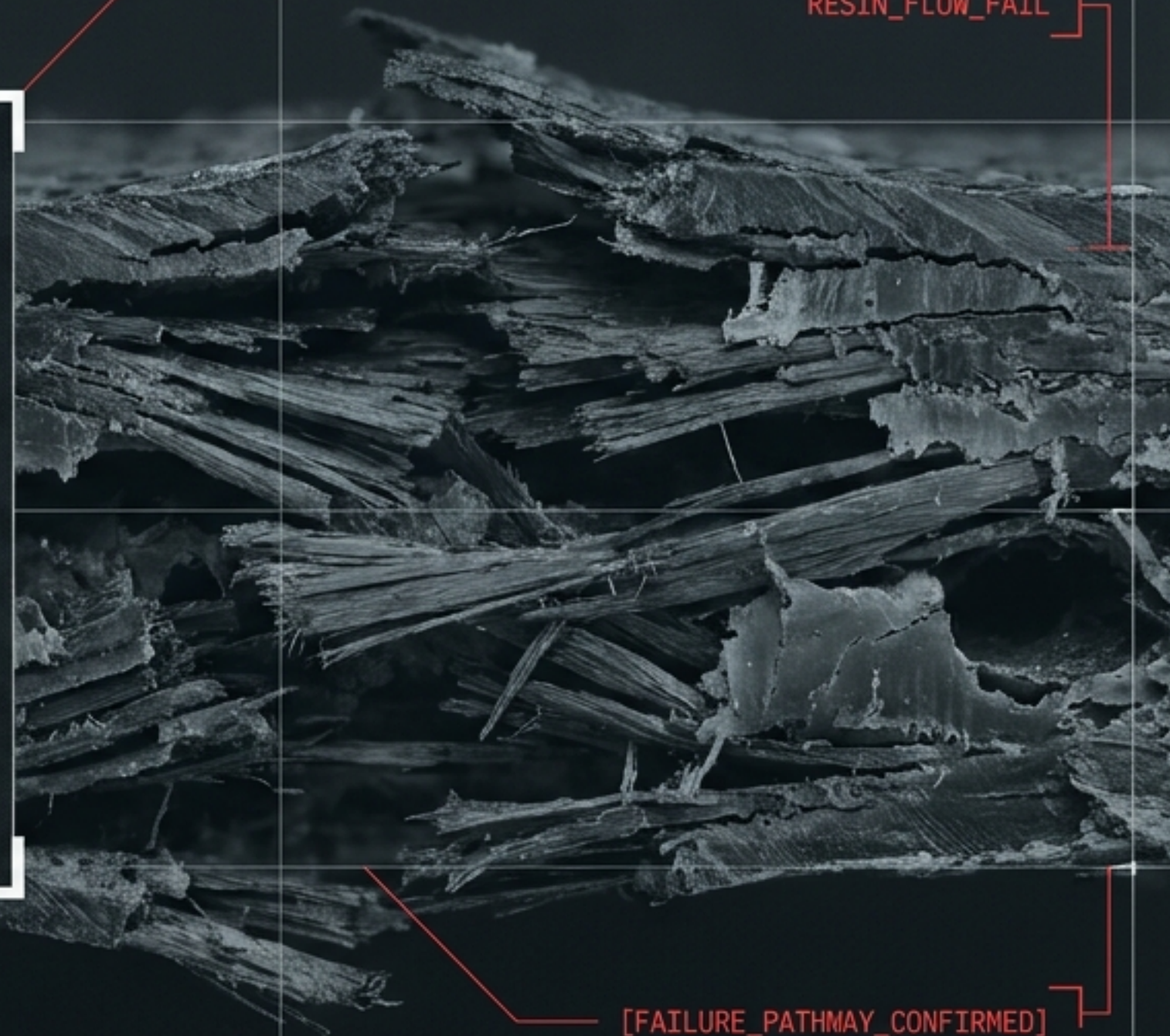


[SYS_FAIL_0x7A] CRITICAL ANOMALY DETECTED
T_v ERROR: >450 °C
SHEAR_STRESS: 12.4 GPa (LIMIT EXCEEDED)
DELAM_DET: POSITIVE (ZONE 4-A)

[WARN: MATERIAL_DEGRADATION_ACTIVE]
VFA_LEVEL: 8.2% (TARGET <2%)
STOICH_DRIFT: +0.15%
RESIN_FLOW_FAIL

How NOT to Make Hempoxies

A Failure Analysis & Diagnostic Logbook Mapping
Strict Operational Boundaries, Stoichiometric
Drift, and Degradation Vulnerabilities.



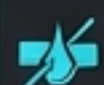
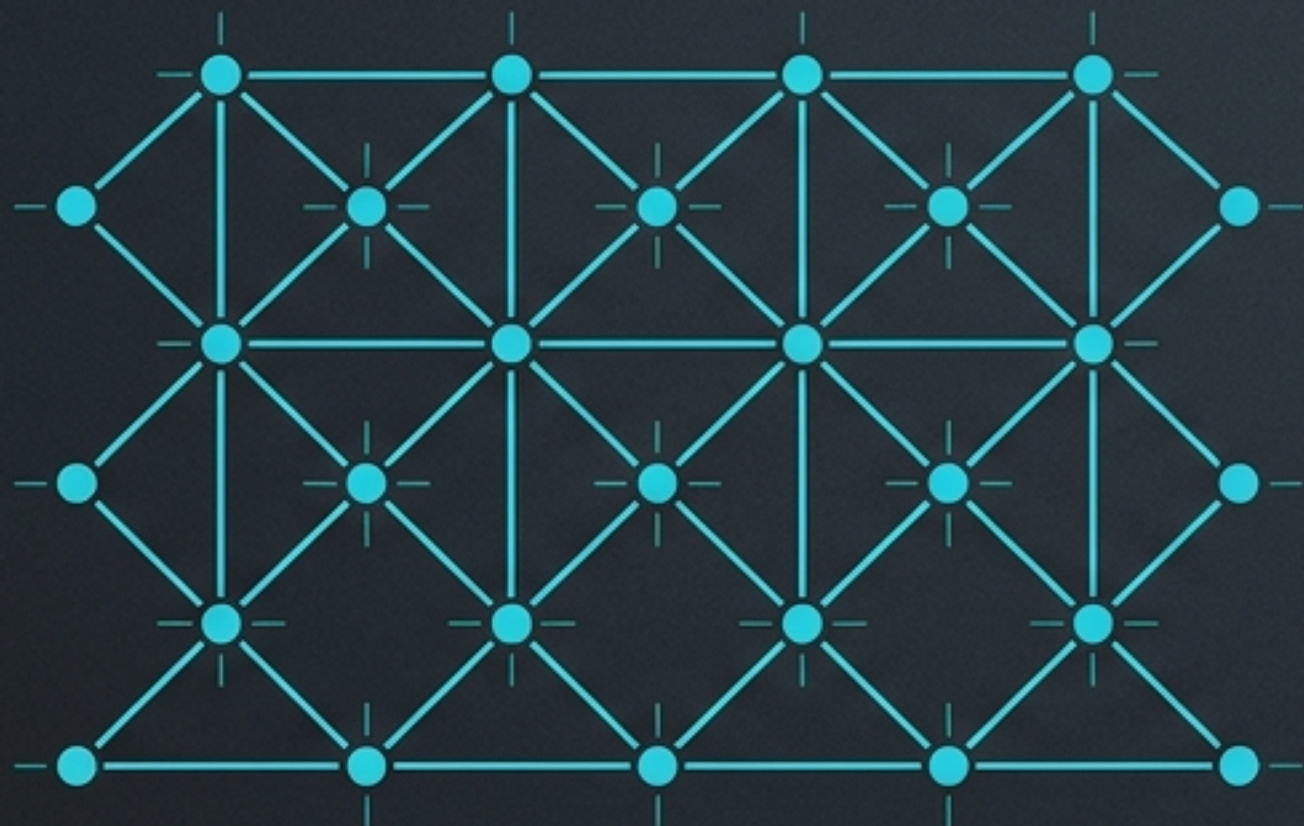
[ALERT: STRUCTURAL_INTEGRITY_COMPROMISED]
FIBER_PULLOUT: 65%
VOID_CONTENT: 3.8%
ADHESION_LOSS: 92%

[FAILURE_PATHWAY_CONFIRMED]
MICROCRACK_DENSITY: HIGH
MOISTURE_INGRESS: DETECTED
THERMAL_CYCLING_FAIL

The Zero-Margin Paradox of Dynamic Vitrimers

The Theoretical Promise

SYSTEM STATUS: NORMAL [CYAN]



Zinc-catalyzed transesterification allows bond exchange without crosslink loss.



Enables self-healing, thermal thermoforming, and chemical recyclability.

