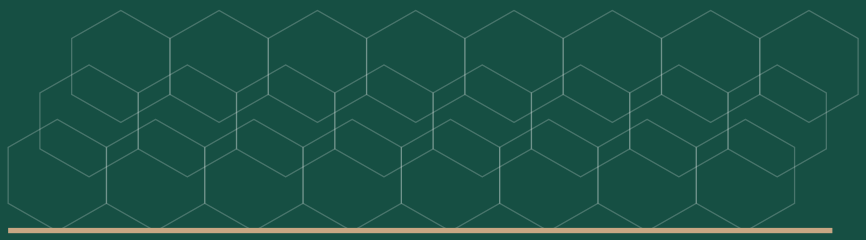
LANDRY INDUSTRIES SCIENTIFIC RESEARCH PROGRAMME

HEMPOXIES

The science and engineering of hemp-derived vitrimers and advanced carbon composites

Definitive master research programme 2026–2027
Consolidated monograph | Version 31.0



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CONTROLLED RESEARCH PROPOSAL — ALL EXPERIMENTS ON HOLD

Not peer reviewed. No experimental results, funded contract, material certification or manufacturing capacity established.

Editorial and scientific status

This monograph replaces the fragmented presentation of the twenty-volume v30 conversation draft with thirty substantive chapters. It is a newly consolidated scientific proposal, not a verbatim transcript or an assertion of new empirical research. The principal source basis is the original v9–v25 programme PDFs dated 14 November 2026, the accompanying machine-readable registers, the v7 environmental inventory and the literature-audited research proposal. Their original records are retained as embedded PDF attachments. Historical drafts are subordinate to explicit later amendments; conflicts remain on HOLD pending controlled resolution.

The author is the research programme proponent. Laboratory principal investigator, facility safety officer, method reviewers, signatories and independent reviewers remain to be appointed. The stated 2026–2027 horizon is not a promise of completion. The proposed chemistry is motivated by published component-level precedents; the integrated material has not been demonstrated. Engineering equations in this edition are analytical models. Numerical examples are labeled illustrative and must not be copied as approved operating conditions.

Controlled planning baseline	Quantity
Independent preparation slots	222
Existing qualification-test units	3,750
Quality requirements / validation crosswalk	55 / 55
Programme authorization gates	9
Open red-team findings (critical)	15 (7)
Phase I independent preparations	27
Illustrative initial funding envelope (CAD)	25,000

Important distinctions. The historical 573-entry registry is unreconciled and not additive. The 3,750 qualification units are not synthesis batches; the 222 slots exclude separately authorized scouts, precursor synthesis, method-validation aliquots and fresh confirmation batches unless a formal amendment establishes otherwise. Every physical allocation is still on HOLD.

Reference status. Internal source text was reopened for this consolidation. External sources are linked with their inherited verification status; no exhaustive new publisher/full-text or standards-edition audit has been performed. Mandatory normative text, safety approval, and legal/IP review remain outstanding. The deduplicated reference register is an editorial aid, not certification of all source claims.

Abstract

HEMPOXIES investigates integration of epoxidized hempseed oil, sebacic acid, zinc acetylacetonate, optional furfuryl glycidyl ether and paired hemp lignin fractions into candidate dynamic polymer networks, with distinct hemp-derived carbon morphologies used to investigate mechanical and functional reinforcement. The scientific premise combines established epoxy–acid and dynamic covalent chemistry with biomass-derived carbon production; it does not infer integrated material performance from individual precedents. The proposed programme proceeds from precursor characterization through a randomized 3×3 factorial neat-network experiment, fresh confirmation, reactive diluent and lignin screening, six-morphology reinforcement screening and two-loading simplex-centroid hybrid experiments. Existing qualification allocations address mechanical, thermal, rheological, electrical, fatigue, creep, healing, reprocessing and environmental behavior. Independent replication and engineering scale-up are conditional on evidence and funding. Quantitative life-cycle assessment and techno-economic analysis use a common physical inventory and functional equivalence, distinguish carbon origin from climate benefit, and model rather than assert production at 1–100 tonnes per year. Nine controlling readiness gates, 55 quality requirements and 15 open risk findings govern execution. The initial commissioning objective is a qualified, funded 27-preparation neat-network investigation, not deployment of a commercial material.

Keywords: hempseed oil; epoxidized vegetable oil; dynamic covalent networks; vitrimer; lignin; biochar; porous graphitic carbon nanosheets; composite mechanics; experimental design; metrology; life-cycle assessment.

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PART I

Scientific foundations and literature

Research scope • prior art • falsifiable hypotheses

CHAPTER 1

The research platform and scientific mission

1.1 Rationale and research questions

Industrial hemp provides chemically diverse feedstocks rather than a single engineering material. Seed oil offers triglyceride unsaturation that may be converted to epoxide functionality; stalk fractions contain cellulose, hemicellulose and lignin; selected biomass can be converted into carbon-rich solids. Their common biological origin is not evidence that they will form a cohesive, high-performance, repairable composite. The programme is valuable precisely because those relationships are unresolved. It asks whether a reproducible network can be produced from qualified precursor lots, whether dynamic network behavior can be distinguished from competing relaxation mechanisms, and whether engineered carbon fractions improve useful properties at acceptable processing and environmental cost.

The intended system is a platform of identifiable material candidates, not a universal resin called HEMPOXIES. An unsuccessful oil network might motivate an alternative architecture; a useful static thermoset need not be mislabeled a vitrimer. A filler that improves conductivity but reduces mechanical durability might be considered for a functional component, not a structural application. Every decision must be conditioned on the intended function and the appropriate comparison material.

1.2 Evidence and decision hierarchy

Separate literature precedent (external source), proposed design (controlled protocol), assumption (model input), observation (traceable measurement), independently confirmed result, and application certification. A proposal can be scientifically coherent without containing any completed measurements. In this monograph, all preparation schedules and candidate processing methods are proposals. A claimed measurement must identify its material, parent batch, instrument, method revision, conditions, uncertainty and validity decision. Application-specific acceptance criteria remain unfilled until the qualified laboratory and application owner approve them.

The primary progression criterion is not maximum strength or maximum hemp content. Safety, material identity, method fitness, reproducibility and mandatory application constraints precede optimization. Only among feasible candidates should the programme compare cost, environmental burden and performance.

Source basis: v9, v10, v18, v24, v25.

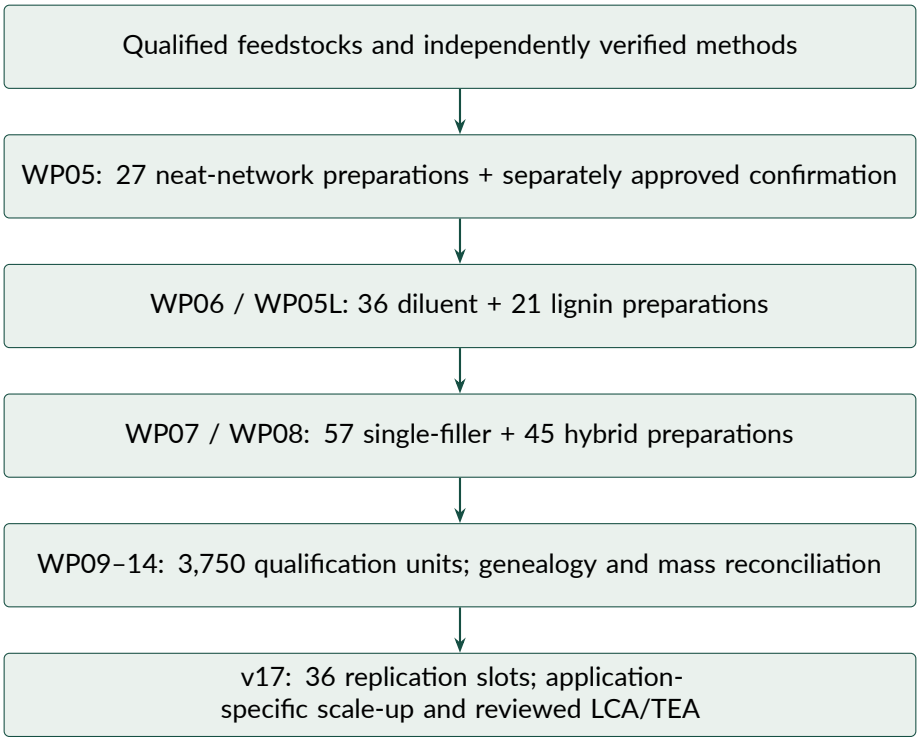


Figure 1.1: Conceptual dependency map. Each transition requires release; scouts and confirmation are not included automatically in the 222 slots.

