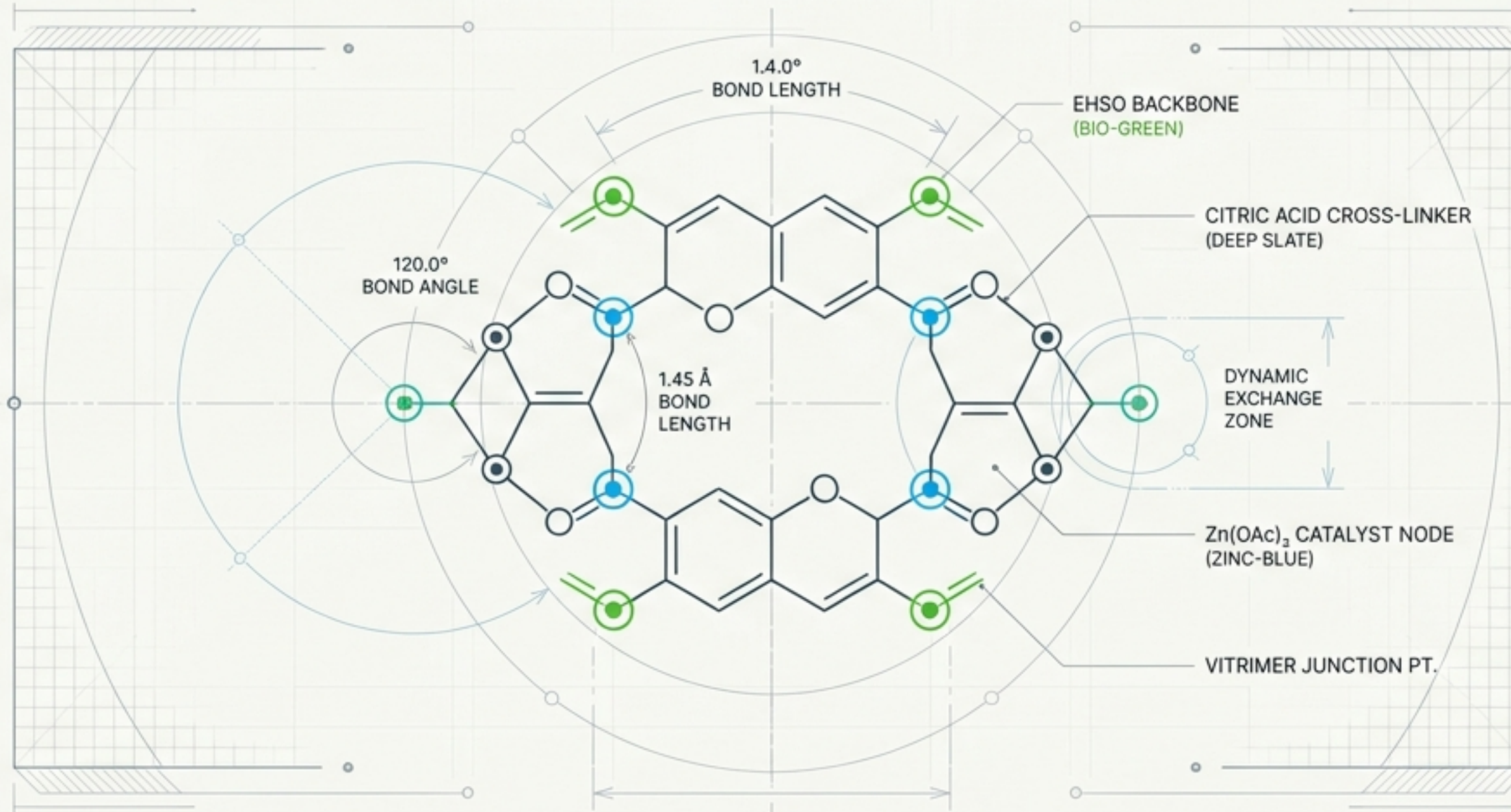


Hempoxies: The Bio-Architectural Blueprint

A structural vitrimer platform for the circular economy.

Specifications: Platform v.17.2 | Matrix: EHSO / Citric Acid / $\text{Zn}(\text{OAc})_2$ | Status: Open-Source (LOBL-V1)