The Manufacturing Reality

SYSTEM CRITICAL: FAILURE PATTERNS ACTIVE [RED]

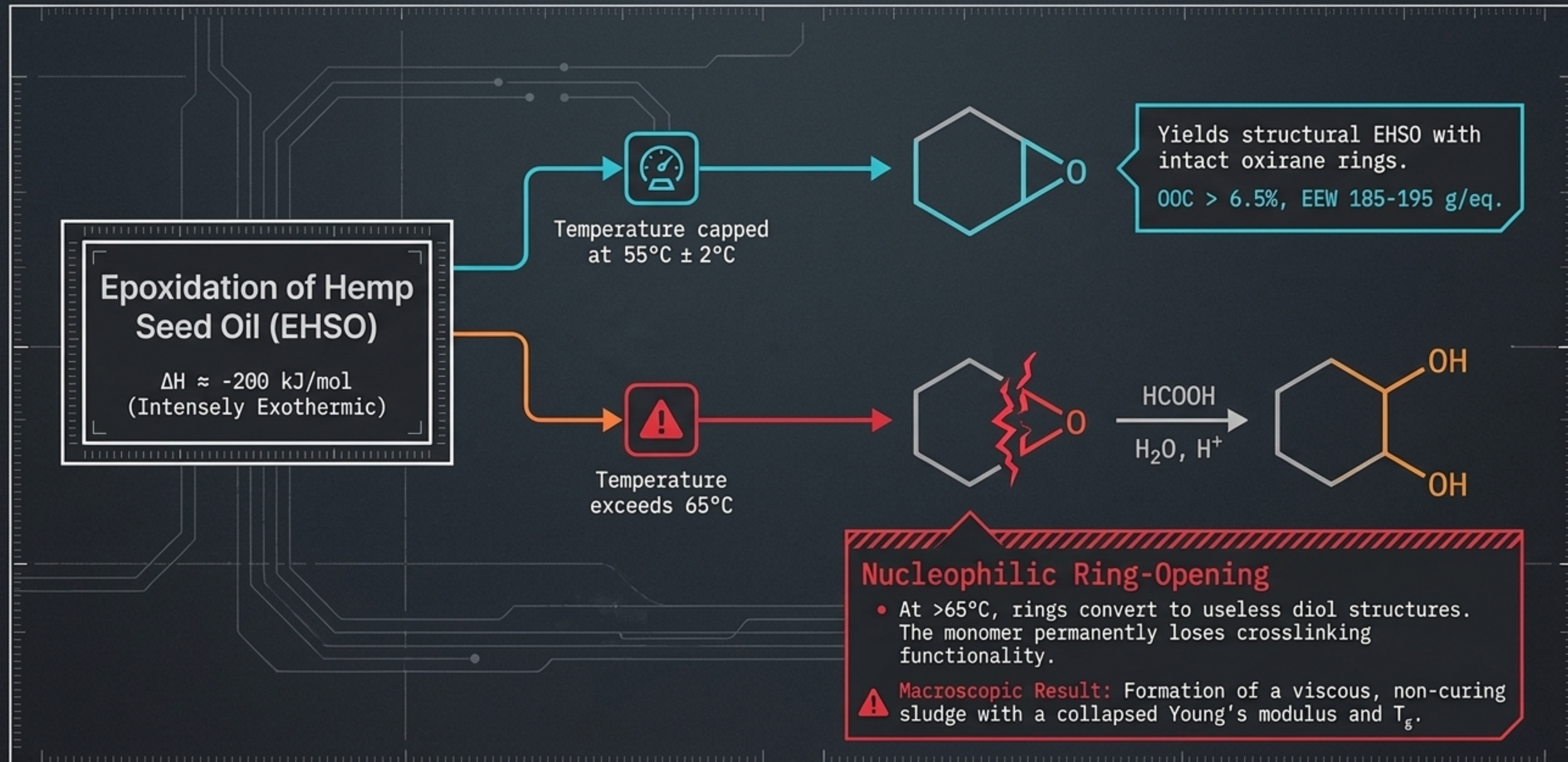


Replacing static petroleum thermosets introduces severe stoichiometric and rheological sensitivities. Margin for error: Zero. **[ZERO MARGIN]**



Uncontrolled processing results in sludge, premature gelation, and permanent malleability loss.

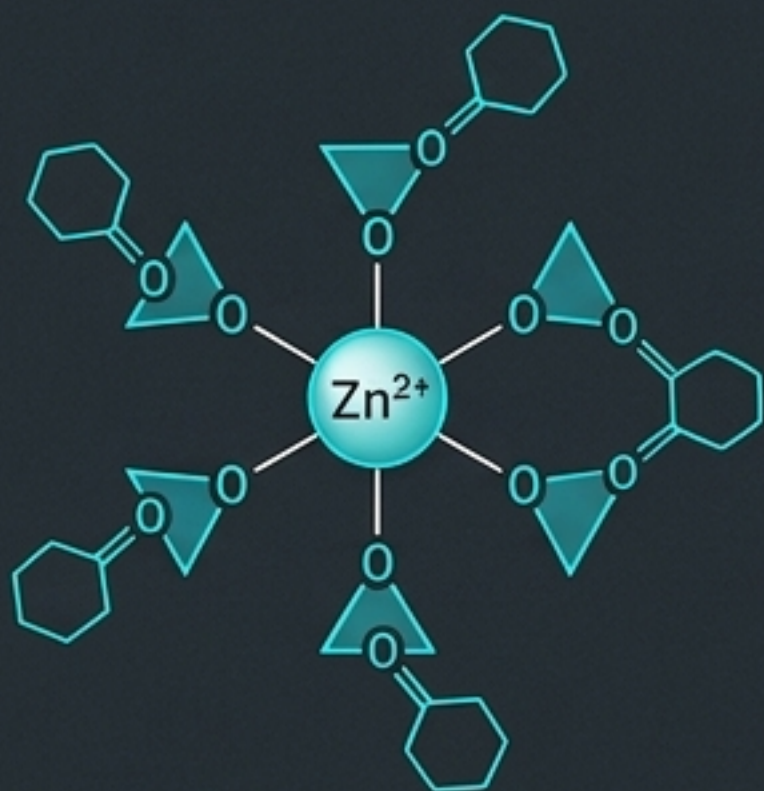
Precursor Trap 1 - The Exothermic Sludge



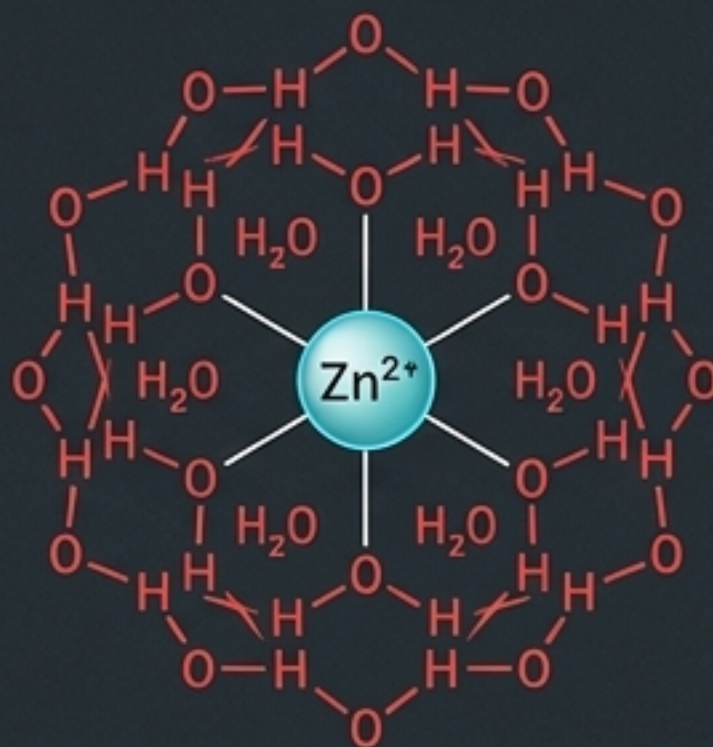
Precursor Trap 2 - The Catalyst Poisoning

The Blocked Keyhole Schematic

Dry State (<500 ppm)

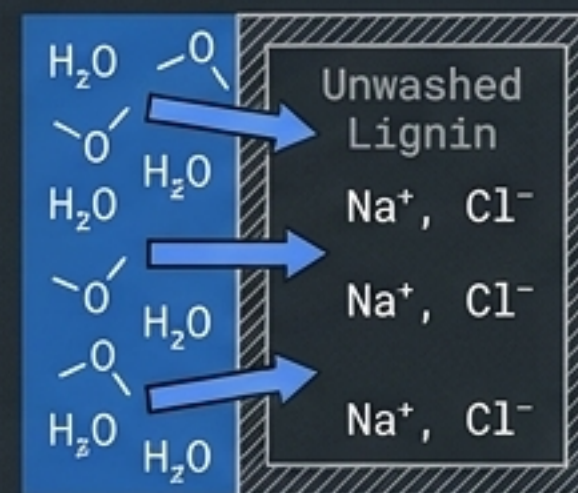


Wet State (>2000 ppm)



Bond-exchange rate $k(T)$ drops to zero. The material becomes a static, brittle thermoset incapable of self-healing.