CHAPTER 2

Scientific precedents and boundaries of prior art

2.1 Polymer and carbon precedents

Montarnal et al. introduced exchange-enabled permanent organic networks in Science (2011), DOI 10.1126/science.1212648. Capelot et al. investigated metal-catalyzed transesterification, and Denissen, Winne and Du Prez reviewed the vitrimer class. These are evidence that appropriate chemical architectures can permit rearrangement without simply melting a thermoplastic; they do not establish that epoxidized hempseed oil with a given acid/catalyst ratio will produce the necessary network or service stability. The v10 evidence register distinguishes directly checked source records from inherited and secondary corroboration.

Shuttleworth et al. reported epoxidized hempseed-oil thermosetting resin and halloysite-reinforced materials (2017), DOI 10.1021/acs.jpcb.7b00103. This is a closer feedstock precedent than generic vegetable oil data, but differs from the proposed carbon morphologies and exchange chemistry. Wang et al. reported interconnected porous carbon nanosheets derived from hemp for supercapacitors (2013), DOI 10.1021/nn400731g. Their device and carbon morphology do not establish the mechanical reinforcement performance of those nanosheets in a crosslinked polymer. These separate research traditions motivate, but do not validate, their integration.

2.2 Prior art and terminology

Use graphitic porous carbon nanosheets when morphology, ordering and porosity justify that description. Graphene implies structural evidence beyond a Raman D/G signature. Oxidized and reduced products require paired parent characterization; avoid calling them graphene oxide or reduced graphene oxide without adequate structural identification. The existence of published hemp nanosheet processes and patent publications (including US20140328006A1 and US10170251B2) precludes broad claims of novelty based solely on hemp carbon or nanosheets. Patentability and freedom to operate depend on actual claims, jurisdictions and legal status; neither has been established.

A vitrimer claim requires more than heat-induced stress relaxation. The evidence must discriminate residual conversion, physical viscoelasticity, degradation, network damage and dynamic exchange. Similarly, reprocessing, repair, biodegradation and renewable origin are different properties. Commercial hemp epoxy is not interchangeable with a qualified EHO precursor. Certified organic agriculture is not automatically certification of processed polymer products.

2.3 Evidence audit protocol

Maintain a claim-to-source map: claim, material/system studied, experimental method, reported result, limitations, DOI or official catalogue, verification date, full-text status and reviewer. Prioritize primary sources over generic reviews. Standards are candidate

method identifiers until full normative text and scope are approved; a catalogue verification does not establish technical compliance. Internal programme files are source evidence for designs, not external validation. Appendix E retains the v10 evidence-register entries unchanged, including their limitations.

Source basis: v9 pp. 1–3, 6, 43; v10 §05; v18 p. 3; v25 RT-13, RT-14; literature-audited proposal.

CHAPTER 3

Programme architecture and experimental strategy

3.1 Stage gates and precedence

Safety and institutional approval take precedence. The v18 decision-level hierarchy identifies v18, then the applicable campaign-specific v11–v17, then v10 and v9 supporting methods; the v19–v25 supplements add funding, procurement, quality, validation, readiness and risk controls without silently changing the formulation designs. Unresolved conflicts remain HOLD. This editorial v31 synthesis changes no approved design. In particular, WP08's v15 two loadings (2 and 5 dry wt%) supersede the older 3 wt% proposal. The five-factor full factorial in early documents is archival, not an instruction to execute.

Campaign	Design	Slots
WP05	3 acid ratios × 3 catalyst levels × 3 blocks	27
WP06	4 FGE levels × 3 ratios × 3 blocks	36
WP05L	6 paired type/loading arms + 1 control, 3 blocks	21
WP07	6 carbon types × 3 levels + 1 neat, 3 blocks	57
WP08	7 mixture points × 2 loadings + 1 neat, 3 blocks	45
v17	3 labs × 4 materials × 3 preparations	36
	Total	222

3.2 Controls and falsifiability

A clean experimental design isolates variables through concurrent controls. An unfilled matrix tests reinforcement effects; a catalyst-free material helps examine catalyst-associated behavior; a named commercial epoxy provides a conventional benchmark; a separately named commercial bioepoxy supports renewable-material comparison. Historical controls cannot silently replace newly manufactured controls with different processing or conditioning. The bioepoxy reference is missing from v16 allocations; v17 replication does not eliminate that discrepancy.

Every stage has a proposed primary response and mandatory integrity constraints. When a candidate fails, establish whether the method or material is responsible, retain the result, and either redesign or terminate. No reinforcement campaign should begin if no appropriately confirmed neat matrix exists. The original v11–v15 designs are exploratory and do not guarantee statistical power.

Decision / release basis. Release only the scoped activity whose predecessor and safety requirements are met. The overall programme remains HOLD.

Source basis: v10, v11–v18, v25.

PART II

Feedstocks and molecular precursors

Agriculture • oil composition • epoxidation • lignin

CHAPTER 4

Industrial hemp and feedstock fractionation

4.1 Feedstock variability

Hemp seed and stalk are different biological materials with distinct chemical composition and economic functions. Cultivar, growing environment, harvest maturity, storage, water content and processing history influence the suitability of both. A biomass fraction selected for pyrolysis does not automatically satisfy the purity and morphology requirements of a precursor selected for short carbon fibers. The programme should preserve separate seed, bast and hurd provenance rather than treat all hemp feedstock as interchangeable.

WP01 calls for three independently sourced oil lots, with representative aliquots, reference oil and analytical blanks as appropriate. Aliquots measure within-lot variation, not independent agricultural replication. Traceable provenance, storage, harvest and extraction history become covariates in later chemical studies. Agricultural yield is measured on a specified dry basis; commercial quantities and land area must not be inferred from an arbitrary literature average.

4.2 Fractionation and mass balance

For wet feed mass m_w and moisture mass fraction w, $m_d = m_w(1-w)$. Define stage yield $Y_i = m_{\text{accepted},i}/m_{\text{input},i}$ on an explicit basis. If sequential yields represent compatible dry-mass streams, cumulative yield is $\prod_i Y_i$. Chemical additions and volatile products require a complete mass ledger rather than forcing every mass ratio below one. Preserve separate measurements of oil, press cake, bast, hurd, lignin-rich fractions, losses, waste and moisture.

4.3 Agronomic boundaries

Hemp is not treated as a nitrogen-fixing crop. Inventory fertilizer, irrigation, machinery, land use and field emissions, including direct and indirect nitrous oxide when applicable. Degraded land is not automatically safe or productive; contamination may enter ash, char or liquid waste streams. Indoor production carries electricity, heating, cooling and infrastructure burdens, and must be compared per useful biomass output. Organic-origin claims require an appropriate certification scope and documented chain of custody. No global hemp acreage or universal sequestration yield is adopted.

Decision / release basis. Verify lot identity, moisture, composition, storage and intended-use criteria before releasing feedstock.

Source basis: v9 WP01; v18 pp. 4, 11; v21–v22; v7 WP15.

CHAPTER 5

Hempseed oil chemistry and quality

5.1 Triglyceride functionality

Hempseed oil is a variable mixture of triglycerides containing saturated and unsaturated fatty-acid chains. The unsaturated sites offer potential functionalization into epoxide groups. The distribution of unsaturation across molecules matters: a mean concentration does not specify whether the individual molecules possess sufficient functionality to form a system-spanning network. Oxidation during storage may change the chemistry and introduce acidity, hydroperoxides or other reactive species. Oil qualification therefore requires more than an origin certificate.

