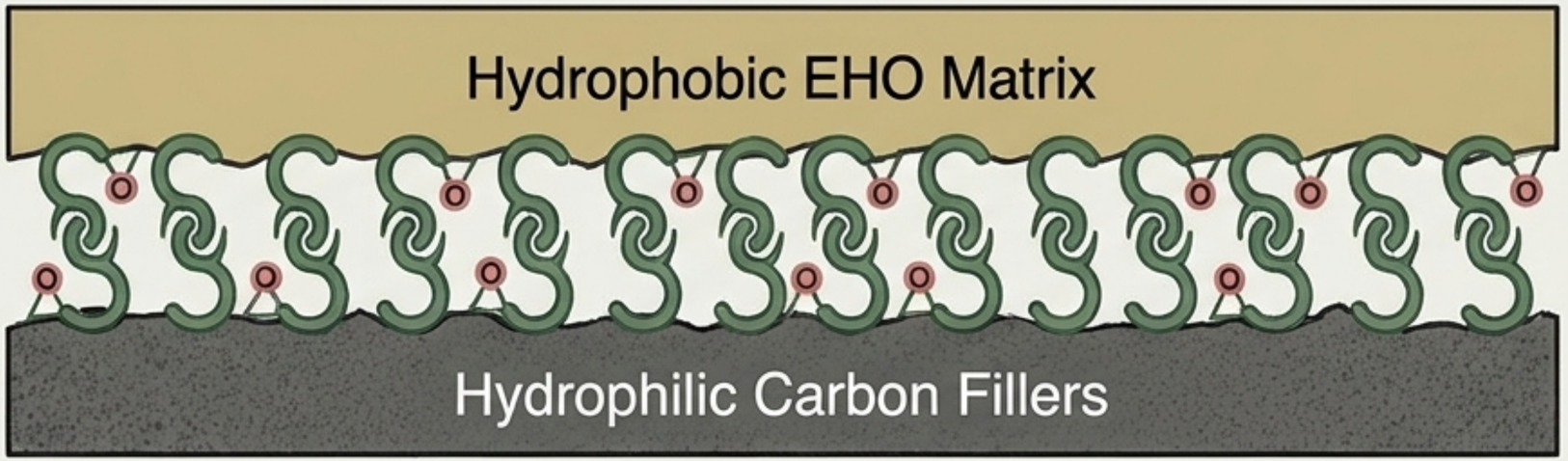
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The Interfacial Velcro: Epoxidized Kraft Lignin

Turning waste lignin into a reactive co-monomer to prevent mechanical embrittlement.



Unmodified Lignin:
Phase separation and mechanical embrittlement.

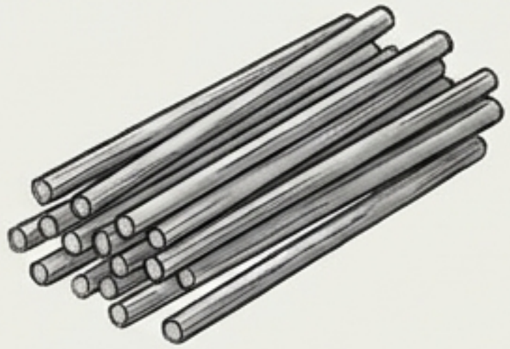
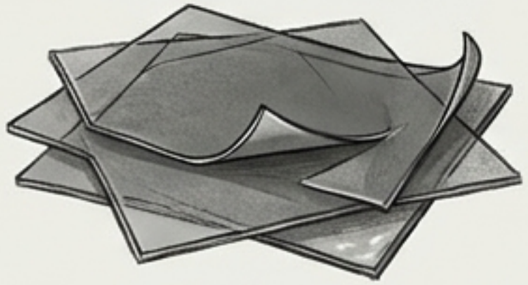


Epoxidized Lignin:
Covalently linked interfacial compatibilizer bridging the matrix directly to the fillers.