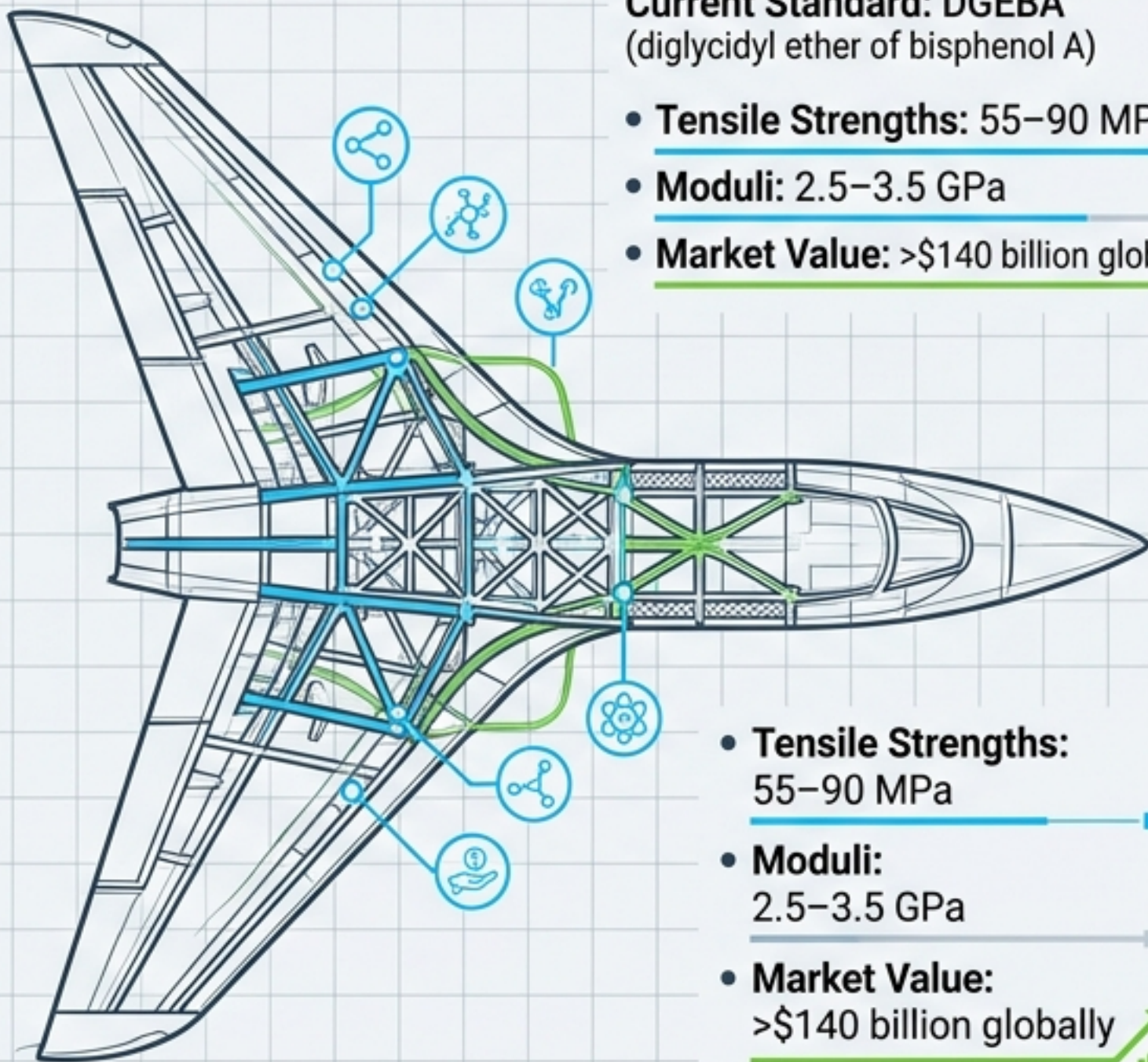
The Thermoset Paradox: Unbreakable, Unrecyclable

The Performance Imperative

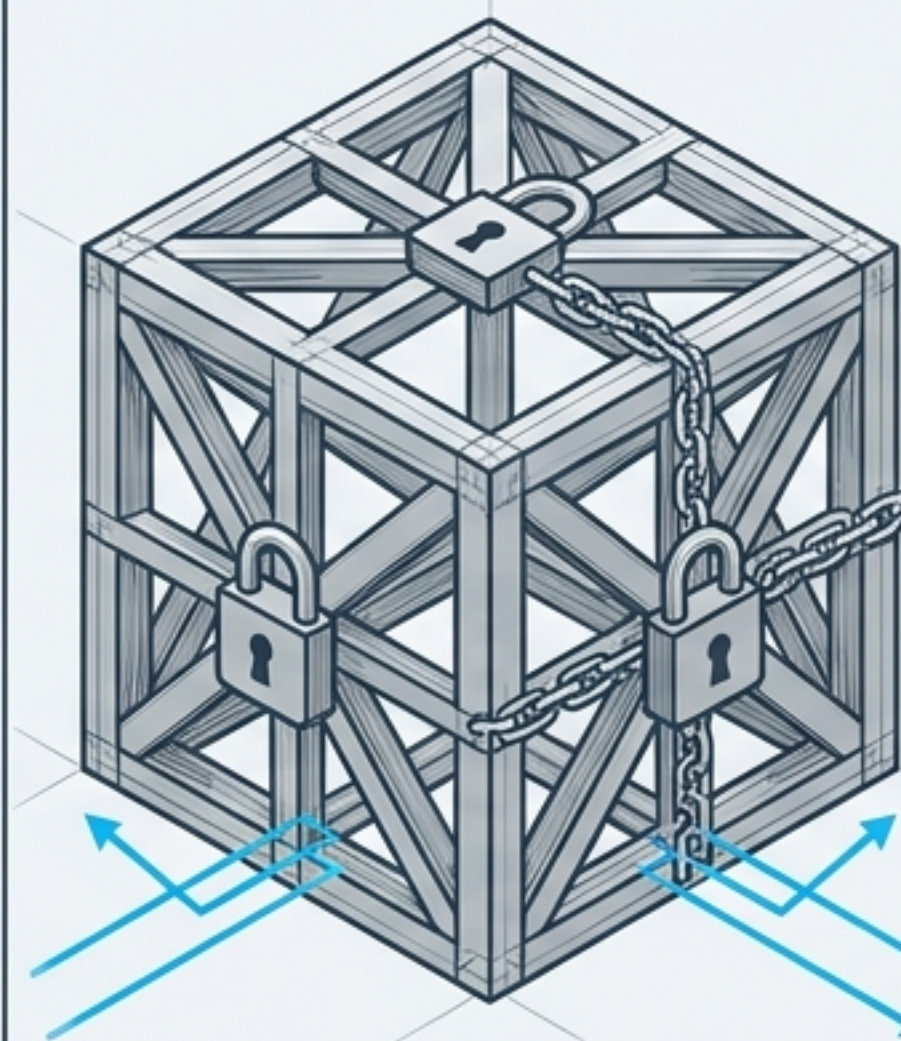
Current Standard: DGEBA
(diglycidyl ether of bisphenol A)

- **Tensile Strengths:** 55–90 MPa
- **Moduli:** 2.5–3.5 GPa
- **Market Value:** >\$140 billion globally

- **Tensile Strengths:** 55–90 MPa
- **Moduli:** 2.5–3.5 GPa
- **Market Value:** >\$140 billion globally



The Environmental Liability



1. **Petroleum-derived feedstocks**
(net-positive emissions)



2. **Toxic intermediates**
(bisphenol A, volatile amines)



3. **Permanent cross-linking**
preventing reshaping or repair



300,000 tonnes of thermoset waste generated annually with zero viable reprocessing pathways.

Introducing Hempoxies Platform v.17.2

A fully bio-derived structural vitrimer system utilising epoxidized hemp seed oil (EHSO) as the matrix backbone.