5.2 Quality measurements

Iodine value measures unsaturation through a defined analytical reaction and is normally reported as grams of iodine per 100 g oil. Acid value describes the amount of base required to neutralize acidic constituents (normally mg KOH/g); it is not equivalent to free sebacic acid charge. Karl Fischer water determination must be verified in the matrix, and fatty-acid profiling may be useful during WP01. Residual oxidants and other contaminants require process-specific assays. Historical source records list P01 identity/provenance, iodine value, acid value and water; their numerical limits are not approved.

For acid value AV in mg KOH/g, a simple titration-equivalent estimate is $n_{\mathrm{acid}} = mAV/56105.6$ in equivalents, where m is grams and the denominator is mg per mol KOH. This estimate describes titratable acidity, not necessarily reactive carboxyl functionalities under cure conditions. Incorporating endogenous acidity into a formulation requires a formally reviewed chemical model.

5.3 Supplier and retained material

The procurement route may use purchased EHO or custom synthesis. Obtain lot-specific certificates, safety data, origin, grade, shelf life, storage conditions and analytical samples. Retain representative reference aliquots when stability permits. Documentary identity and analytical acceptance are separate; unresolved results prevent release.

Source basis: v18 WP01; v21, v22 P01–P02, v23; literature-audited proposal references 10–15.

CHAPTER 6

Epoxidation and precursor network suitability

6.1 Chemical transformation

Epoxidation converts suitable carbon–carbon double bonds into oxirane functionalities. Peracid epoxidation is the historical proposed route; it is not Swern oxidation. Side reactions can include epoxide opening, degradation and residual acidity. The actual pathway, reaction energetics, compatible equipment, chemical inventory, quench, waste and exposure controls must be selected by a qualified laboratory. The programme does not supply a released numerical synthesis recipe.

6.2 Equivalent weight and conversion

Epoxy equivalent weight (EEW) in g/eq is related to epoxy equivalents by $n_E = m/EEW$. For an ideal interpretation of measured oxirane oxygen mass fraction w_O attributable only to one oxygen per epoxide, $EEW = M_O/w_O$, with $M_O \approx 16$ g/mol. If oxirane oxygen is reported as percent, $EEW \approx 1600/\%OOC$. Matrix interferences, endpoint and assay validity must be evaluated. A lower EEW indicates more epoxy equivalents per gram, not necessarily favorable functionality distribution or network integrity.

Theoretical maximum epoxide content may be estimated from initial unsaturation under complete selectivity assumptions, but comparing initial and final iodine values is complicated by mass gain and side chemistry. Use molar balances with appropriate product mass corrections. Preserve measured initial unsaturation, epoxy assay, acid value, water, yield, residual chemistry and spectroscopy. Assess gelation/cure in addition to EEW to close RT-01.

6.3 WP02 commissioning

The v18 precursor pathway retains low/mid/high approved conversion targets, with suitable historical controls as a separate proposed programme. These are not part of the 222 controlled comparative slots. The historical batch EEW coefficient-of-variation target of 10% is provisional, not a release limit. Quote a qualified purchased EHO route and an independently priced custom synthesis route; compare accepted grams, quality and total cost. Supplier preformulated hemp epoxy is a separate benchmark, not an undocumented substitute for chemically defined EHO.

Decision / release basis. No precursor synthesis without separate facility authorization, reaction-hazard evaluation and approved methods. Confirm lot chemistry and cure feasibility before comparative release.

Source basis: v9 WP02; v10; v18 p. 4; v21 pp. 1–2; v25 RT-01, RT-03, RT-08.

CHAPTER 7

Hemp lignin and functionalized lignin

7.1 Heterogeneous aromatic fractions

Lignin is a structurally heterogeneous aromatic polymer fraction. Extraction, molecular-weight distribution, hydroxyl functionality, residual carbohydrates, ash, moisture and prior chemical exposure may influence dispersion, reactivity and network behavior. Literature concerning wood-derived or commercial kraft lignin cannot simply be transferred to isolated hemp lignin. Pair unmodified and functionalized samples from a qualified parent lot when possible.

7.2 Functionalization and analytical evidence

The programme investigates introducing epoxy functionality into lignin; it does not assume that every hydroxyl group reacts or that a measured EEW describes a uniform molecular product. Verify parent identity, hydroxyl assay, ash, moisture, molecular-weight information where appropriate, residual reagents, and epoxy equivalent weight with validated matrix-compatible techniques. Insolubility and chemical interferences may require method adaptation. Surface or morphological evidence alone cannot establish covalent integration into a network.

7.3 Equivalent balance in a multicomponent network

For EHO, FGE and epoxidized lignin, where each actually contributes measured epoxy functionality,

$$n_E = \frac{m_{\mathrm{EHO}}}{EEW_{\mathrm{EHO}}} + \frac{m_{\mathrm{FGE}}}{EEW_{\mathrm{FGE}}} + \frac{m_{\mathrm{EL}}}{EEW_{\mathrm{EL}}}. \tag{7.1}$$

Only include terms justified by qualified measurements. Reactive acid functionality introduced by lignin may affect stoichiometry; an approved amendment is required when the base calculation is no longer adequate. Record unmodified lignin on a dry PHR basis and avoid silently treating it as epoxy-bearing. WP05L uses 5, 10 and 15 PHR of each lignin type plus neat control after WP06 confirmation (Chapter 10). Selection may result in zero lignin if no candidate provides useful performance.

Source basis: v9 WP03 and WP05L; v13; v18 p. 4; v22 P06–P07.

PART III

Dynamic polymer chemistry and matrix development

Network science • Phase I • reactive diluent and lignin screening

CHAPTER 8

Epoxy–acid networks and vitrimer science

8.1 Network formation and exchange

In a suitable epoxy–acid system, acid-mediated epoxide ring opening may produce ester and hydroxyl functionalities, enabling a crosslinked network when molecular functionality and reaction extent support gelation. Transesterification in an ester-containing network may permit exchange-mediated topology rearrangement. A catalyst can influence both initial cure and subsequent exchange; it cannot be assumed to have a single function. The topology of the actual material depends on functionality distribution, conversion, stoichiometry and competing reactions. The term associative exchange should be reserved for appropriately supported mechanistic interpretation.

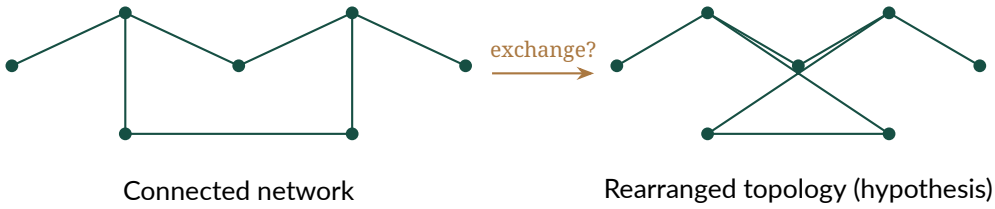


Figure 8.1: Conceptual network rearrangement, not a chemical structural determination or measured mechanism.

8.2 Viscoelasticity and apparent exchange time

For a simple Maxwell element, stress relaxation under constant small strain may obey $G(t) = G_0 \exp(-t/\tau)$ and $\tau = \eta/G_0$. Actual dynamic networks often exhibit multiple relaxation modes or a nonrelaxing plateau. A useful exploratory model is

$$G(t) = G_\infty + \sum_{j=1}^{J} G_j \exp(-t/\tau_j). \tag{8.1}$$

A model must be selected by fit quality, physical suitability and identifiability, not solely by visual appeal. Within a regime where Arrhenius behavior is supported,

$$\ln \tau = \ln \tau_0 + \frac{E_a}{RT}. \tag{8.2}$$

Apparent activation energy derives from the slope of $\ln \tau$ versus $1/T$; it does not uniquely identify a chemical mechanism. A convention sometimes associates topology freezing temperature with an extrapolated viscosity of 10^{12} Pa s. It is not a sharp service threshold. A vitrimer may creep at lower temperatures over sufficiently long time.

8.3 Evidence hierarchy for mechanism

First establish chemical conversion, gel retention and thermal stability. Conduct repeated small-strain relaxation with matched thermal witnesses, catalyst-free controls and appropriate reference networks. Check residual cure and degradation before attributing relaxation to exchange. Measure changes in mass, insoluble fraction and chemical spectra; neither a smooth relaxation trace nor qualitative crack closure suffices. Report competing explanations explicitly. If associative exchange is not established, call the material a candidate dynamic network rather than a demonstrated vitrimer.