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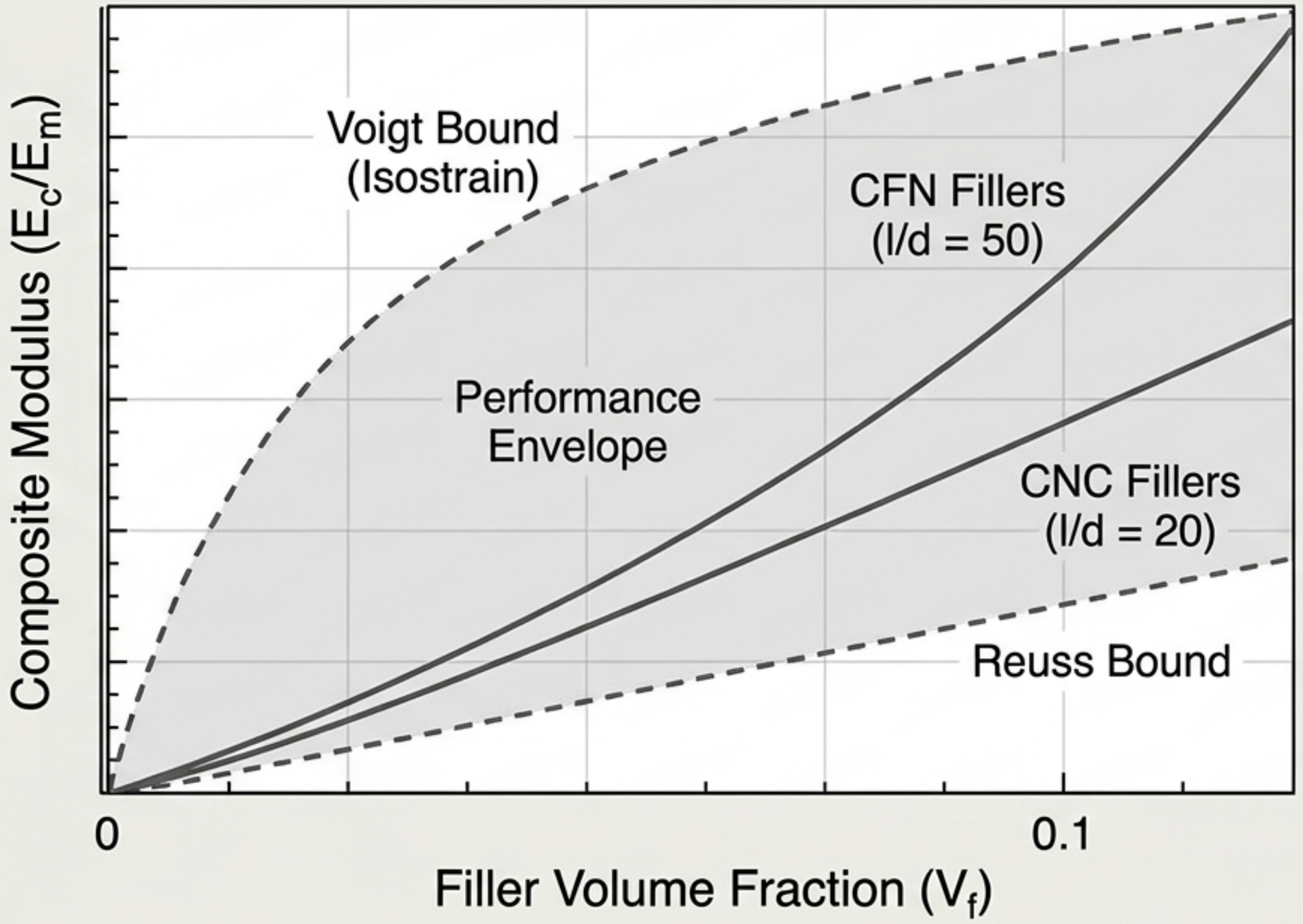
Engineering Structural Bullion: Multi-Scale Carbon Morphologies

Morphology Matrix

Pyrolytic Biochar	Cellulose Nanocrystals (CNCs)	Carbonized Fiber Nanosheets (CFNs)
		
Scale: Micro (150-900 m2/g surface area)	Scale: Nano (15-30 aspect ratio)	Scale: Nano-sheet (5-20 nm thickness)
Origin: 600 C pyrolysis of hemp hurd	Origin: Acid hydrolysis of bast fiber	Origin: 1000 C carbonization + ball-milling
Function: Mechanical reinforcement and uniform thermal distribution during reprocessing.	Function: High-aspect-ratio stress transfer; surface sulfate groups hydrogen-bond to catalyze the dynamic network.	Function: Partially graphitic structure introduces electrical percolation pathways for electrostatic discharge.

Gemini Notebook

Predictive Mechanics: Nanocrystal Stress Transfer



Halpin-Tsai Projections:

- High-aspect-ratio CNCs transfer mechanical stress efficiently across the matrix.

- Projected Young's modulus of 1.8 to 2.8 GPa at just 3-5 wt% loading.