The Ionic Magnet



Ionic impurities from unreacted epichlorohydrin act as magnets for water ingress, causing premature hydrolytic cleavage.

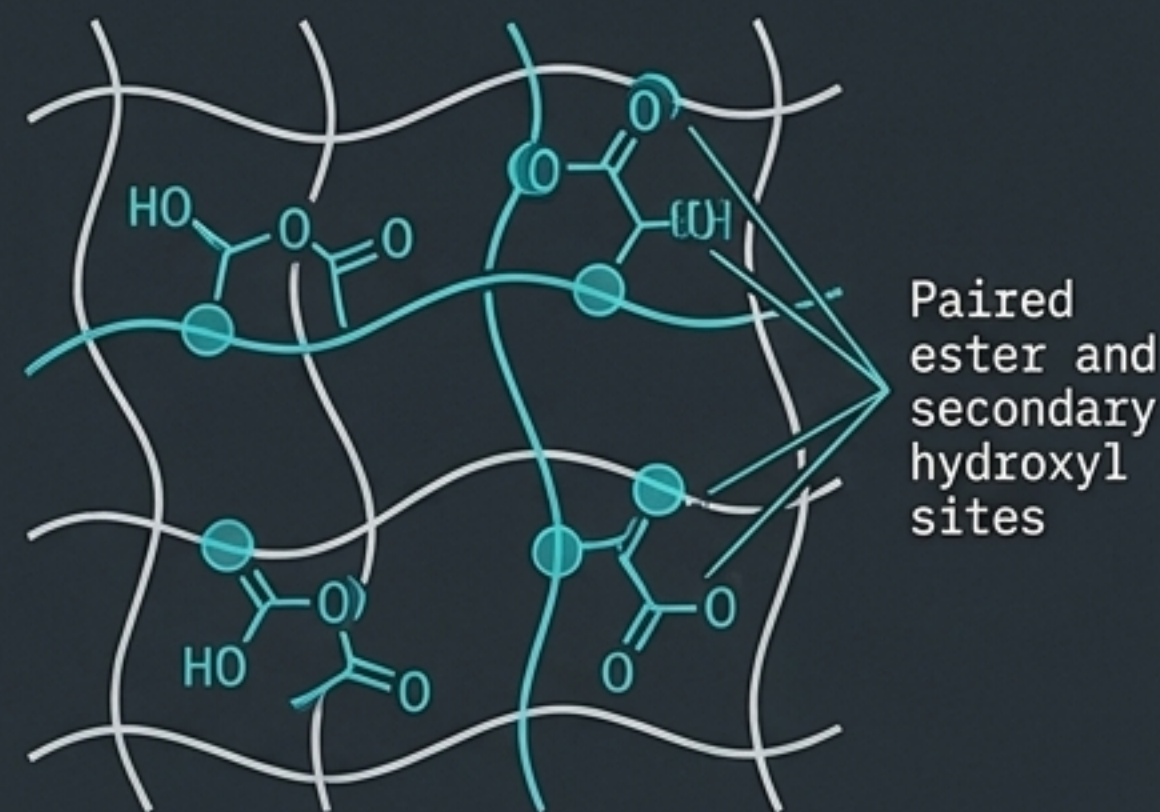
The 1:1 Stoichiometric Myth Guarantees Failure

A FAILED (1:1 Equimolar Ratio)



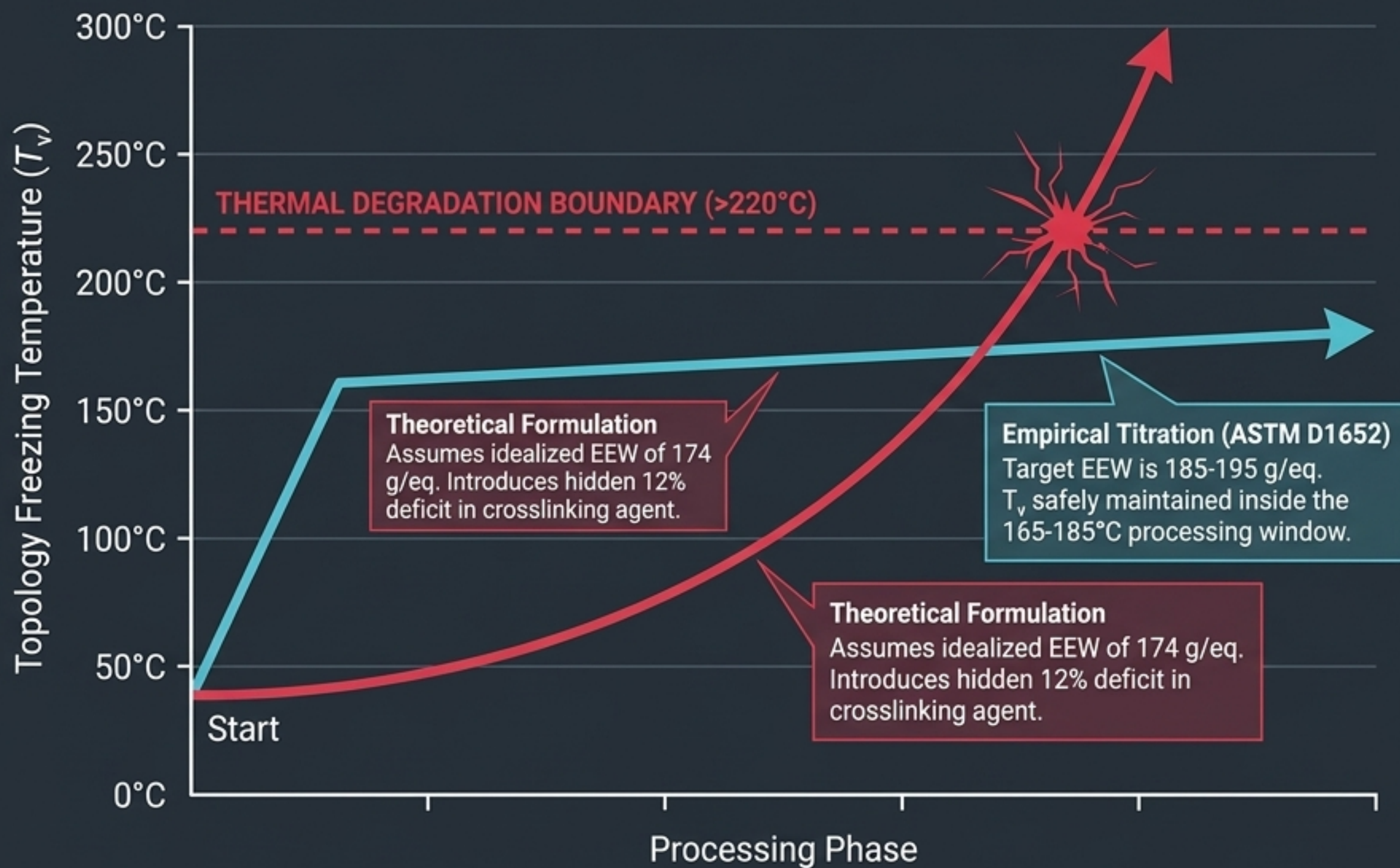
- MECHANISM: Insufficient secondary hydroxyl groups generated. Unreacted acids act as internal plasticizers.
- CONSEQUENCE: Elevated moisture uptake, T_g drop of up to 30°C, severe viscoelastic creep.

B SAFE (1.51:1.00 Operational Ratio)



- MECHANISM: Target is strictly 1:0.8 Epoxy-to-Carboxyl. This 20% molar epoxide surplus accommodates triglyceride steric hindrance.
- CONSEQUENCE: Complete hardener consumption and preservation of vitrimeric dynamics.

Mathematical Drift Pushes T_v into the Degradation Zone



⚠ Diagnostic Callout Box

CATASTROPHIC CONVERGENCE

Attempting to thermally reprocess or self-heal this theoretical batch results in total thermal degradation of the bio-backbone before bond exchange can ever activate.