Source basis: v10 §02; v11; v16; v25 RT-02; Montarnal, Capelot, Denissen precedents in inherited evidence register.

CHAPTER 9

Phase I: neat-network experimental design

9.1 Controlling design

Phase I preserves the v11 27 independent preparations: three acid/epoxy equivalent ratios 0.8, 1.0 and 1.2 crossed with zinc acetylacetonate loadings 0, 2 and 5 PHR on EHO, each condition once in three randomized complete blocks. No FGE, lignin or carbon filler. Appendix A reproduces the actual randomized schedule from the original CSV; all target and actual unmeasured fields remain blank. The 10 g nominal EHO scale is a planning basis, not a released safe quantity or total cured mass.

9.2 Mass and equivalent calculations

For batch EHO mass m, ratio r, active acid fraction p and appropriate acid equivalent weight AEW,

$$n_E = m/EEW, \tag{9.1}$$

$$m_A = r n_E AEW/p, \tag{9.2}$$

$$m_{cat} = m\,\mathrm{PHR}/100. \tag{9.3}$$

Nominal pure sebacic acid equivalent weight is 101.125 g/eq. Use measured effective equivalent weight or justified assay correction, avoiding double correction. The catalyst calculation retains the inherited EHO basis; report chemical form, hydration and active loading. Across all 27 slots the nominal EHO total is 270 g and nominal catalyst 6.3 g. At equal 10 g EHO per batch the ratio-weighted sum equals 270 g at ratio 1.0.

Hypothetical EEW (g/eq)	Pure acid total (g)	Total nominal feed (g)
200	136.519	412.819
250	109.215	385.515
300	91.013	367.313

These calculations exclude scouts, controls, separate precursor preparation, analytical sampling, losses, reserves and confirmation. They are illustrations, not prescriptions. Actual EEW, functionality, acid assay and catalyst form remain unassigned.

9.3 Primary outcome and progression

Freeze the primary endpoint as normalized stress remaining after a specified duration, temperature and valid linear viscoelastic strain selected after separately authorized scouting, before comparative runs. Secondary endpoints include gel retention, conversion, tensile modulus and thermal stability. Acceptance requires predeclared integrity constraints and meaningful effect threshold with appropriate matched controls. Three batches per cell are exploratory; confirm any promising result on new independently mixed batches sized using relevant variance and effect size. Do not progress to additive campaigns if no baseline passes.

Decision / release basis. G08 signed by PI and safety lead only after G01–G07, separately authorized scouting, applicable critical-risk evidence and complete preregistration.

Source basis: v11 pp. 1–4; v19; v24; v25; original v11 and v24 CSVs.

9.4 Thermal scouting, cure kinetics and process safety

Reaction energetics

Reactive polymer manufacture couples chemistry, temperature, viscosity and heat removal. Heat generation depends on conversion rate. For a simplified, well-mixed batch,

$$mC_p\frac{dT}{dt} = mH_r\frac{d\alpha}{dt} + Q_{ext} + P_{mix} - UA(T - T_c), \tag{9.4}$$

where H_r is positive heat generation per unit mass of the stated basis, α conversion, U heat transfer coefficient and A area. An ideal adiabatic rise is $\Delta T_{ad} = H_r/C_p$ assuming constant properties. These models require measured data. They are not safety calculations for an uncharacterized reactor.

Calorimetric conversion may be estimated as $\alpha = \Delta H_t/\Delta H_{total}$ where the heat signal represents the target reaction and baseline is appropriate. Residual cure enthalpy after a defined thermal history may support an estimate $1 - \Delta H_{res}/\Delta H_{total}$, subject to overlapping reactions, sample mass and completeness of the reference. Cure chemistry and network exchange remain distinct phenomena.

Candidate kinetic models

An autocatalytic empirical expression is

$$\frac{d\alpha}{dt} = (k_1 + k_2\alpha^m)(1-\alpha)^n, \qquad k_i = A_i e^{-E_i/(RT)}. \tag{9.5}$$

Fit only with appropriate calorimetric data and identifiability assessment; mobility limitations may require diffusion corrections. Gelation and vitrification can alter viscosity and apparent rate. No kinetic constants, exotherm or safe cure profile are established for HEMPOXIES. Thermal scouting must evaluate actual material behavior and credible worst-case deviations within the approved facility limits.

Scout authorization and stop conditions

Scouts are separate physical activities with separate risk assessment, scale, approved methods, equipment and trained personnel. Release of the comparative design is not their authorization. Require temperature monitoring, containment, emergency response, waste pathway, control limits and stop criteria. Document failed transitions and retained thermal witnesses. Do not transfer historical temperature schedules into actual operating instructions without review.

Source basis: v9 WP05; v19 Service B; v24 G02/G05; v25 RT-03, RT-05.

CHAPTER 10

Reactive diluents and lignin campaign

10.1 WP06: FGE screening

Furfuryl glycidyl ether may alter viscosity and reactive functionality; a reactive diluent is not chemically equivalent to an inert solvent. WP06 retains 0, 10, 20, 30 PHR on EHO crossed with acid ratios 0.9, 1.0, 1.1 in three blocks (36 slots). Nominal EHO mass is 10 g each, total 360 g; nominal FGE total 54 g. Use measured EHO and FGE EEW in the epoxy equivalent sum, retain selected WP05 catalyst PHR on EHO and document catalyst per total epoxy equivalents. If the WP05 winner lies outside the WP06 acid-ratio grid, quote three fresh exact-baseline batches by amendment; do not reuse earlier WP05 batches as concurrent controls.

The proposed primary response is viscosity at a locked temperature, shear condition and elapsed time; characterize working-time behavior, cure, gel, thermal properties, strength and dynamic response. A lower viscosity may compromise crosslink density, strength or service creep. Selection must meet mandatory constraints before ranking. Fresh independent confirmation precedes the lignin campaign.

10.2 WP05L: paired lignin screening

Use selected WP06 matrix (including zero FGE if selected). Compare unmodified and epoxidized lignin at 5, 10 and 15 dry PHR on EHO, plus zero-lignin control, all in three complete blocks. On the 10 g EHO planning basis, dry lignin masses are 0.5, 1.0, 1.5 g per nonzero arm. Nominal total EHO 210 g and total lignin 18 g (9 g per lignin type). Actual acid charge depends on measured reactive constituents and approved stoichiometry. Use the original v13 schedule in the embedded register.

Estimate type, loading and type-by-loading effects among six filled arms; compare each with concurrent control and paired types at equal loadings. The selection rule must consider conversion, gel, viscosity, strength, Tg, relaxation and creep. Zero lignin is a valid decision. The downstream parent matrix must be frozen and independently confirmed.

Source basis: v12 and v13 original campaigns and CSVs; v18; v25.

PART IV

Engineered hemp carbon morphologies

Six separately qualified material families • no raw hemp reinforcement

CHAPTER 11

Hemp biochar: precursor conversion and characterization

11.1 Material identity and production rationale

Biochar is a carbon-rich solid produced by thermal conversion of biomass under controlled oxygen-limited conditions. Hemp hurd is the proposed precursor in WP04A. The product is neither elemental carbon nor a single molecular compound. Carbon content, residual hydrogen and oxygen, ash, porosity, particle dimensions and thermal history depend on both biomass and conversion process. The programme therefore treats biochar as an engineered lot rather than a generic filler with a universal elastic modulus. Published biochar performance cannot replace lot-specific characterization.

For reinforcement, particle size, shape, porosity and surface chemistry can influence matrix wetting, viscosity, dispersion, void formation and interfacial stress transfer. A low-cost carbonaceous fraction might be useful for dimensional control or functionality even if it provides little stiffness enhancement. Conversely, a highly porous material may adsorb resin or catalyst and impair cure. The proposed comparisons must evaluate these outcomes rather than assume that adding carbon improves the material.