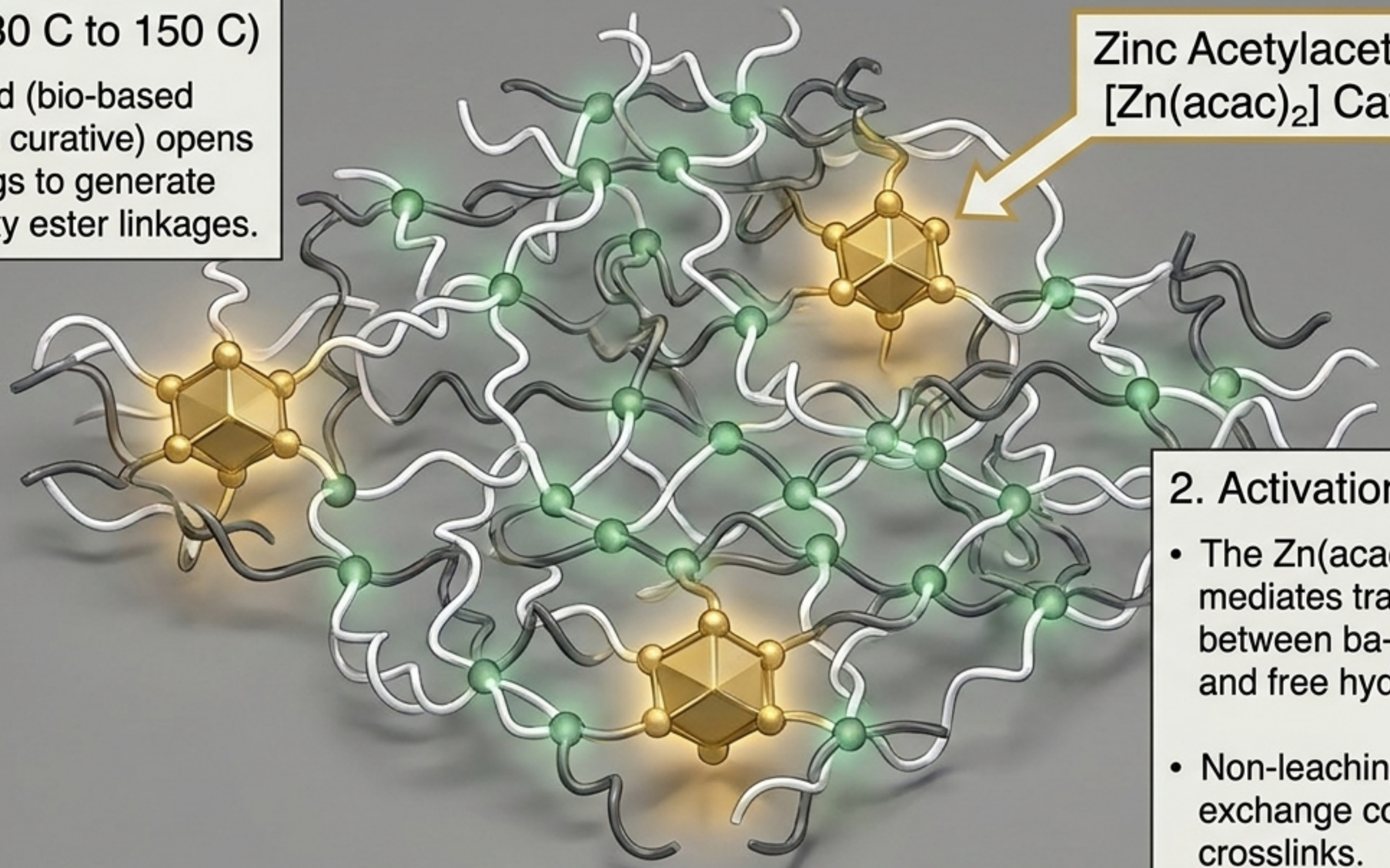
- Achieves a 5-8x improvement over the unreinforced EHO control.

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Activating the Dynamic Network via Zinc Catalysis

1. Curing (80 C to 150 C)

- Sebacic acid (bio-based dicarboxylic curative) opens epoxide rings to generate beta-hydroxy ester linkages.