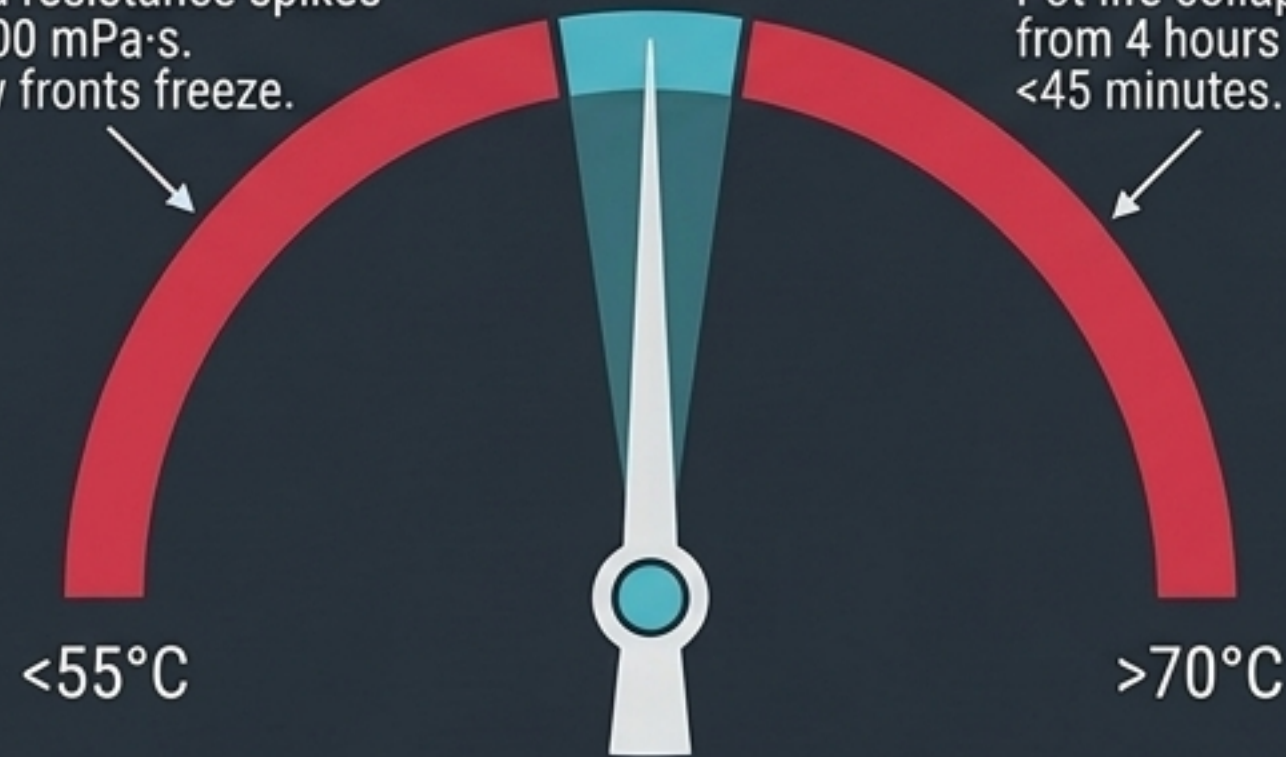


The Rheology Tightrope During Infusion

Resin Temperature

Viscosity Stall

Fluid resistance spikes
>1500 mPa·s.
Flow fronts freeze.



Flash Gelation

Pot life collapses
from 4 hours to
<45 minutes.

Degassing Vacuum

FGE Volatilization

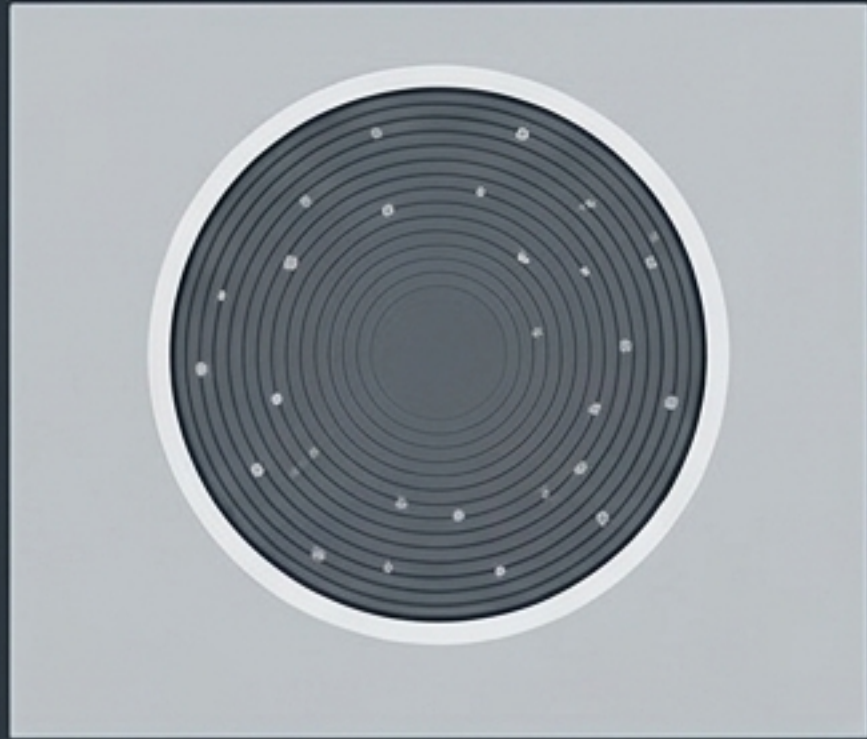
Low-boiling Furfuryl
Glycidyl Ether
flashes into vapor.



Consequence of FGE Volatilization: Alters stoichiometry permanently and seeds massive structural macro-voids into the resin line during **Vacuum-Assisted Resin Infusion (VARI)**.

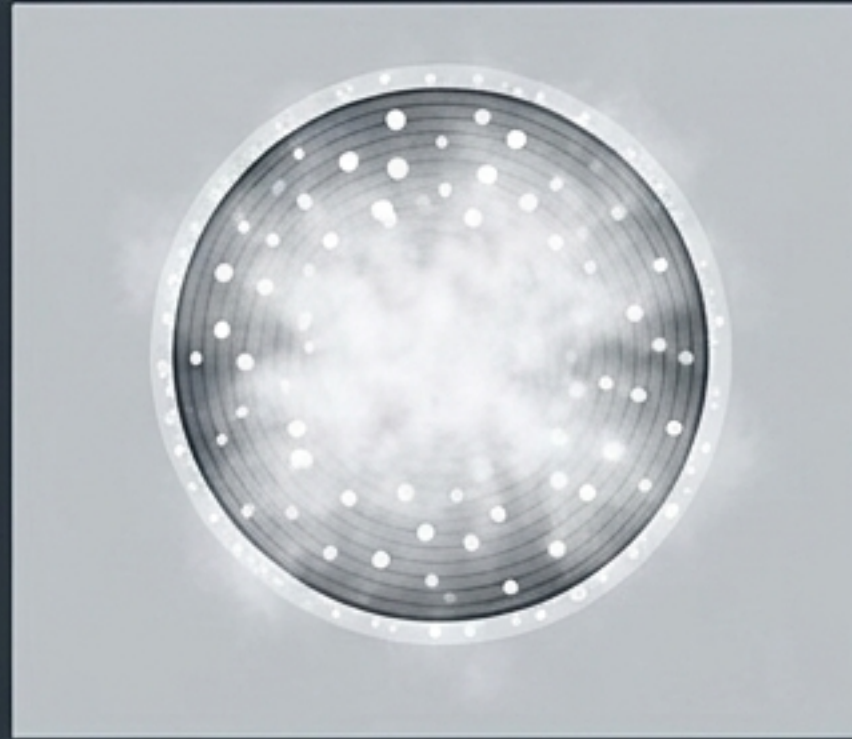
The Interfacial Steam Bomb

25°C - Ambient State



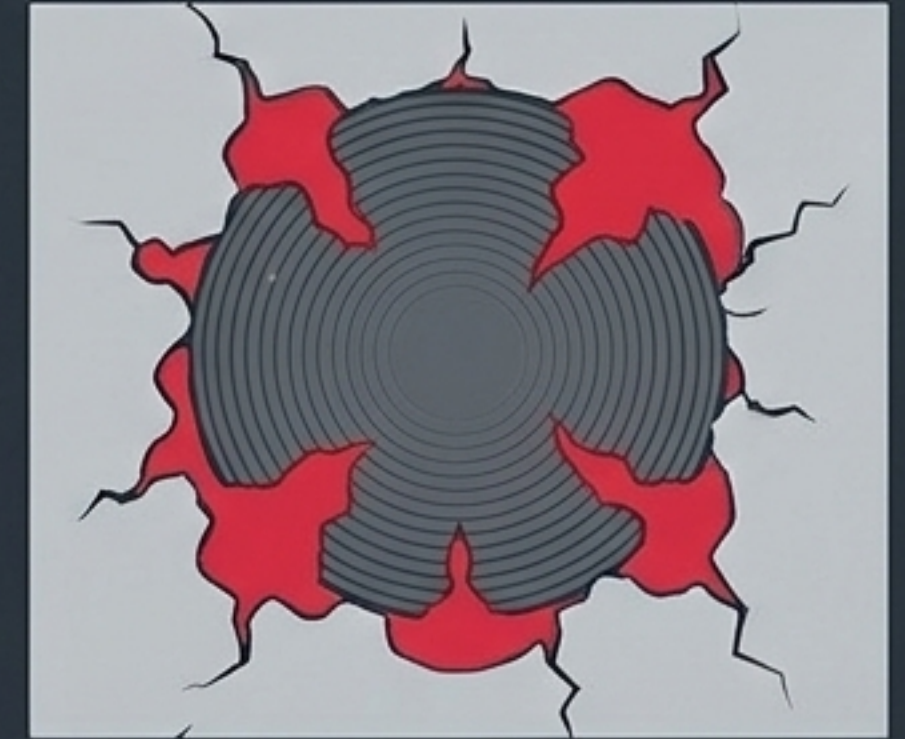
Carbon preforms invisibly harbor 8-12 wt% micro-porous moisture.