11.2 Conversion and mass closure

For dry precursor mass m_b and dry recovered char mass m_c, define $Y_{char} = m_c/m_b$. If the carbon mass fractions are $x_{C,b}$ and $x_{C,c}$, respectively,

$$R_C = \frac{m_c x_{C,c}}{m_b x_{C,b}}. \tag{11.1}$$

Mass yield and carbon retention are distinct. As an illustrative calculation, 100 kg of biomass containing 45 kg elemental carbon, converted to 30 kg of char with 80% carbon, yields 24 kg of recovered carbon, or 53.3% of input carbon. The remaining carbon must be assigned to gas, condensate, residual streams or unresolved imbalance. None of these quantities is a measured HEMPOXIES yield.

11.3 Research and release framework

The facility should verify precursor identity, approved atmospheric and thermal controls, product recovery, mass balance, moisture and safe handling. The historical candidate thermal conditions are not authorized. Record primary conversion history and secondary classification or milling history separately. P08 requires ash, elemental

analysis and thermal-history evidence; particle dimensions, gas adsorption, Raman and thermal behavior provide supplementary application-specific evidence. Respiratory and combustible-dust hazards must be assessed for the actual material.

Decision / release basis. Release only a traceable, independently characterized biochar lot with approved criteria and suitable waste and exposure controls.

Source basis: v9 WP04A; v14; v18; v21–v22 P08; v7 WP15B.

CHAPTER 12

Activated hemp biochar

12.1 Activation as a separate process

Activation modifies the pore structure and surface properties of carbonized material through controlled treatment. The v9 baseline describes physical activation of qualified WP04A char; the actual apparatus, atmosphere, process conditions and acceptance limits require facility approval. Other chemical routes are separate proposals requiring their own risk assessment, selectivity and residue analysis. Activation can consume solid carbon, change ash composition and increase washing, drying or treatment burdens. A higher measured adsorption surface area is not sufficient evidence of better reinforcement.

Porous carbon may interact with the polymer matrix through wetting, transport into accessible pores, adsorption of reactive constituents and interfacial bonding. These possibilities introduce confounding: observed modulus or cure changes could result from different chemical exposure rather than pore geometry alone. Use a qualified parent char and document the relationship between parent and activated lot. Maintain comparable formulation and process controls where possible.

12.2 Characterization strategy

Specific surface area may be estimated through an approved adsorption model, with careful selection of the relative-pressure range. BET surface area is a model-derived quantity, not a direct geometrical measure of every pore. Pore-size distributions also depend on probe, model and accessibility. Record pretreatment, adsorbate, method, analysis range and uncertainty. Complement porosity data with ash, elemental composition, residual chemistry and microscopy where appropriate.

12.3 Yield and environmental implications

Define the activation yield $Y_a = m_{a,accepted}/m_{parent,dry}$. Separately record overall recovered solids and qualified product yield. The environmental and economic models include treatment energy, material inputs, washing, wastewater and rejects. A 50% qualified activation yield would require two kilograms of parent char per kilogram of accepted product, before additional losses; this is only a sensitivity example. Evaluate incremental benefit against the concurrent unactivated reference and appropriate process controls.

Decision / release basis. P09 requires BET, pore-distribution, residual activation reagent and parent-lot evidence. Do not release unidentified porous solids as an activated grade.

Source basis: v9 WP04B; v14; v18; v21–v22 P09; v7.

CHAPTER 13

Hemp-derived short carbon fibers

13.1 Morphological definition

The short-carbon-fiber research branch seeks elongated carbonized structures derived from hemp bast rather than intact raw hemp fibers. Preservation of an elongated shape through precursor treatment and carbonization is not guaranteed. Shrinkage, fragmentation, embrittlement and irregular particulate formation may prevent the target aspect ratio. The product cannot be assigned a conventional PAN-carbon-fiber modulus based on its name or carbon content. A characterization record must explicitly distinguish genuine short fibers from equiaxed fragments.

The v9 route retains investigation of precursor stabilization, thermal behavior and controlled carbonization. The development sequence requires a facility-reviewed precursor history, thermal feasibility and appropriate morphology characterization. Historical candidate temperatures are not release settings. Fiber classification and separation may produce substantial rejected solids; only conforming output qualifies as the intended morphology.

13.2 Stress transfer and effective reinforcement

A simplified critical-length expression for an ideal cylindrical fiber under uniform interfacial shear is

$$l_c = \frac{\sigma_f d_f}{2\tau_i}, \tag{13.1}$$

where σ_f is fiber tensile strength, d_f diameter and τ_i an idealized interfacial shear strength. It follows from balancing axial load $\sigma_f \pi d_f^2/4$ against interfacial shear over a transfer length on each side. Real short structures may be irregular, porous and chemically heterogeneous; the expression provides a design intuition rather than a validated micromechanical predictor. Length efficiency and orientation must be measured or justified.

13.3 Qualification and processing

P10 requires SEM morphology, aspect-ratio distribution and elemental carbon. Use predefined representative image selection, calibrated scale and distributional statistics. Characterize post-mixing morphology when processing may break fibers. Record precursor lot, carbonization history, contamination, density and accepted yield. A reinforcement result must be interpreted in the context of orientation and dispersion. If an elongated carbon morphology is not established, reclassify it transparently rather than relabeling arbitrary particles as fibers.

Source basis: v9 WP04C; v14; v18; v22 P10.

CHAPTER 14

Graphitic porous hemp carbon nanosheets

14.1 Scientific precedent and distinct product class

The research cited in the programme on hemp-derived interconnected carbon nanosheets establishes a relevant precursor and morphology precedent for electrochemical devices (Wang et al., 2013). The reported route involves hydrothermal conversion and activation, not merely grinding ordinary char. The associated patent publication US20140328006A1 is prior art, not independent replication. Access to source protocols and appropriate pressure-reactor and high-temperature capabilities would be necessary before commissioning a laboratory route. No HEMPOXIES nanosheet synthesis, dimensions, conductivity or yield is established by this monograph.

Graphitic porous nanosheets should be understood as thin carbon-rich structures that may exhibit partial ordering, defects and accessible porosity. They are not automatically single-layer pristine graphene. High defect density and oxygen functionality may be useful for interfacial interactions, but can also disrupt electrical pathways or increase water affinity. The intended architecture requires direct material evidence and meaningful comparisons rather than marketing terminology.

14.2 Complementary structural methods

TEM and AFM provide complementary evidence concerning lateral dimensions and thickness; sample preparation and image selection influence observed distributions. Raman D and G features can help describe carbon ordering and defects but cannot uniquely identify graphene or a layer count across all disordered carbon systems. XRD may provide information about stacking and structural order; broad peaks and disorder require careful interpretation. Gas adsorption characterizes accessible surface area and pore structure. XPS can provide surface elemental and chemical-state evidence with appropriate calibration and fitting. P11 requires TEM/AFM, Raman, XRD and BET, and intended-use criteria must be fixed before lot release.

14.3 Functional relevance

A nanosheet filler may alter modulus, transport, electrical conductivity, viscosity and fracture through particle connectivity, large aspect ratio and interfacial interactions. Yet restacking, agglomerates and porosity can reduce effective load transfer. The material should be studied before and after processing when practical. Conductivity of a compacted powder cannot be equated to bulk composite conductivity; record direction, geometry, compaction and contact effects. Compare accepted material cost and qualified yield with other morphologies. The electrical and structural research branches should have separate endpoints.

Decision / release basis. Do not claim graphene identity, pristine graphene performance or a verified nanosheet manufacturing route without suitable independent evidence.

Source basis: v9 WP04D and prior art; v14; v18; v22 P11; v10 evidence register.



Figure 14.1: Idealized morphology distinctions, not microscopy images, scale measurements or evidence of actual HEMPOXIES products.

CHAPTER 15

Oxidized hemp carbon nanosheets

15.1 Surface modification hypothesis

The oxidized-nanosheet branch examines whether controlled surface oxygen functionality can improve dispersion, compatibility or useful interfacial behavior in the parent matrix. Its starting point must be a qualified porous graphitic nanosheet lot, not an arbitrary carbon powder. The original programme identifies this route as exploratory and does not contain a verified hemp-specific operating protocol. Oxidation may change lateral dimensions, lattice ordering, pore accessibility, residual chemistry and water uptake. These changes can confer advantages in one application and disadvantages in another.