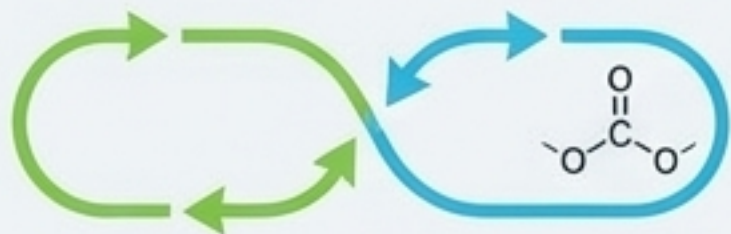
Bio-Derived Content

$\geq 95\%$ by mass
(excluding catalyst).

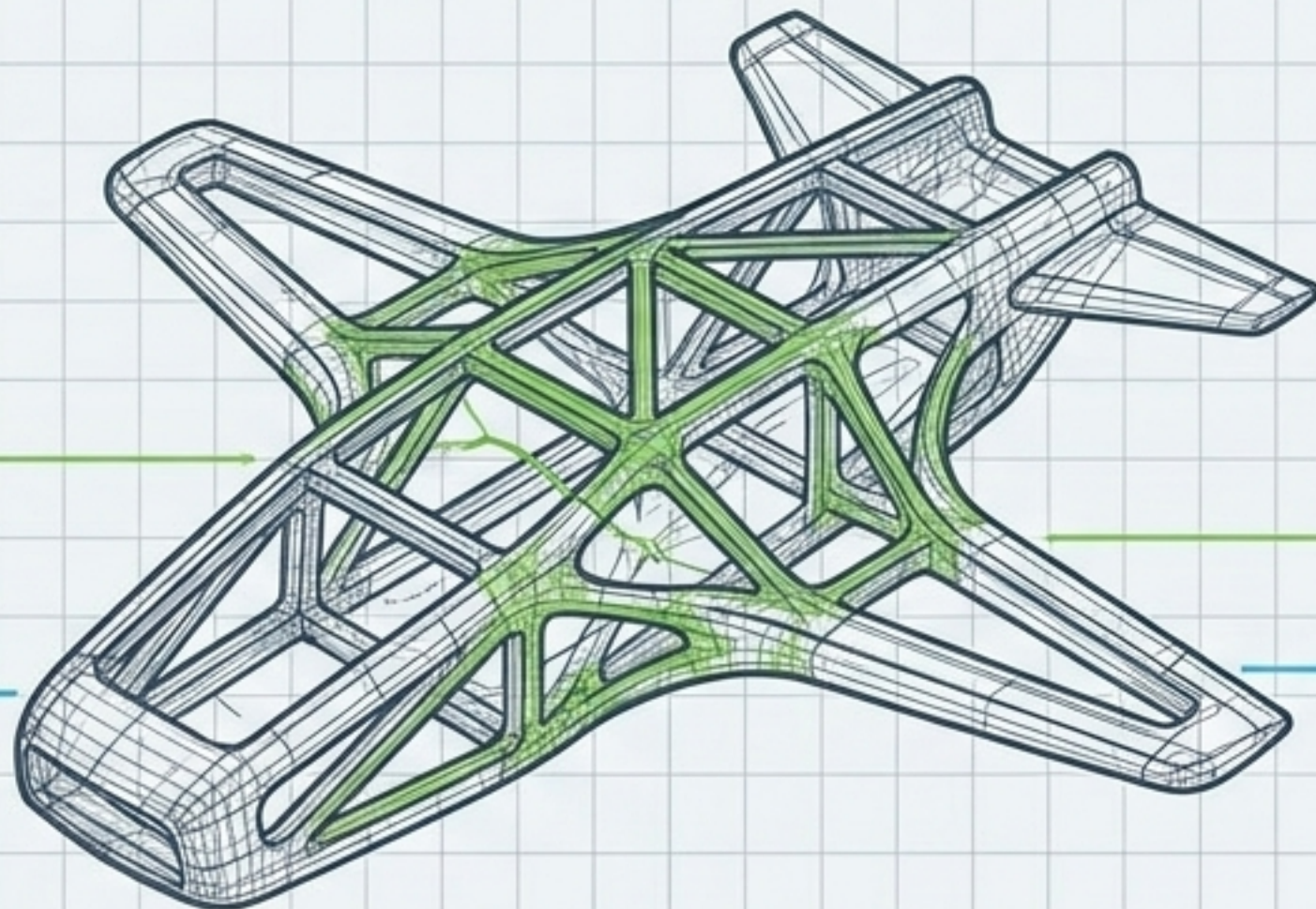
100% bio-derived
feedstocks.



Circular Capability



Infinite reprocessing and heat-repair via solid-state recycling.