100°C - Vaporization



Vaporization begins inside the closed mold.

120°C - Gelation



High-pressure steam pockets physically decouple fiber from resin.

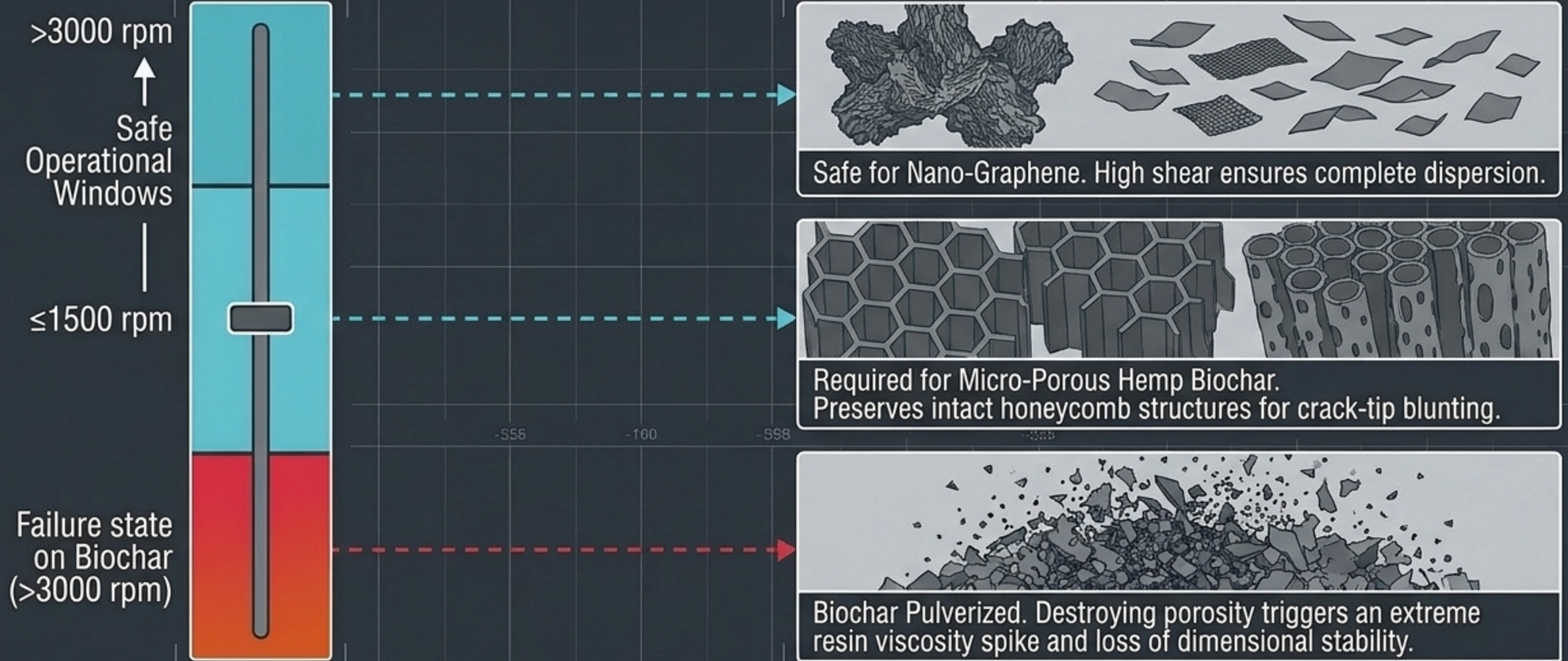
Impact Metric

Interfacial Shear Strength (IFSS) collapses from an optimal 45-55 MPa down to **<20 MPa** (early flexural delamination).

RULE: Red-Line Mandate.

Processed fiber preforms and fillers must be vacuum-dried at 105°C for 2 hours immediately prior to infusion to reach **<0.5 wt%**.

High-Shear Pulverization of Biochar Microstructures



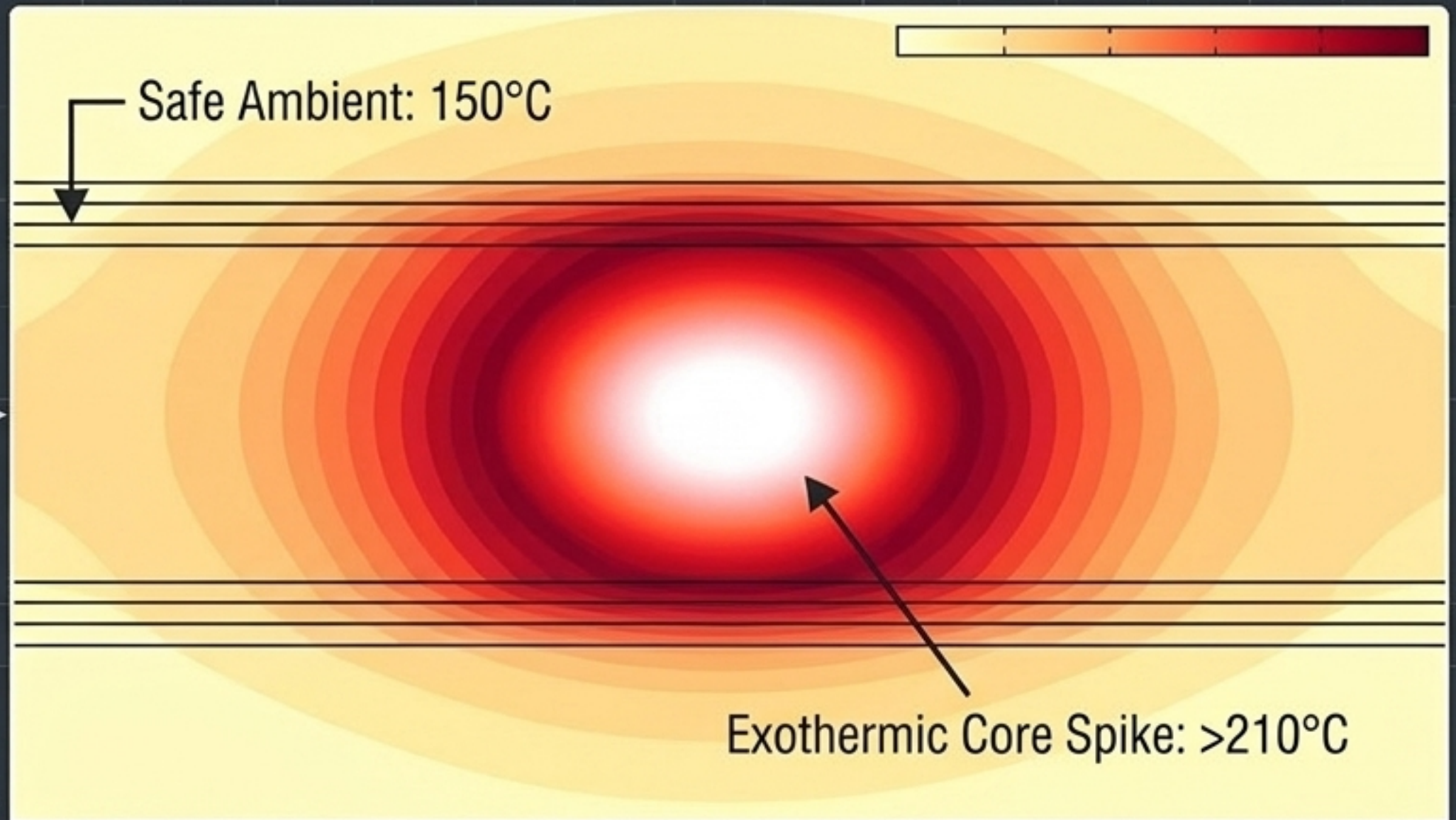
MANDATE: Staged dispersion is mandatory. Never subject biochar to >1500 rpm.

The Heat Transfer Trap Causes Exothermic Core Spikes

Physics of the Exotherm:

$$\rho \Delta H \frac{d\alpha}{dt}$$

Heat generation (≈ 300 J/g) violently outpaces low polymer thermal conductivity ($\kappa \approx 0.2$ W/m·K).