In a reactive epoxy–acid matrix, surface groups may affect cure by interacting with catalyst, reacting with functional groups or changing local water content. The research shall not assume these interactions are benign. Any decision to include surface acid equivalents in a stoichiometric model requires measured functionality and formal change control.

15.2 Paired study and characterization

Preserve the parent nanosheet aliquot and parent identifier. Qualify the proposed treatment separately with the responsible facility, then compare parent and oxidized product using matched representative sampling. Record yield, purification losses, residual reagents, XPS O/C ratio with uncertainty, and selected structural observations. An increase in O/C above relevant uncertainty is evidence of changed surface composition, not proof of a specific graphene oxide structure. Evaluate morphology retention and storage stability. The parent-product relation must remain intact throughout composite screening.

15.3 Trade-offs and decisions

If oxidation improves dispersion but lowers conductivity or causes cure inhibition, select based on the intended application and mandatory constraints. The project may reject an oxidized morphology even when its intended surface chemistry is achieved. The chemical conversion and functional engineering decision are separate milestones. P12 requires parent-lot review, XPS O/C and residual reagent assay; full methods and limits remain pending.

Decision / release basis. No oxidation work without facility-approved chemical, thermal and waste controls. Use the designation oxidized hemp carbon nanosheets until stronger structural evidence supports more specific nomenclature.

Source basis: v9 WP04E; v14; v18; v22 P12.

CHAPTER 16

Reduced hemp carbon nanosheets

16.1 Purpose and mechanistic limits

Reduction of an oxidized carbon surface may decrease oxygen-containing functionality and change electrical connectivity. It need not restore a pristine graphitic structure. Structural defects and fragmentation introduced by prior treatment may remain. The programme examines paired oxidized and reduced products as distinct carbon materials, not as interchangeable commercial graphene grades. No reduction chemistry or approved operating schedule is currently selected.

The desired functional direction depends on the candidate application. Reducing surface oxygen may improve electrical transport in one system while impairing dispersion or matrix adhesion in another. A net increase in composite conductivity may require a connected filler network and suitable contact resistance rather than merely a change in the powder's surface composition.

16.2 Paired qualification and release

Archive the oxidized parent and identify its original parent. Establish treatment-specific process and environmental approvals. Measure retained morphology, surface O/C, structural indicators, residual chemistry, accepted yield and functional behavior. Use comparable XPS acquisition and analysis when interpreting a paired difference. P13 requires paired parent review, XPS O/C and Raman or TEM structure. A lower O/C ratio alone does not justify the term reduced graphene oxide.

16.3 Comparison with the six morphology families

WP07 concerns formulation-process systems: geometry, chemistry, porosity, dispersion and conversion may covary. Pairing and common parent material improve interpretability but cannot isolate all variables. Record these limitations in the model and avoid overstating causal mechanisms. Where different processing is needed to achieve workable dispersion, introduce separately approved matched process controls or interpret the result as a comparison of complete formulations rather than geometry alone.

Source basis: v9 WP04F; v14; v18; v22 P13; v25 RT-09.

PART V

Composite formulation and optimization

Individual morphology screening • mixture designs • mechanics

CHAPTER 17

Individual carbon-reinforced composite formulations

17.1 Controlling WP07 design

The original v14 campaign compares six qualified carbon morphologies at 0.5, 2 and 5 dry wt% of total feed plus a concurrent neat control in each of three randomized blocks, giving 57 independent preparations. It follows confirmed WP05L selection, including zero lignin if selected, and WP04 carbon qualification. The planning basis is 10 g total dry matrix feed per preparation, not 10 g EHO. Preserve the parent ratios of EHO, FGE, lignin, acid and catalyst.

$$m_f = \frac{m_m w}{1-w}, \qquad m_{f,received} = \frac{m_f}{s_{dry}}. \tag{17.1}$$

Here w is dry filler fraction of total feed, m_m dry matrix mass, and s_{dry} measured dry solids fraction. At 10 g matrix, the proposed 0.5, 2 and 5 wt% loadings require 0.050251, 0.204082 and 0.526316 g dry filler. The campaign uses 570 g dry matrix and approximately 14.052 g dry filler, excluding additional needs. Final cured mass fraction can differ from feed fraction because of process losses.

17.2 Mechanical models and dispersion

For an ideal void-free mixture of solid constituents, mass fractions w_i and appropriate densities ρ_i give $\rho_c^{-1} = \sum_i w_i/\rho_i$. For two phases the idealized Voigt and Reuss stiffness expressions are

$$E_V = V_f E_f + V_m E_m, \qquad E_R^{-1} = V_f/E_f + V_m/E_m. \tag{17.2}$$

These are loading idealizations, not predictions for randomly dispersed porous carbon. Orientation, length, interface strength and defects can dominate. In simple screening, one may examine a length/orientation efficiency model $E_c \approx V_m E_m + \eta_o \eta_l V_f E_f$, but fitted factors cannot be interpreted as intrinsic morphology constants without adequate data. Measured density and microscopy must inform void and dispersion interpretation; intrinsic filler porosity complicates the use of theoretical density.

Suspension viscosity depends on loading, shear, temperature, time and evolving cure. Maintain controlled mixing and thermal history; quantify energy per mass, actual viscosity, sedimentation and agglomeration. Preserve fiber and sheet morphology. The v14 provisional void gate of at most 2% is not an approved acceptance criterion; approve its method, uncertainty and application relevance. For electrically functional material, use appropriate geometry and contact correction, retain below-detection outcomes as censored values rather than zeros.

17.3 Selection rule

The primary proposed endpoint is tensile modulus relative to concurrent neat material, with practical strength, strain, rheology, viscosity, cure, Tg, gel, creep, relaxation and process constraints. Analyze 19 arms with block effects; compare filled arms against concurrent control using prespecified multiplicity control. Among the 18 filled arms, investigate morphology-by-loading interaction. Reject unsafe cure, cure inhibition or unacceptable defects. Select up to three candidates, including none. Fresh independent confirmation precedes hybrid design. The complete v14 schedule is reproduced in Appendix A.

Source basis: v14 original design and CSV; v18; v25 RT-09.

CHAPTER 18

Hybrid carbon composites and mixture optimization

18.1 Controlling simplex-centroid design

The v15 update supersedes the earlier single 3 wt% hybrid plan. Use three confirmed carbon morphologies denoted A, B and C (not the later composite finalist slots A/B/C). Each of two total filler loadings, 2 and 5 dry wt%, contains three vertices, three equal binary mixtures and one equal ternary mixture. Add a concurrent neat control to each of three blocks: 45 independent preparations. If fewer than three suitable morphologies exist, redesign by approved amendment; if none, stop. Define mixture fractions $x_A + x_B + x_C = 1$.

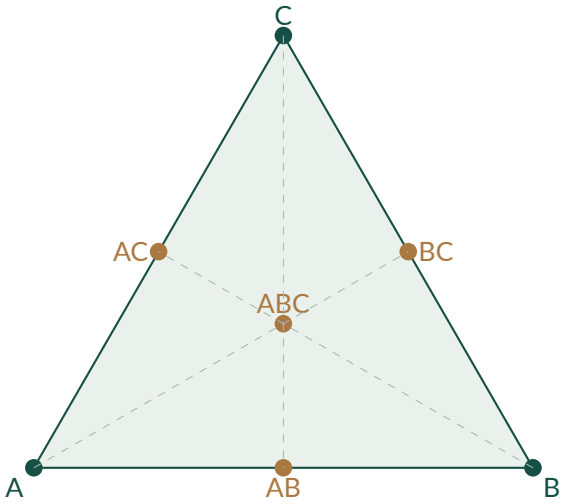


Figure 18.1: Seven simplex-centroid mixture points at each loading. One additional neat control per block is outside the mixture simplex.