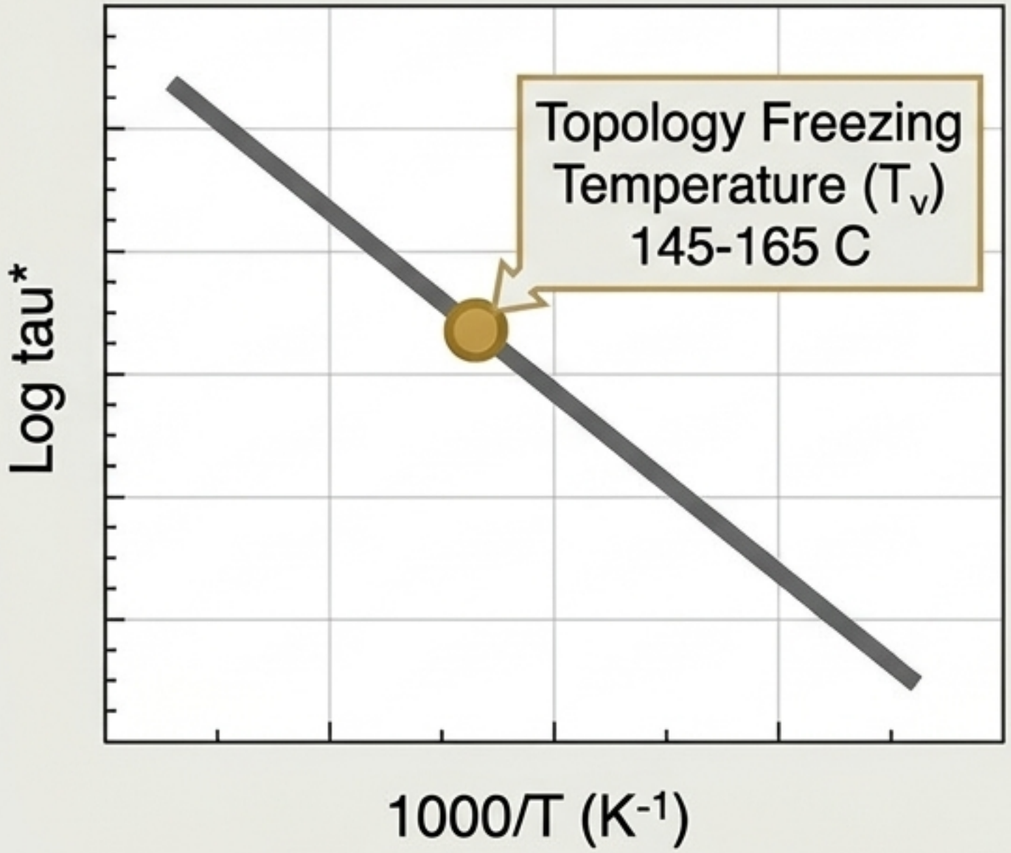
2. Activation

- The $Zn(acac)_2$ catalyst mediates transesterification between ba-hydroxy esters and free hydroxyl groups.
- Non-leaching associative exchange conserves total crosslinks.

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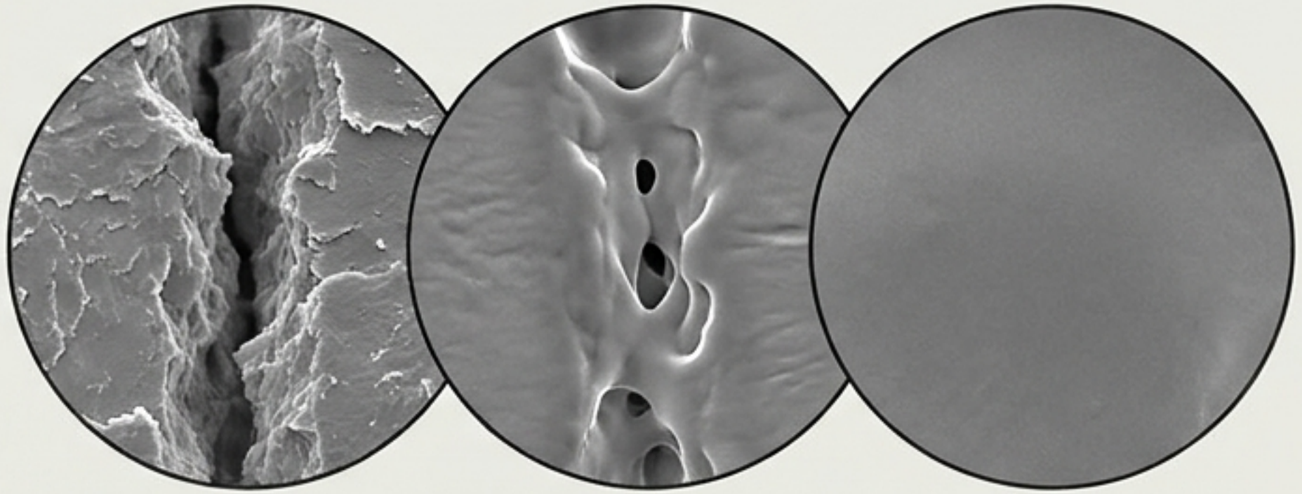
The Thermodynamics of Autonomous Self-Healing

The Math



Kinetic modeling proves predictable behavior. Activation energy (E_a) = 90-110 kJ/mol.