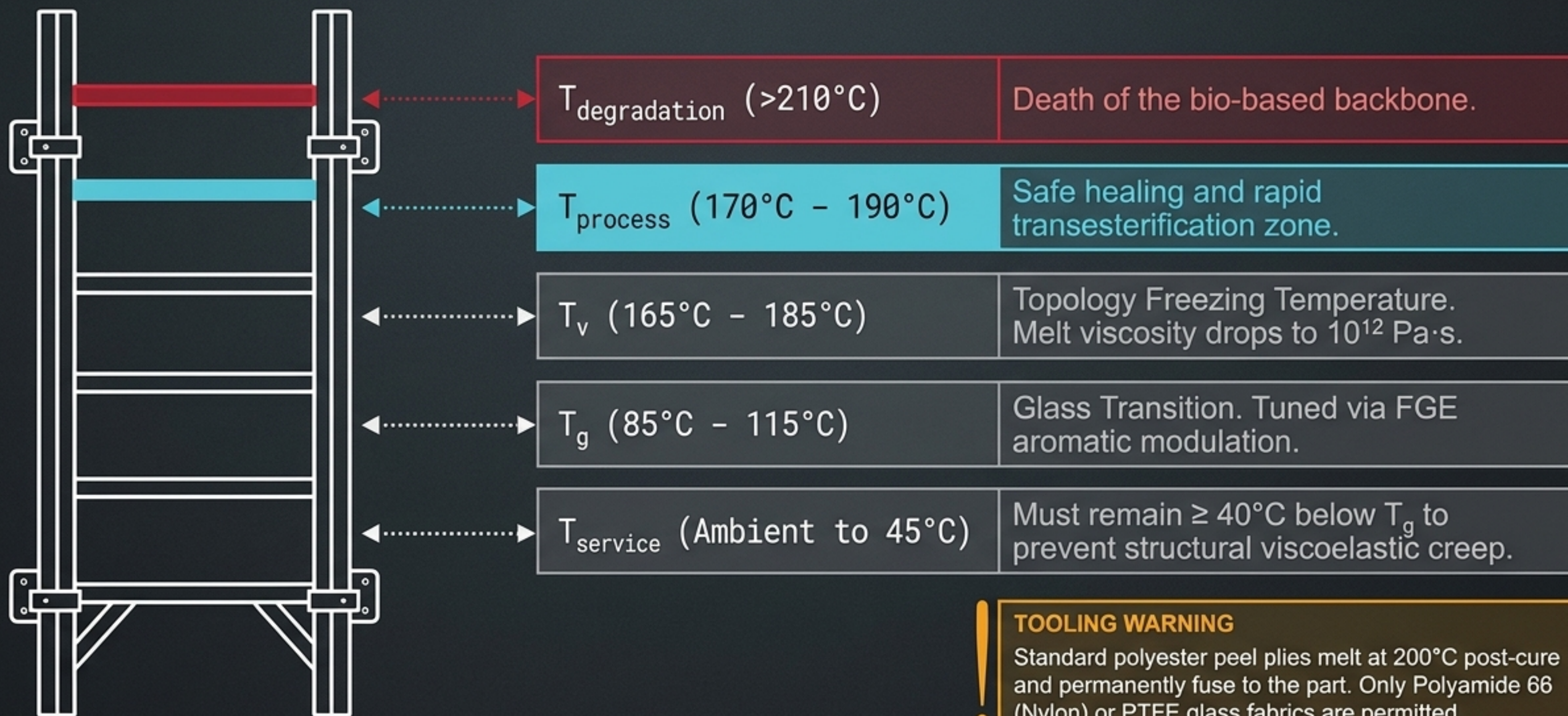


⚠ Catastrophic Consequence: Core temperatures spike >50°C above oven setpoint. Exceeding 210°C triggers thermal cleavage of ester bonds, volatile gas release, and massive internal delamination.

⚠ RULE: Red-Line Mandate.

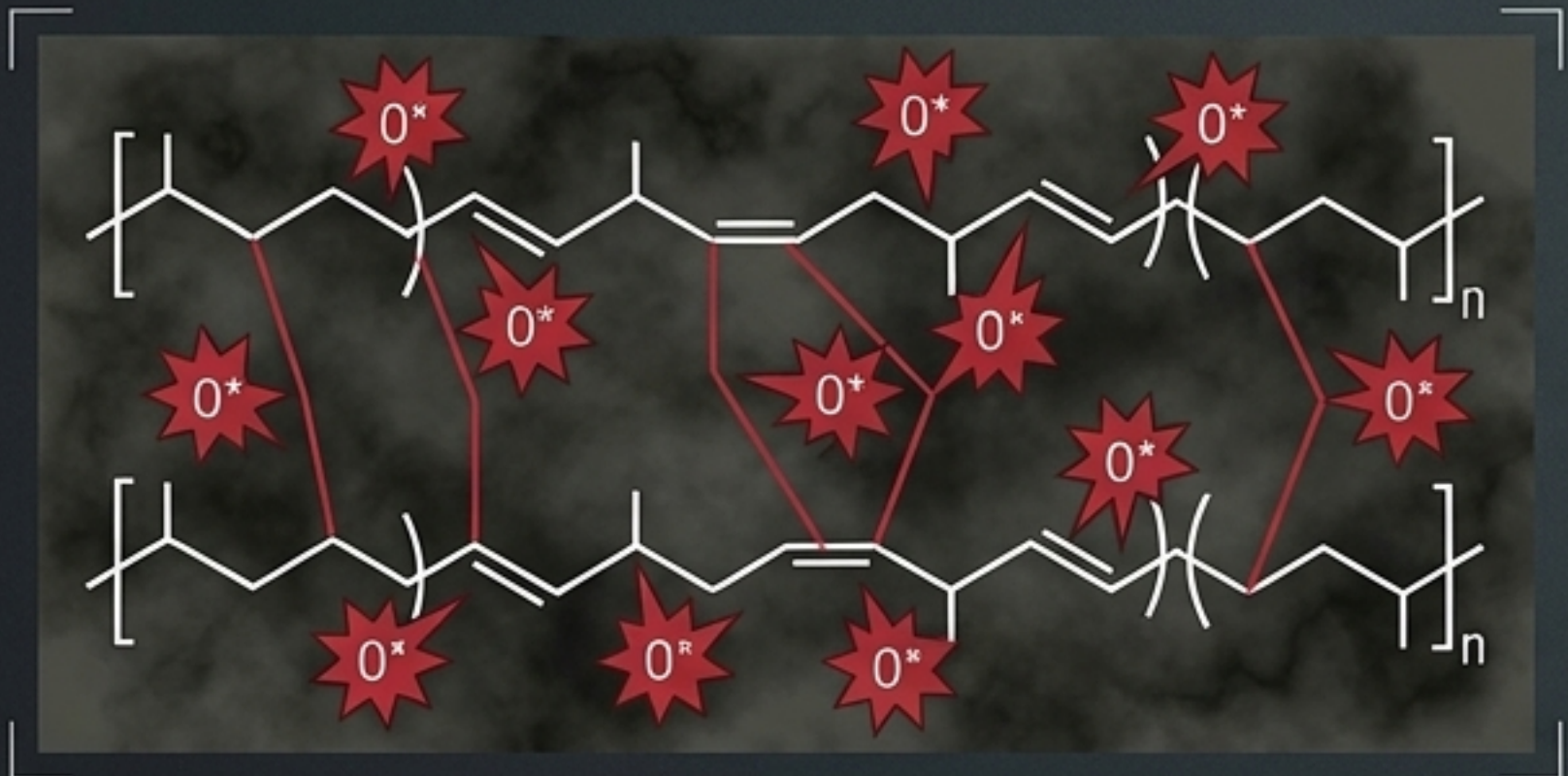
Cure schedules demand multi-stage isothermal dwells (80°C, 120°C, 150°C, 180°C) and ramp rates $\leq 1.5^\circ\text{C/min}$.