18.2 Mass and statistical models

The 10 g dry matrix basis gives filler mass 0.204082 g at 2% and 0.526316 g at 5%. Constituent i receives $m_f x_i$. Across the original 45 slots, total dry matrix is 450 g and nominal dry filler is about 15.338 g, equally allocated by design across the three symbolic components. Confirm exact quantities from released identities, solids measurements and approved scale. The v15 primary endpoint is proposed tensile modulus. Use concurrent single-filler vertices at the same loading and block. A simple mixture regression is

$$y = \sum_i \beta_i x_i + \sum_{i<j} \beta_{ij} x_i x_j + \beta_{ABC} x_A x_B x_C + \epsilon. \tag{18.1}$$

Only fit models supported by design and uncertainty. The weighted vertex reference $y_{add} = \sum_i x_i \bar{y}_i$ is an empirical benchmark, not a mechanistic physical law. Define $D = y_{mix} - y_{add}$ with the desired direction specified. For equal binary mixtures, the quadratic interpolation coefficient is $\beta_{ij} = 4D_{ij}$; for the special cubic term, $\beta_{ABC} = 27D_{ABC} - 12\sum D_{ij}$.

These expressions describe the idealized mean surface, not validated material interaction coefficients. The sparse grid does not establish off-design prediction or a percolation threshold.

18.3 Confirmation and advancement

Maintain matching processing history, filler basis and control. Evaluate multiplicity for prespecified contrasts, including comparison with the best relevant single-filler alternatives. A positive contrast above uncertainty is evidence against the chosen additive reference, not independent proof of molecular synergy. Constrain strength, strain, voids, cure, viscosity, thermal response, creep and processability. Confirm selected formulations independently. Finalist A/B/C in v16 refer to selected complete composite recipes, not the mixture-component labels. Up to three finalists may advance, and the programme may select a single-filler rather than a hybrid.

Source basis: v15 and CSV; v16; v18; v25 RT-10.

PART VI

Characterization, durability and circularity

Qualification allocations • metrology • failure mechanisms

CHAPTER 19

Chemical, thermal and physical characterization

19.1 Analytical architecture

Use the v22 55-requirement material register and one-to-one v23 validation crosswalk. Documentary checks and calculated quantities must receive suitable verification; laboratory-developed and modified assays require validation proportionate to risk. Standard methods require local applicability assessment for the matrix and range. Set the intended measurand, sample preparation, range, unit, precision, bias, uncertainty and decision rule before generating validation data. The v23 example of three levels, two operators, three days and two independent aliquots per cell gives 36 observations for a suitable quantitative method; it is not a universal test allocation. All actual limits and method approval fields are blank.

Use FTIR and chemical assays as complementary evidence of functionality and cure. DSC distinguishes thermal transitions and residual reaction under specified histories. DMA reports storage and loss moduli and loss tangent $\tan\delta = E''/E'$, with the glass-transition criterion explicitly defined. TGA reports mass-loss behavior under defined atmospheres and heating histories, not safe operating bounds or intrinsic fire resistance. TMA and relevant dimensional methods support expansion and stability measurements. Gel extraction provides an operational insoluble fraction and requires suitable solvent, duration, dry mass and appropriate interpretation of nonpolymeric solids. If m_f is verified retained insoluble filler mass, a simplified filler-corrected polymer gel fraction is $(m_{res} - m_f)/(m_0 - m_f)$, conditional on appropriate mass conservation and no filler or other insoluble losses. Record uncertainty and limitations.

19.2 Measurement uncertainty

For measurement model $y = f(\mathbf{x})$, first-order propagation gives

$$u_c^2(y) = \sum_i \sum_j c_i c_j \,\mathrm{Cov}(x_i, x_j), \qquad c_i = \partial f/\partial x_i. \tag{19.1}$$

Include reference uncertainty, calibration, sample preparation, precision, bias and environment as relevant, avoiding duplication. Expanded uncertainty is $U = ku_c$ with justified coverage factor. In the inherited illustrative EEW example, independent components 1.2, 1.5 and 2.0 g/eq give $u_c = 2.77$ g/eq and $U = 5.55$ g/eq for $k = 2$. A hypothetical result of 250 g/eq gives approximately 244.45–255.55 g/eq; hypothetical limits 230–270 would pass the conservative two-sided rule. These are not actual specifications or data.

The v22 proposed conservative rule requires the full interval $[y - U, y + U]$ within both limits. Overlap is HOLD pending approved disposition. Define one-sided and documentary rules separately. Control charts require a stable method and suitable baseline; provisional 2σ warning and 3σ action levels are monitoring proposals, not material specifications.

Source basis: v22–v23; v9 pp. 21–30; v16.

CHAPTER 20

Mechanical, thermal and functional qualification

20.1 Allocation and validity

The v16 register contains 3,750 rows, all HOLD, all requiring physical genealogy and source linkage. Qualification uses fresh independently prepared lots at approved scale after finalist selection. It is not supported automatically by the 10 g screening basis. Candidate standards include ASTM D638, D790, D695, D5045, D256 and D7791 where applicable, plus corresponding ISO methods; obtain current normative text and specimen validity requirements. A fracture result that fails validity cannot be reported as an established plane-strain toughness. Determine mass and geometry for each destructive cohort.

Package	Scope	Allocated units
WP09	Mechanical baseline	375
WP09F	Fatigue	135
WP10	Thermal and functional	180
WP11	Stress relaxation / witnesses	180
WP11C	Creep and recovery	180
WP12	Healing and thermal controls	600
WP12R	Repeated repair	405
WP13	Reprocessing	432
WP13R	Chemical recovery	120
WP13W	Thermal-history witnesses	324
WP14	Environmental durability	819
	Total	3,750

20.2 Engineering measurements

Under engineering definitions, tensile stress $\sigma = F/A_0$ and strain $\varepsilon = \Delta L/L_0$. Elastic modulus requires an approved strain interval and displacement measurement appropriate to specimen geometry. Record loading rate, conditioning, anisotropy, failure location and uncertainty. Five coupons from a single batch characterize within-batch variation, not five independent syntheses. For an ideal rectangular three-point bend specimen, nominal stress at central load is $3FL/(2bh^2)$; standard validity and shear effects govern practical use. Fracture and impact measurements must match material behavior and test geometry. Fatigue runouts are censored, not failures at the termination cycle.

Electrical conductivity for an appropriate uniform bulk specimen is $\kappa = L/(RA)$ after suitable contact and geometry corrections. Surface resistance, volume resistivity and dielectric strength are different measurands. Conductivity may be anisotropic; the sparse WP07/WP08 loading grids cannot establish a universal percolation exponent or threshold. Thermal conductivity and thermal diffusivity similarly require defined direction and conditions. Do not infer electromagnetic shielding, reliable resistive heating, dielectric safety or electrochemical suitability solely from a measured powder conductivity.

Source basis: v9 WP09–10; v16 registry and supplement; v23.

CHAPTER 21

Time-dependent performance, repair and reprocessing

21.1 Inherited durability and dynamic-test allocations

The original qualification registry retains the conditions below. They are candidate research parameters, not released process settings; each requires safety, method, mass and application review. Full specimen-level identity is provided in the embedded CSV. Controls and independent terminal cohorts must be maintained.

Package	Inherited design and interpretation	Units
WP09F	Five material groups; three maximum stress fractions 0.4/0.6/0.8 of proportional limit, stress ratio 0.1, 2 Hz, 100,000-cycle runout, subject to validity.	135
WP11	Five materials including catalyst-free instead of commercial epoxy; proposed 160/180/200/220 °C, two relaxation coupons plus one thermal witness per batch and temperature.	180
WP11C	Five standard groups; 23/40/60 °C and 0.1/0.2 proportional-limit stress; 168 h loading plus 24 h recovery.	180
WP12	Neat and finalist A; virgin, cut unhealed, nine healed conditions and nine corresponding heat-only conditions (160/180/200 °C × 5/30/60 min).	600
WP12R	Five standard groups, cycles 1–3, damage-heal, heat-only, damage-no-heat; independent terminal cohorts.	405
WP13	Neat, A, B and conventional epoxy; cycles 0–3, separate tensile, DSC and gel units.	432
WP13W	Neat, A, B and C; thermal-history witnesses at cycles 1–3, not identical coverage to WP13.	324
WP13R	Five groups, hydrolysis/solvolysis, active/solvent-only; approved chemistry not selected.	120
WP14	Neat, A, B: baseline and dry, humid heat (85 °C/85% RH), water and UV exposures, 168/500/1000 h. Several exposure details unresolved.	819

The five standard groups are neat, conventional epoxy and finalist A/B/C. Actual group coverage differs by package. The WP13/WP13W mismatch and missing separate commercial bioepoxy qualification remain unresolved. Never silently relabel an allocated comparator. Long-term 1000 h creep is not allocated in WP11C.