Structural Performance

Projected tensile strength:
 >180 MPa

Modulus:
 >8 GPa

Densities:
 $1.12\text{--}1.18$ g/cm³

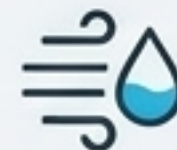


Processability



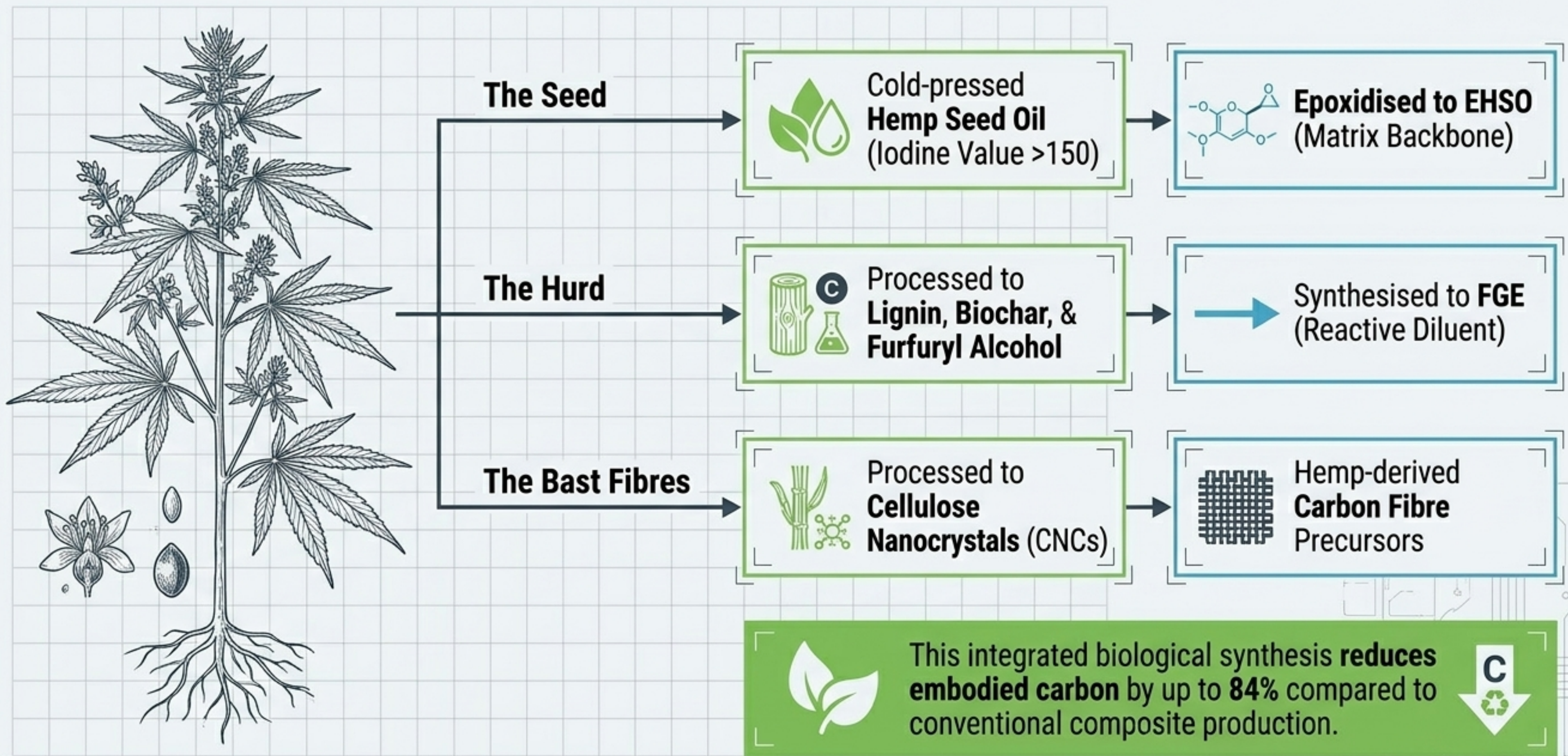
Viscosity

<500 cP



at 40°C for industrial
vacuum infusion.

The Integrated Biorefinery: Whole-Plant Valorisation



Fixed-Datum Matrix Formulation (5 kg Batch)

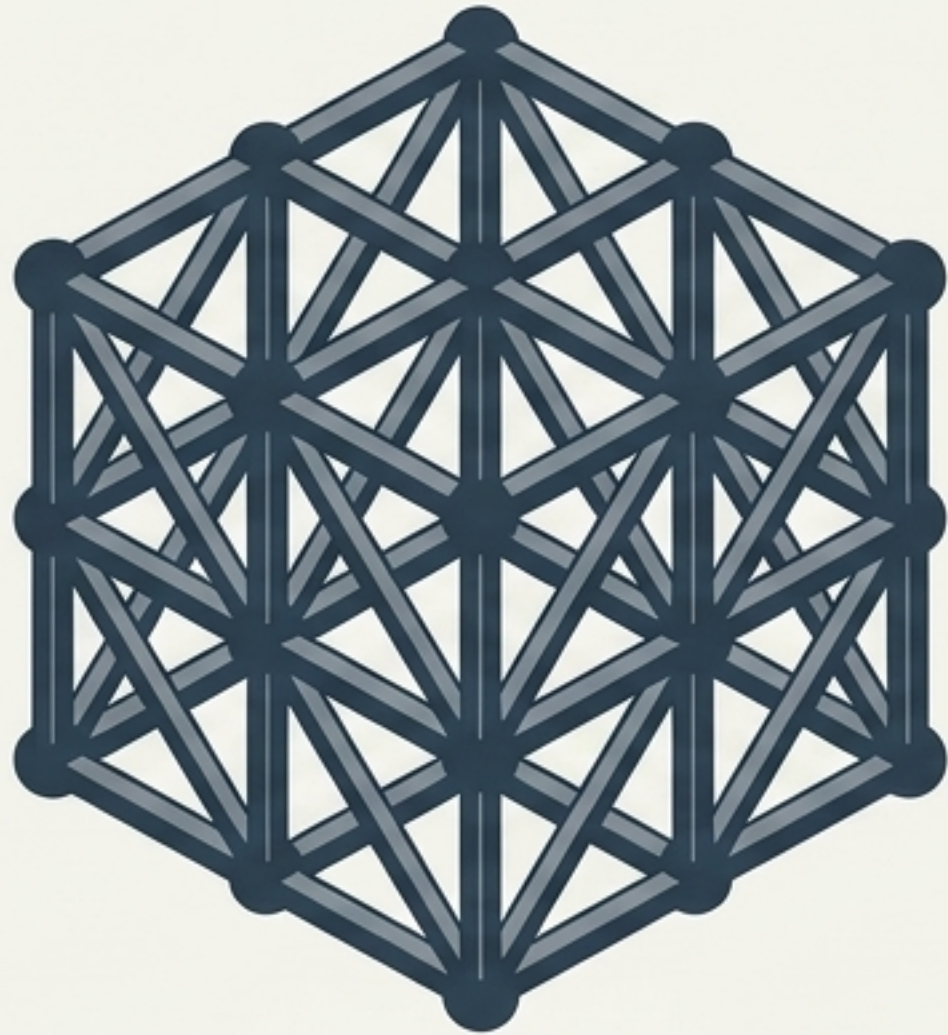
Component	Weight %	Parts	Functional Role
EHSO	47.8%	90.0	Bio-epoxy backbone (Oxirane oxygen: 8.0–10.5%; EEW: 180–220 g/eq)
Citric Acid	11.9%	30.0	Carboxyl cross-linker
Zinc Acetate Dihydrate	1.0%	3.0	Transesterification catalyst
FGE	8.9%	10.0	Reactive diluent

Core Architectural Principle:

A rigid 1:0.8 epoxy:carboxyl molar ratio. This deterministic stoichiometry is mathematically optimised for dynamic exchange while maintaining structural integrity.