The Non-Negotiable Thermal Survival Hierarchy



Ref

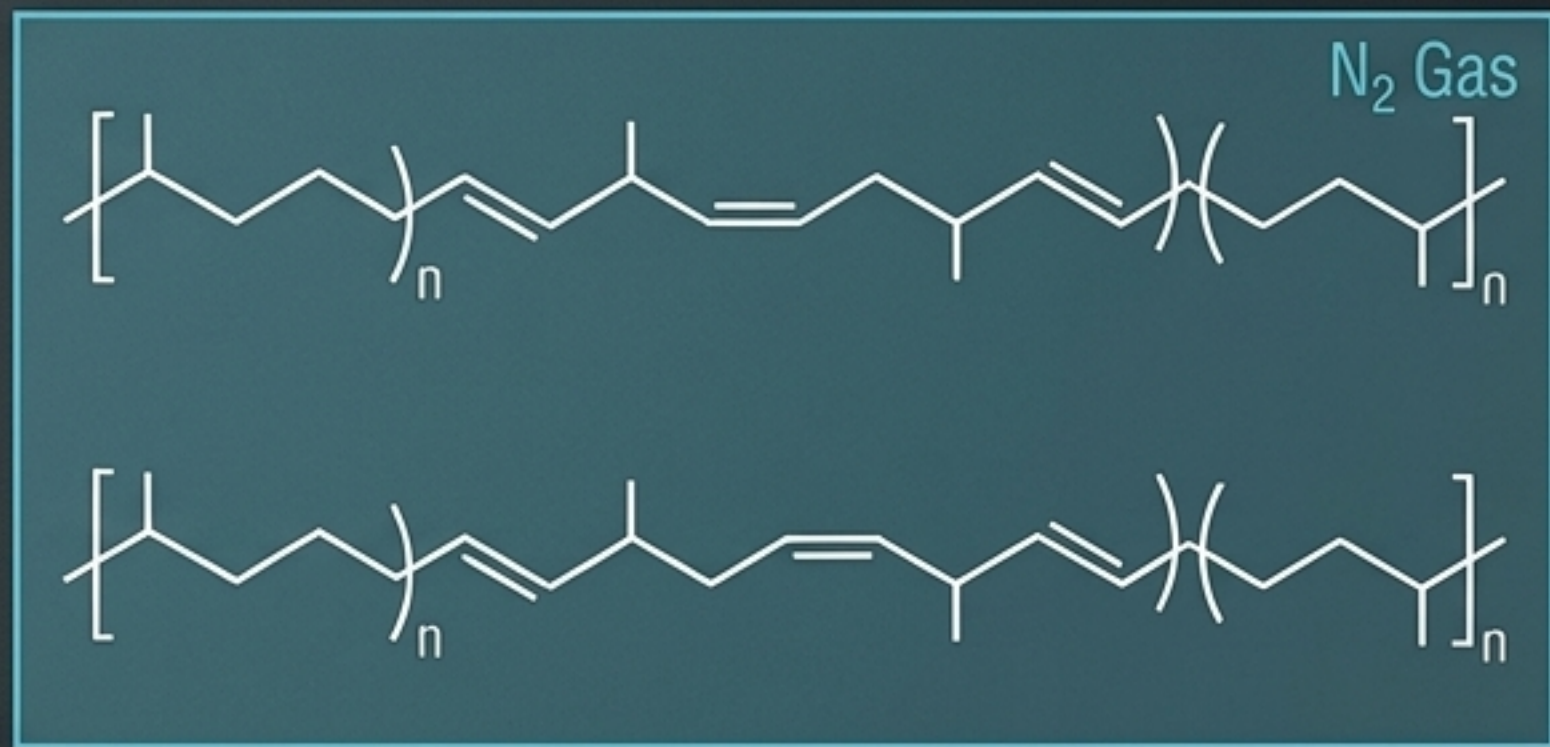
(FAILED)



Mechanism: Radical-mediated crosslinking. The matrix severely darkens.

Result: Chain mobility dies. Dynamic exchange stalls.
 T_v permanently elevates, killing self-healing efficiency
 with each cycle.

Sealed N₂ Purged Environment (SAFE)



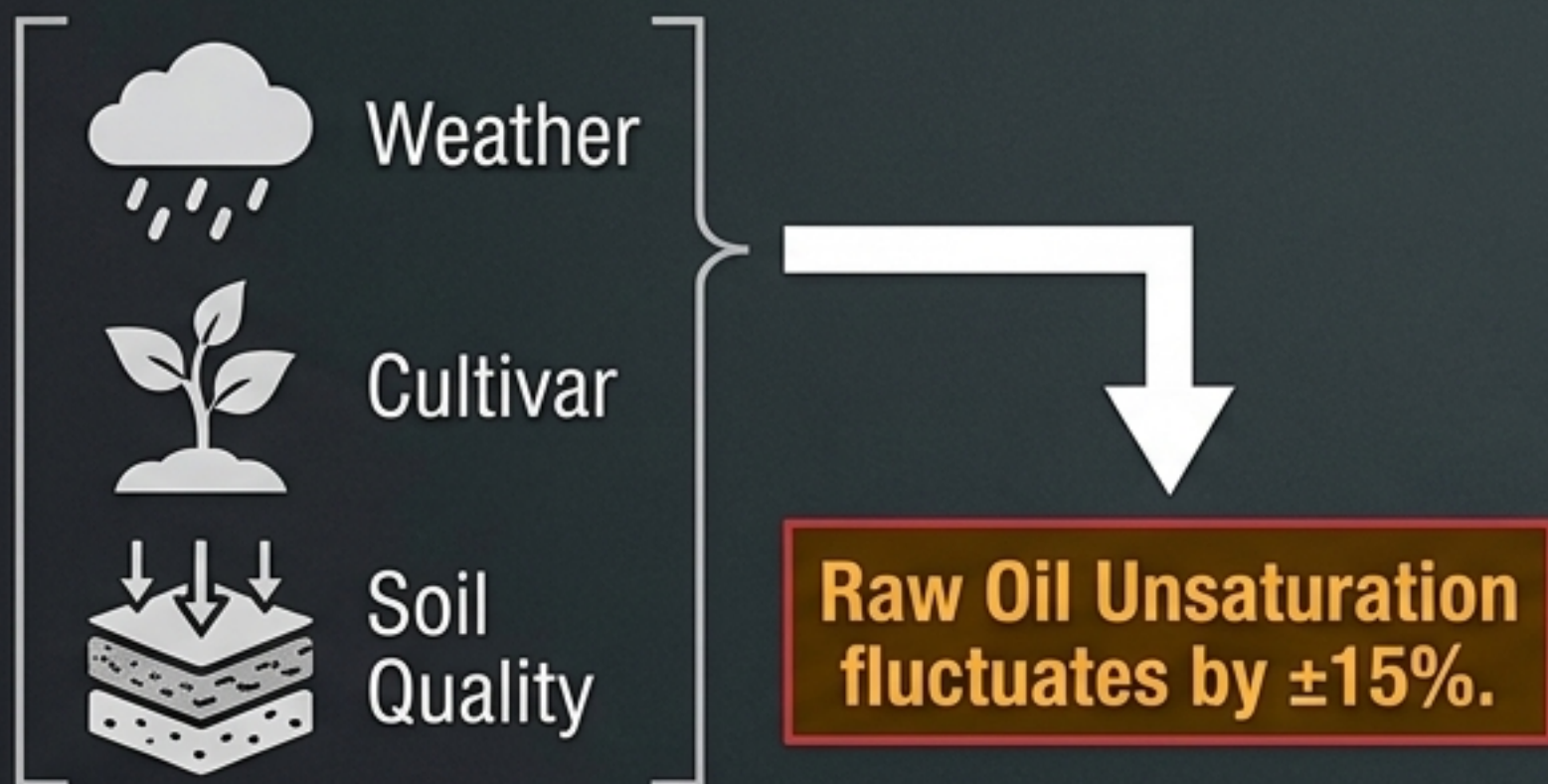
Mechanism: Inert environment prevents oxygen interaction at elevated temperatures.

Result: Vitrimeric malleability, dynamic exchange, and structural integrity are fully preserved.