The Reality



1. Fractured Surface

2. 180 C Annealing (5 mins)

3. Fully Healed (30 mins)

Above T_v, the network achieves a healing efficiency > 85% within 30 minutes, recovering ultimate tensile strength.

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Projected Performance: Hempoxies vs. Petroleum Standards

The Thermoset Matrix

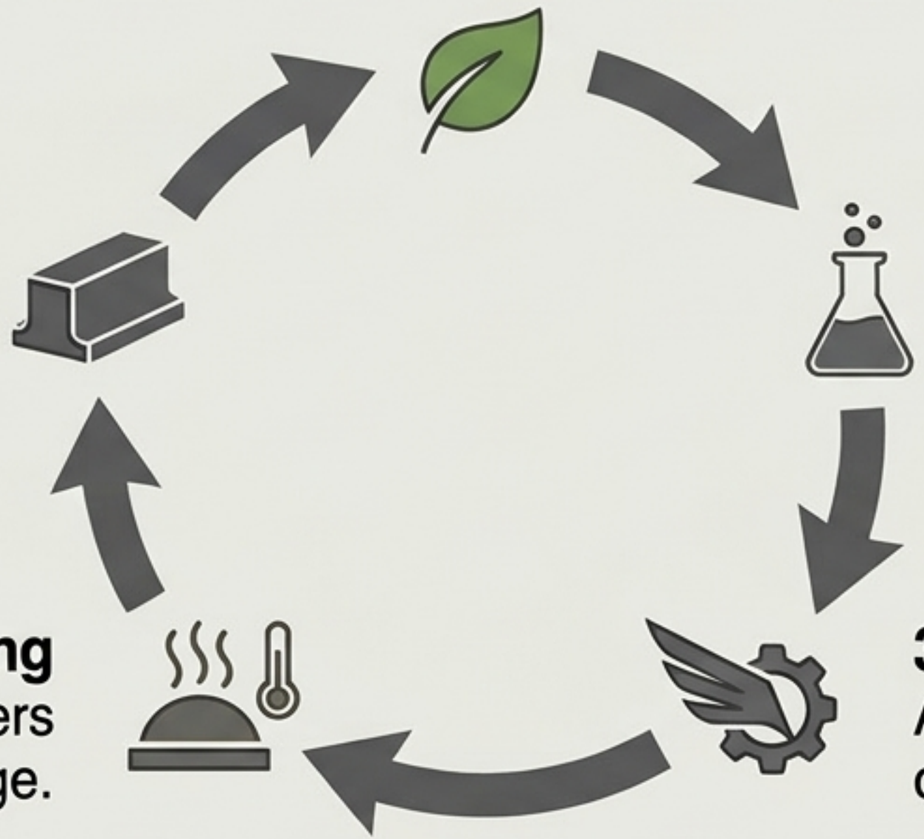
	Hempoxies Target	**DGEBA (Petroleum Ref.)**	**EHO Control**
Young's Modulus (GPa)	1.8 - 2.8	2.5 - 3.5	0.3 - 0.6
Ultimate Tensile Strength (MPa)	35 - 60	55 - 90	8 - 15
Glass Transition (Tg C)	65 - 95	120 - 180	-10 - 15
Healing Efficiency (%)	>85%	0% (Non-healable)	~40%
Bio-Based Content (%)	~95-100%	<5%	~100%

Insight: Hempoxies rival the mechanical stiffness of aerospace-grade DGEBA while introducing unprecedented reprocessability and a near-perfect bio-based carbon profile.

Gemini Notebook

The Closed-Loop Lifecycle of High-Performance Composites

1. Regenerative Cultivation
Industrial hemp fixes ~22 tonnes CO_2/ha/year.



2. Zero-Waste Extraction
Oil for matrix; biomass for carbon and lignin.

3. Hempoxy Service Life
Aerospace, automotive, or construction deployment.

4. Thermal Reprocessing
Controlled heat (>T_v) triggers dynamic exchange.

5. Reformed Component
Ground powder hot-pressed into a functional new part.

A rigorously engineered chemistry transforming the thermoset paradox into a zero-waste, fully regenerative carbon cycle.

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