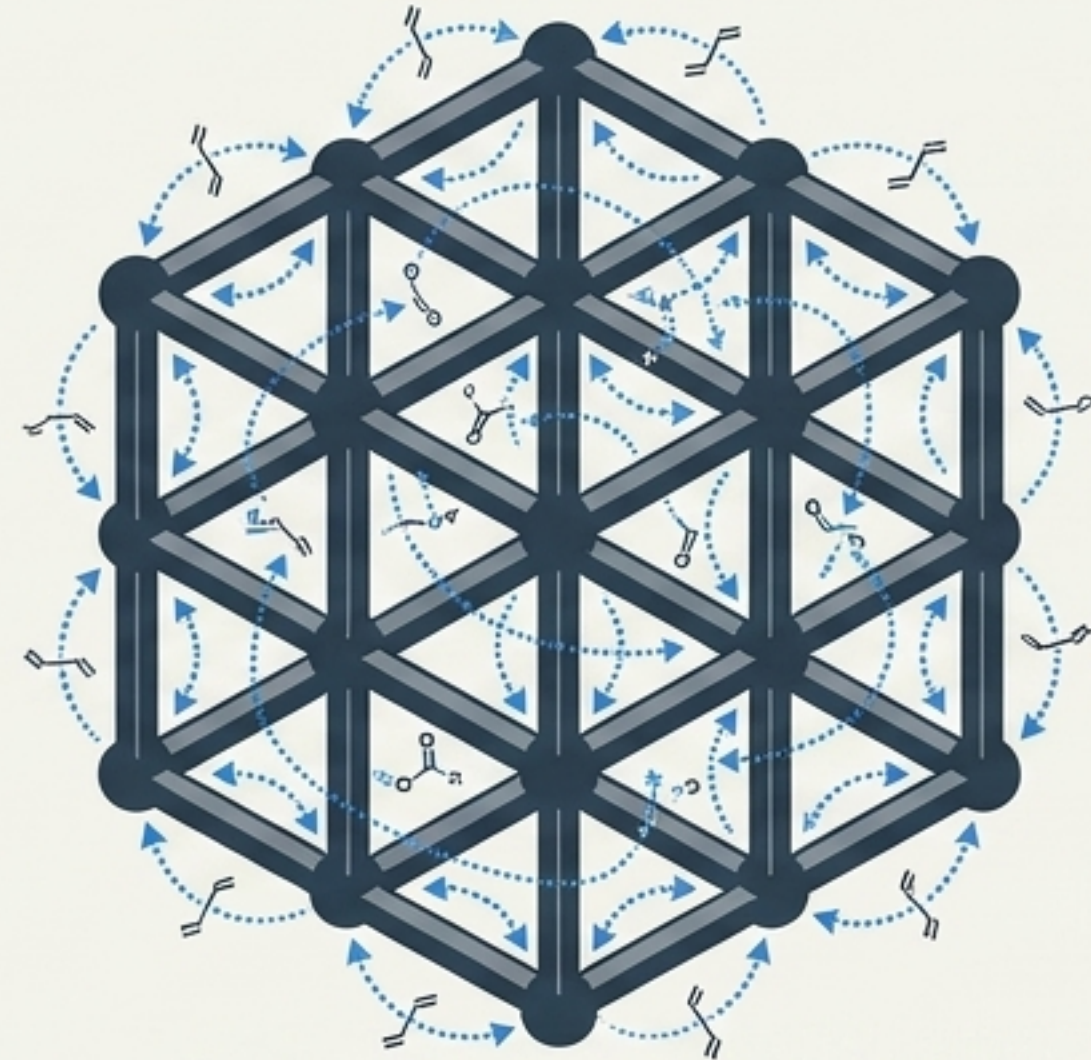
The Vitrimer Engine: Two Distinct Chemical States

Below 150°C - Cured State



Mechanism: Zinc-catalysed ring-opening of **EHSO epoxide** groups by **citric acid** forms rigid β -hydroxy ester cross-links. Steric hindrance of long-chain triglycerides governs self-regulating cross-link density.