Thermal Processing: 180-200°C

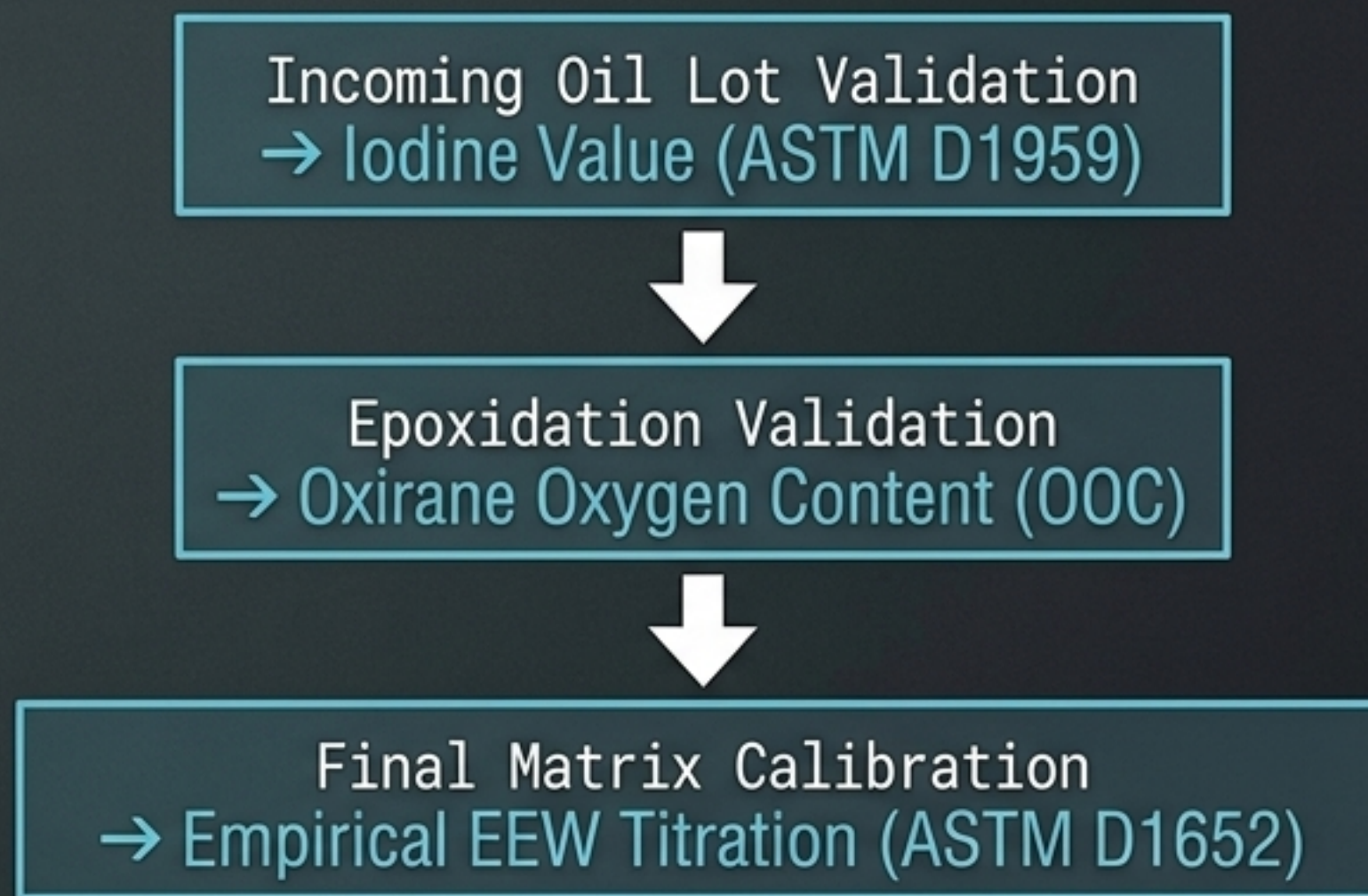
Biomass Stochastics Defy Fixed Recipes

Biological Chaos



FAILURE CONCEPT: Using fixed formula weights on variable agricultural biomass guarantees massive stoichiometric imbalance and network failure.

The Mandated QA Pipeline



CONCLUSION: Hardener mass balances must be dynamically recalculated for every single production batch based on empirical titration.

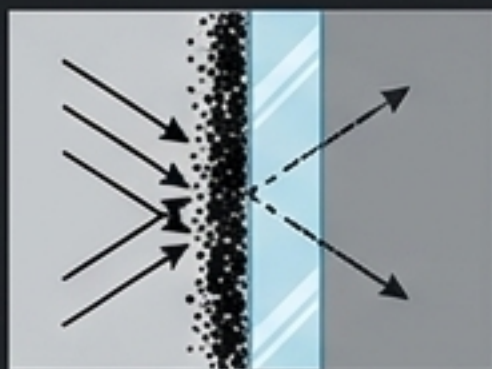
Scale-Up Delusions in OCN Production

Moving from benchtop Diamond Anvil Cells to industrial Piston-Laser Hybrids

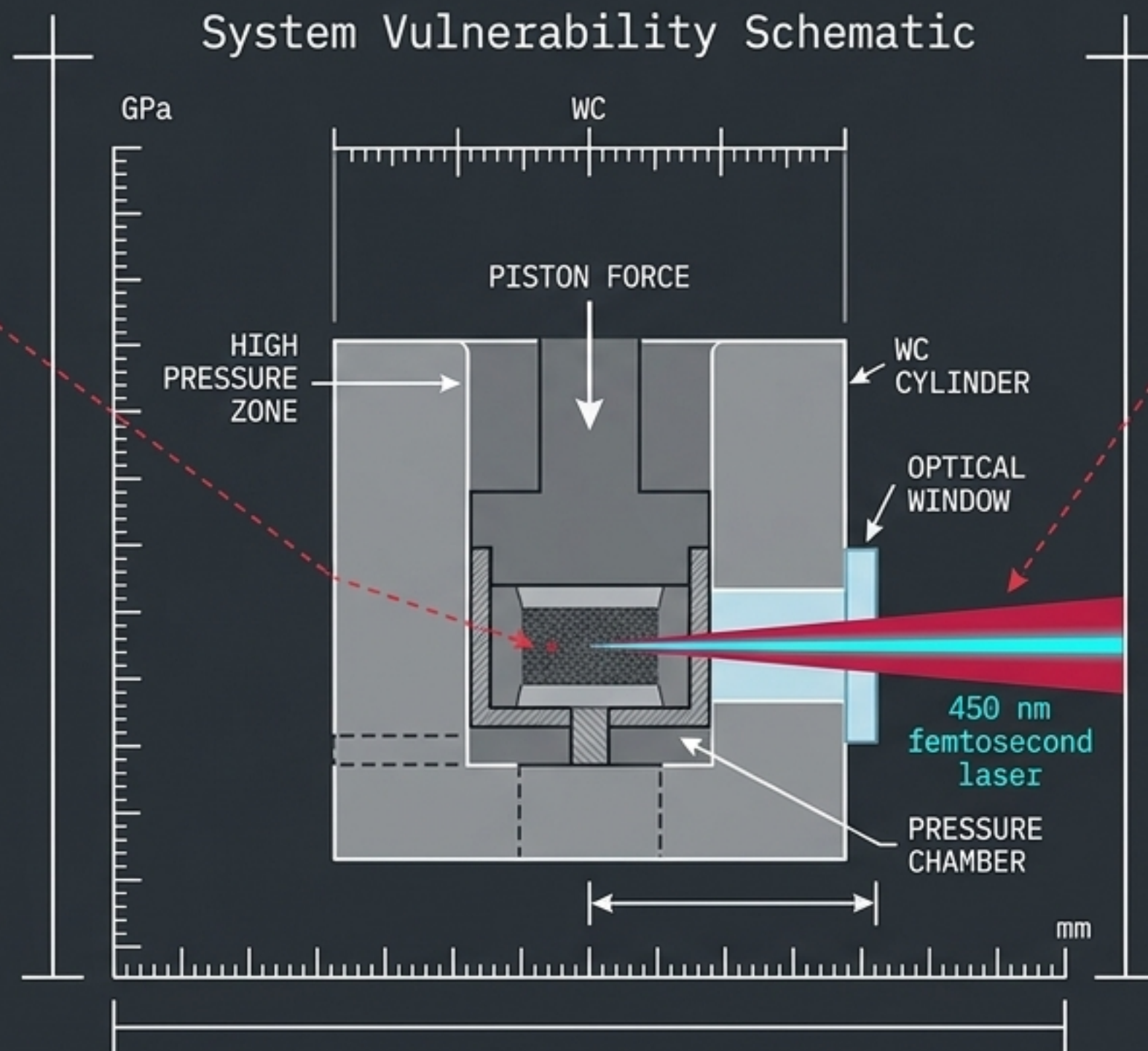
System Vulnerability Schematic

Optical Window Carbon Fouling

Detail: Carbonized species deposit on the entry window, attenuating Resonant Two-Photon Absorption (TPA) 450 nm femtosecond laser intensity.



Effect: Incomplete volumetric polymerization leaves microscopic pockets of unreacted liquid furan inside the nanothread matrix, collapsing shear strength.



Pressure Volatility

Detail: Pressure drops below the strict 5 GPa compression threshold.



Effect: Causes a phase shift away from sp^3 -bonded crystalline nanothreads, producing useless, brittle amorphous carbon black instead.

SYNTHESIS: The Red-Line Control Board

Parameter	Strict Boundary Limit	Primary Consequence if Breached
Epoxidation Temp	$\leq 60^{\circ}\text{C}$ ($55 \pm 2^{\circ}\text{C}$)	Acid-catalyzed ring-opening; diol sludge.
Precursor Moisture	< 500 ppm	Zn^{2+} Catalyst poisoning; loss of self-healing.
Stoichiometry	1:0.8 Epoxy:Carboxyl	Unreacted carboxyls cause creep & moisture uptake.
VARI Infusion	60°C , ≥ 50 mbar	Viscosity stall / FGE volatilization.
Biochar Shear	≤ 1500 rpm	Micro-porous structure pulverization.
Laminate Core	$\leq 190^{\circ}\text{C}$ (Ramp $\leq 1.5^{\circ}\text{C}/\text{min}$)	Thermal ester cleavage & internal delamination.
Thermoforming	N_2 Purged Atmosphere	Thermo-oxidative crosslinking; T_v elevation.

Adherence to these strict parameters guarantees functional vitrimeric composites. Deviation guarantees catastrophic scrap.