Above 150°C - Dynamic State

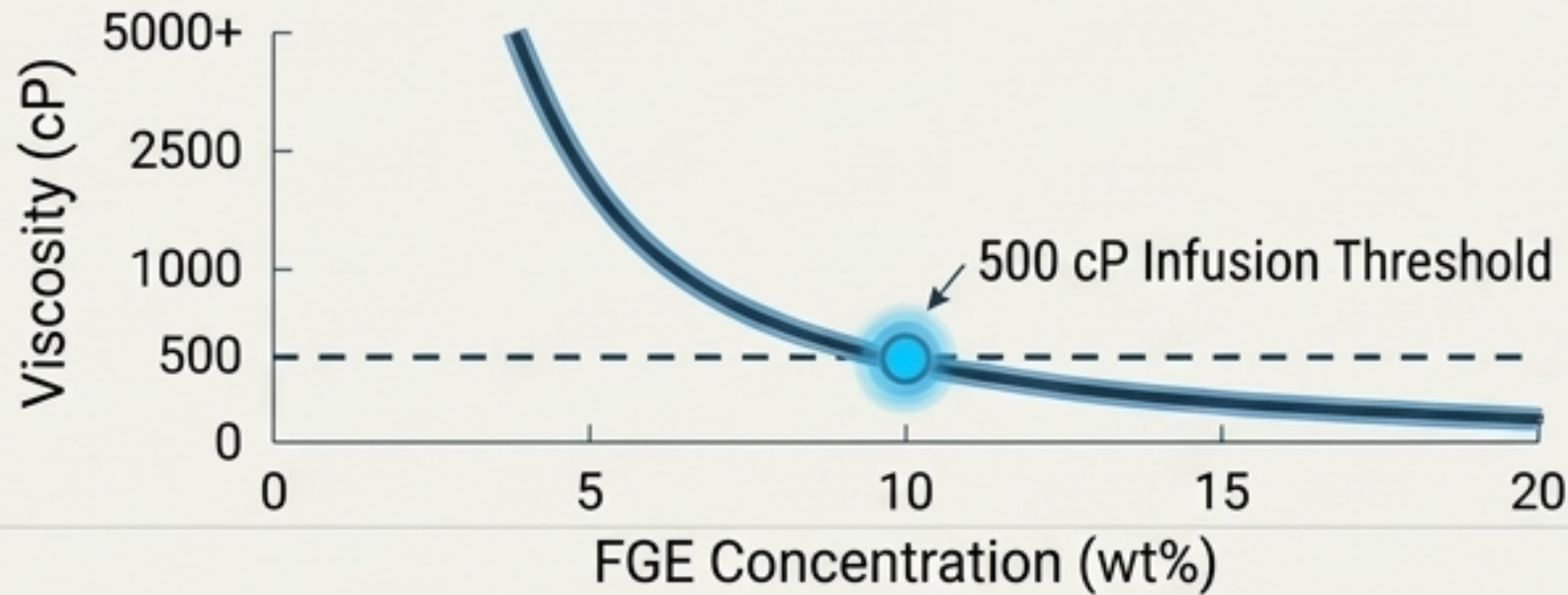


Mechanism: Zinc acetate facilitates associative transesterification. Hydroxyl groups attack neighbouring ester linkages, enabling network rearrangement with constant cross-link density. Dimensional stability is preserved.

Activation energy (E_a) for bond exchange: **80–120 kJ/mol**

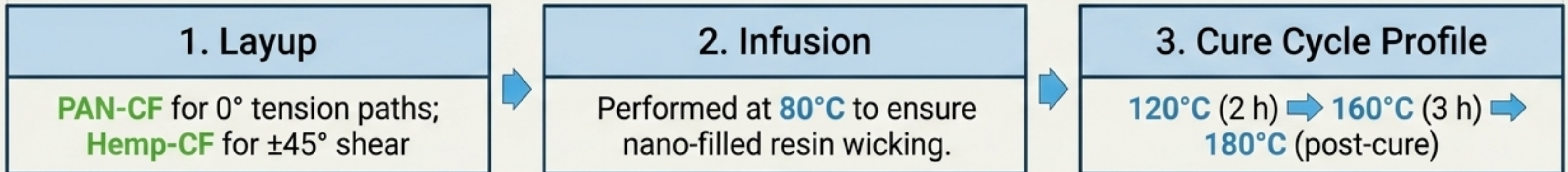
Industrial Processability: Viscosity & VARI Protocol

Rheology Data: FGE Concentration Effects



Inclusion of 10 wt% FGE reactive diluent drops matrix viscosity **below 500 cP** at 40°C, enabling **deep fibre wetting**.

Fabrication Timeline: VARI Process & Cure Cycle



Thermal Constraints: Wide gap between T_g and T_v ($\Delta T \approx 85^\circ\text{C}$) guarantees a safe processing window with no service-temperature creep.

Interfacial Science: The Furan-Carbon π -Stacking Affinity

The Molecular Locking Mechanism

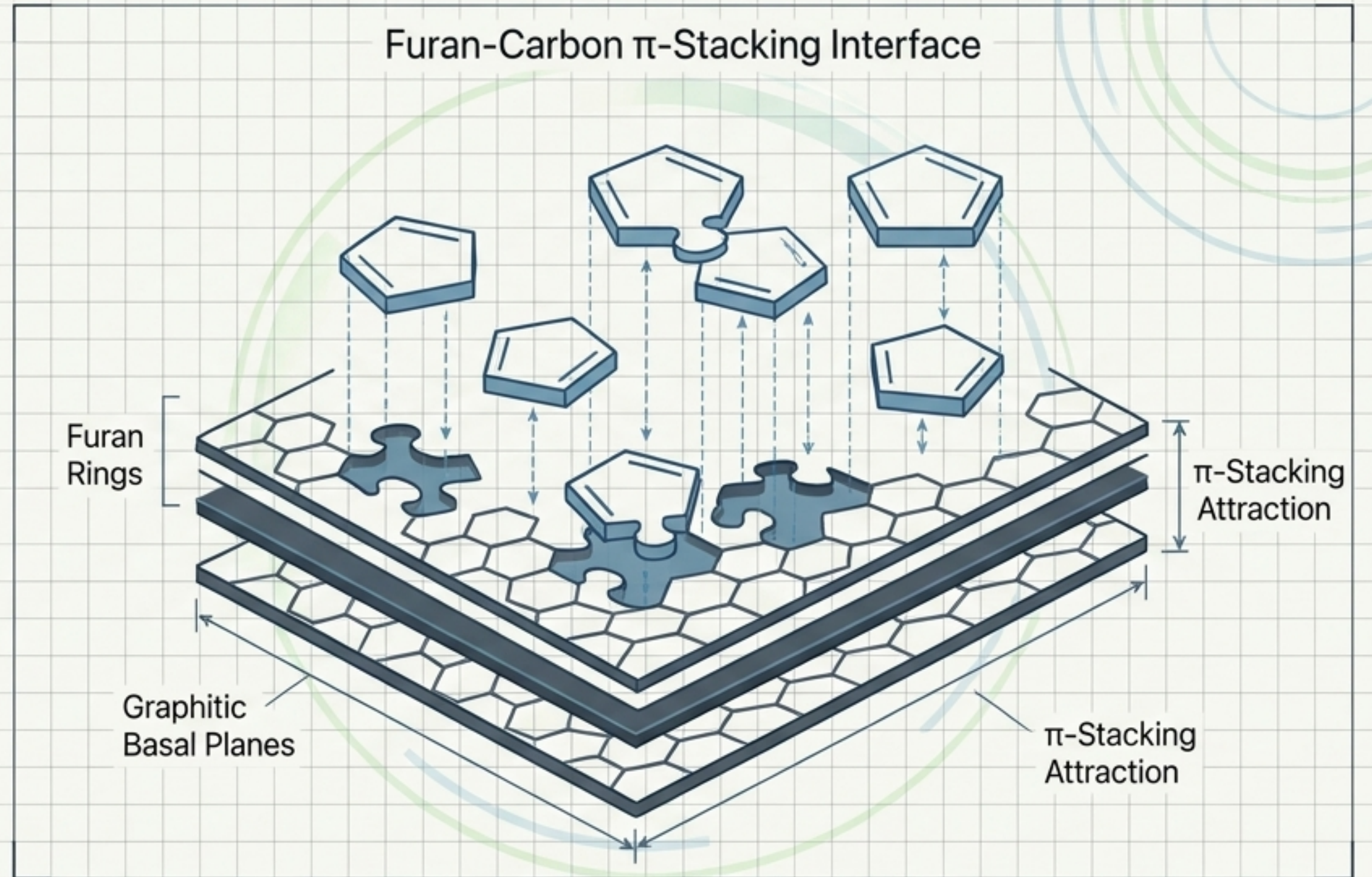
Furan rings from the FGE reactive diluent physically align and molecularly lock with the graphitic basal planes of carbon reinforcements (PAN-CF, biochar, graphene).

Beyond Mechanical Interlocking

This affinity surpasses the simple mechanical interlocking found in conventional DGEBA epoxy systems.

Performance Outcome:

Translates to an estimated 15–20% improvement in interlaminar shear strength (ILSS).



The Structural Showdown: Hempoxies vs. Legacy Thermosets

Key Dimension	Hempoxies Platform	Legacy DGEBA/TETA
Tensile Strength (ASTM D638)	>180 MPa	55–90 MPa
Young's Modulus (ASTM D638)	8–12 GPa base; >40 GPa reinf.	2.5–3.5 GPa
Bio-based Content (ASTM D6866)	95–100%	<5%
Self-Healing Efficiency	>85%	0%
Recyclability (ISO 14040)	Infinite solid-state reprocessing	Non-recyclable

Projections for reinforced variants based on rule-of-mixtures and verified filler moduli (PAN-CF: 230 GPa, Graphene: 1 TPa).

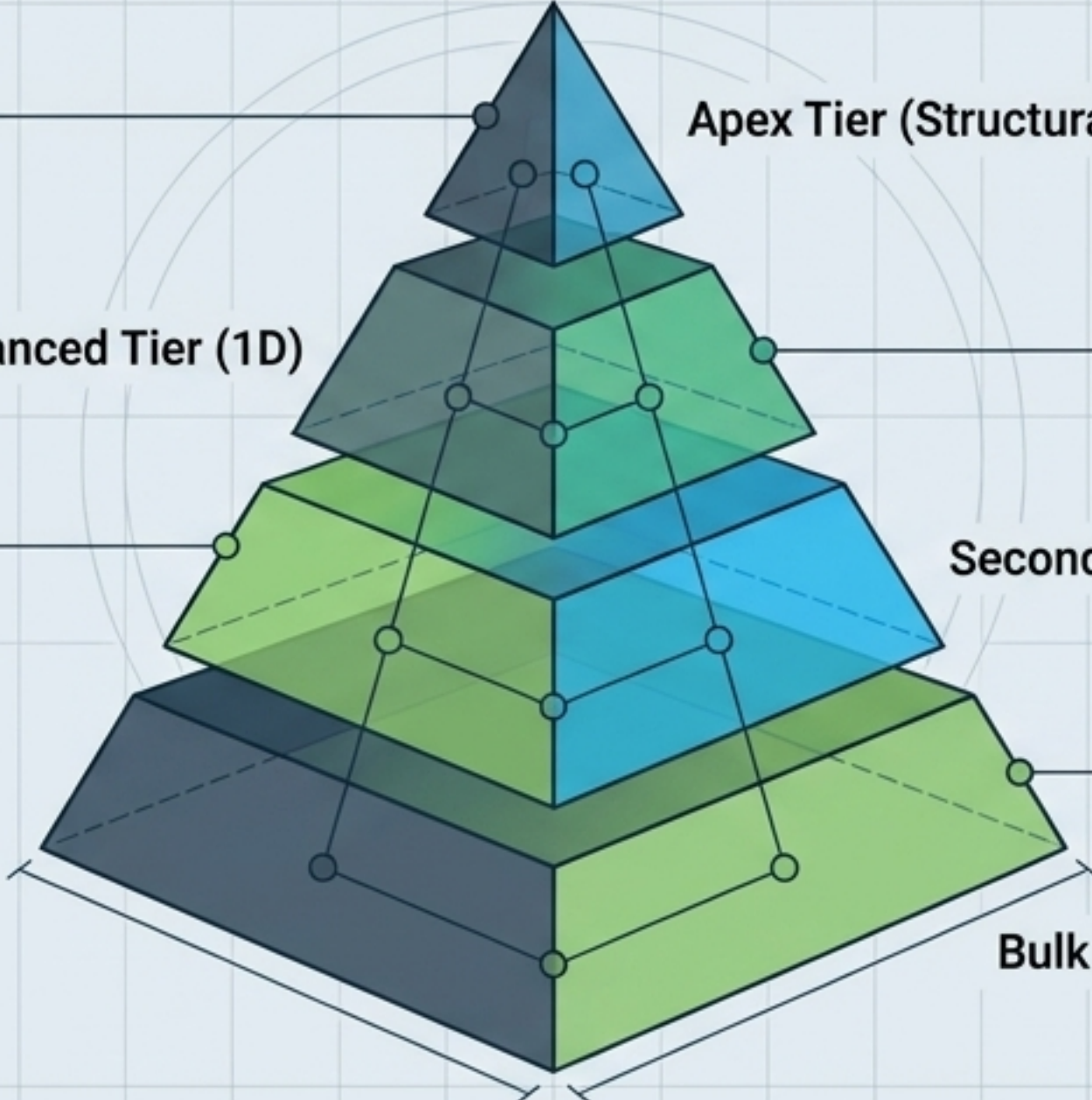
Hierarchical Reinforcement Architecture

A modular mix-and-match adaptability matrix.

Apex Data Points
PAN-CF (30-60 wt%): Primary load bearing
Graphene (0.1-1.0 wt%): Modulus / gas barrier
MXenes (Ti3C2Tx, 0.5-3.0 wt%): EMI shielding

Note: Pre-dispersed in FGE via ultrasonication.

Secondary Data Points
Hemp-derived CF (20-40 wt%): Carbon sequestration
Halloysite Nanotubes (1-5 wt%): Fire retardancy
Technical Lignin (5-10 wt%): UV protection
Basalt Micro-fibres (10-20 wt%): Chemical resistance



Apex Tier (Structural & Defence)

Advanced Tier (1D)

Secondary / Functional Tier

Bulk / Base Tier

Advanced Data Points
CNTs (0.1-0.5 wt%): Interlaminar toughness

Bulk Data Points
Activated Biochar (5-15 wt%): Cost efficiency, porosity

Modular Application Tiers

Tier 1 — Commercial Baseline (#1-F)

Load Matrix:

- 20–40 wt% **hemp biochar** (200 m²/g).

Primary Use-Case:

- Cost-efficient, high-porosity industrial components.

Tier 2 — Structural Hybrid (#1-S)

Load Matrix:

- 35–50 wt% **PAN-CF**
- 10–15 wt% **HBC**

Primary Use-Case:

- EMI shielding components (**HX-SH150**).
- Ballistic protection (**HX-BA160**, V50 ≥ 950 m/s).

Tier 3 — Unified Organic (#1-HCF)

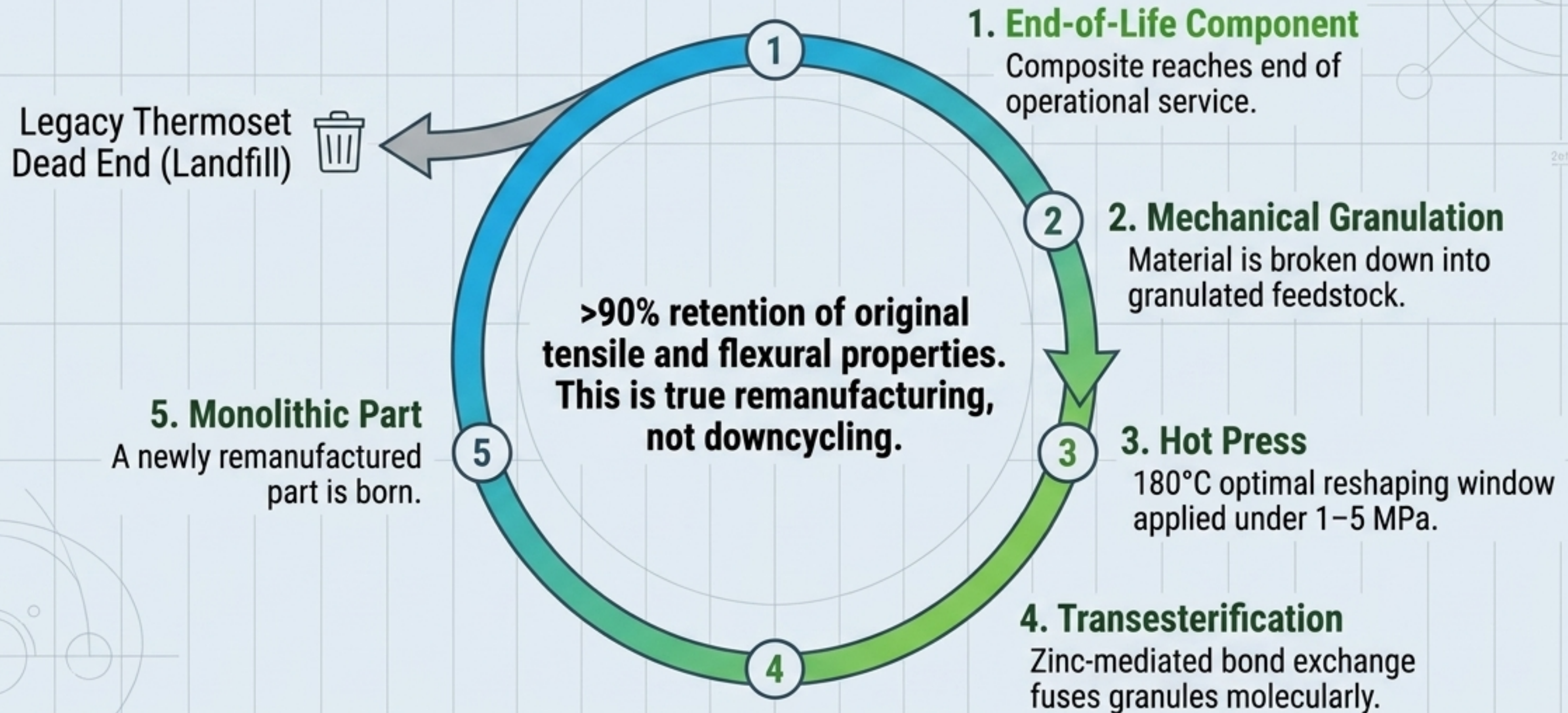
Load Matrix:

- 40–60 wt% **hemp-derived carbon fibre**.

Primary Use-Case:

- 100% **botanical** structural parts.
- Cryogenic applications (**HX-CR100**, UTS ≥ 130 MPa at -196°C).

The Circularity Loop: Solid-State Remanufacturing



Net-Negative Carbon Status: Through 100% bio-derived feedstocks, the system sequesters ~1.6 kg CO₂ per kg of material.

The Open-Source Commercialisation Paradigm



Hempoxies is released as open-source prior art to prevent proprietary enclosure. It proves conclusively that structural-grade aerospace vitrimers can be entirely bio-based.

Data Access Details

- **License:** Landry Open Bio-Composite License (LOBL-V1)
- **Zenodo:** DOI 10.5281/zenodo.16944339
- **Documentation:** Hempoxies Technical Report Series



Future Roadmap

- Experimental validation of mechanical benchmarks.
- ASTM / MIL-STD structural certification.
- Scale-up from 5 kg laboratory batches to pilot production (100+ kg batches).