21.2 Creep, healing and repeated processing

Under constant applied stress, creep compliance is $J(t) = \varepsilon(t)/\sigma_0$. A recovery period helps examine residual strain but cannot independently establish permanent network exchange. Service creep may be unacceptable even when heated repair is feasible. The programme should report actual loading temperature, proportional-limit determination,

recovery and deviations. Fatigue models may explore stress–life relationships with appropriate censoring and limited extrapolation; accelerated tests do not automatically establish service life.

Healing must use separate matched virgin, damaged-unhealed, damaged-healed and heat-only specimens. A ratio of relevant group means $100\bar{P}_{healed}/\bar{P}_{virgin}$ is a recovery metric, with uncertainty and explicit property definition. Destructive-tested virgin specimens cannot subsequently be reused as intact paired specimens. Mechanical recovery is not crack closure, and post-cure is not proof of healing by dynamic exchange. Historical aims of approximately 85% healing, 80% repeated-cycle and durability retention are aspirational and not released limits.

Reprocessing shall measure recovered mass, mechanical properties, conversion, gel and changes in thermal history against matched witnesses. Chemical recovery requires solvent/active controls and separate accounting of recovered fractions, contamination and waste, not an assumption of closed-loop recyclability. Deterioration can accumulate: for a hypothetical constant per-cycle mass recovery 0.9, five cycles retain $0.9^5 = 0.59049$ of initial mass. This is an illustration, not measured performance.

Source basis: v9 WP09F, WP11–14; v16 registry; v25 RT-02, RT-05, RT-15.

PART VII

Experimental statistics and reproducibility

Independent preparations • statistical inference • cross-laboratory transfer

CHAPTER 22

Experimental design, inference and uncertainty

22.1 Experimental unit and blocking

The experimental unit is an independently prepared batch. Nested specimens estimate technical and within-batch variation. Blocks should capture predeclared relevant production-day or other nuisance effects; preserve original randomization schedules and approve amendments before comparative work. Analyze missingness, invalidity and failures explicitly. If a preparation does not cure, its failure is evidence, not an observation to erase. Use exact original treatment assignments in Appendix A rather than reconstructing randomization from identifiers.

22.2 Factorial analysis

For WP05, a fixed-block model is

$$Y_{ijk} = \mu + A_i + B_j + (AB)_{ij} + C_k + \epsilon_{ijk}. \tag{22.1}$$

With complete balanced data, degrees of freedom are 2 acid, 2 catalyst, 4 interaction, 2 block and 16 residual, total 26. Other campaigns have their corresponding blocked factorial or mixture structure. Primary endpoints, meaningful performance effects, integrity constraints, exclusions and multiplicity must be frozen prior to comparative execution. Report effect estimates, confidence intervals and assumptions. Exploratory inference may use batch means or a suitable hierarchical model incorporating nested specimen variation. Do not inflate independent sample size by counting coupons.

22.3 Confirmation, equivalence and missingness

For approximately independent equal-sized groups and a simple two-sided normal approximation, a prospective sample size per group is

$$n \approx \frac{2\sigma^2(z_{1-\alpha/2} + z_{1-\beta})^2}{\delta^2}. \tag{22.2}$$

A standardized effect of one, 5% significance and 80% power gives approximately 16 independent observations per group by this approximation. It is not an approved confirmation count. Adapt for t distributions, blocking, multiple outcomes, dropout, practical minimum effects and observed variance uncertainty. Three preparations per arm are exploratory. Use simultaneous control comparisons where appropriate and avoid ranking by unadjusted favorable p-values.

Equivalence requires a prospectively agreed margin Δ and a suitable interval or two-one-sided-test procedure; absence of statistical significance is not evidence of agreement. A simple equivalence decision may require the appropriate confidence interval for a mean difference to lie fully inside $(-\Delta, \Delta)$. Define relevant material and site contrasts, endpoint, units and direction ahead of time. Report full-data and validity-filtered sensitivity analyses with all original records retained.

Source basis: v10, v11–v17, v23, v25 RT-04, RT-11.

CHAPTER 23

Independent replication and reproducible data

23.1 Controlling v17 transfer study

After qualification, select one lead composite and freeze its recipe, lot provenance, cure, dispersion and test methods. Three independent laboratory slots each prepare four material groups (selected neat matrix, lead composite, conventional epoxy and commercial bioepoxy) with three independent preparations per group: 36 slots. The lead is finalist A or a formally remapped candidate. Participating laboratories remain unconfirmed. The exact original v17 identifiers and local randomization orders appear in Appendix A. Use common feedstock lots initially to investigate site effects, then consider a separate independent-feedstock study. Centrally manufactured blinded witness coupons are separately quoted and not counted in 36.

23.2 Transfer inference

The proposed core panel includes density, tensile modulus and strength, DMA, gel fraction and relaxation where applicable. Primary endpoint proposed for initial transfer is tensile modulus of the lead composite. Freeze equivalence margins with the application owner. Estimate material, site, material-by-site and batch variability using a defensible model. With only three site slots, variance components are exploratory; report site-specific differences and uncertainty. The commercial bioepoxy comparison in v17 does not cure its missing v16 allocation. No participant may substitute material or method silently.

23.3 Data and reporting requirements

Retain native instrument files, calibration records, method revisions, sample geometry, conditioning, actual preparation logs, failures, metadata and versioned analysis scripts. Central coordination allocates blind codes; complete blinding of operators may be impossible when materials visibly differ, so blind analysts where feasible. The transfer gate requires valid controls, traceability, agreed performance bounds, acceptable uncertainty and independent review. Investigate failed transfer for material, preparation, instrumentation and site differences before rerunning. A shared source-file hash supports integrity but not scientific validity.

Source basis: v17 original supplement and CSV; v18; v25.

PART VIII

Engineering and industrial manufacturing

Process development • manufacturing feasibility • bounded applications

CHAPTER 24

Process engineering and manufacturing scale-up

24.1 Scale-dependent thermal and mixing phenomena

The original v17 scale-up sequence is bench repeatability to a 1 kg demonstration, then a 10 kg pilot, conditional on separate stages of review. Each step involves new thermal, mixing, exposure and quality risks. Geometrically similar scale-up from one to ten units of volume increases characteristic dimension by $10^{1/3} \approx 2.154$ and area by $10^{2/3} \approx 4.642$. Thus area per volume falls to 46.4% of its original value. A reacting system may exhibit temperature gradients even if bench tests appear uniform. An approximation to spatial heat transport is

$$\rho C_p \frac{\partial T}{\partial t} = \nabla \cdot (k \nabla T) + q_{rxn}. \tag{24.1}$$

It requires validated material properties and boundary conditions, including conversion-dependent heat release. Thermal diffusivity $a = k/(\rho C_p)$ gives a conduction timescale of order L^2/a. Doubling section thickness may quadruple equilibration time in the idealized model. Do not approve scale changes by multiplying masses or relying on the lumped balance in Chapter 9 without a hazard assessment.

For a stirred system a conventional Reynolds number is $Re = \rho N D^2/\eta$, with impeller rotational frequency N, diameter D and representative viscosity η. In a suitable flow regime an empirical power-number relationship is $P = N_p \rho N^3 D^5$. Mixing energy per mass $E_m = m^{-1} \int P\, dt$ is a useful process descriptor but does not uniquely determine dispersion. In geometrically similar idealized turbulent systems, maintaining constant P/V implies $N \propto D^{-2/3}$; constant tip speed implies $N \propto D^{-1}$ and constant Reynolds number gives $N \propto D^{-2}$ if properties are fixed. No single similarity rule preserves all mixing conditions. Reacting filled systems may be non-Newtonian and require measured time-dependent viscosity and mixing behavior. Preserve particle morphology and monitor aggregation, voids, cure and thermal excursions.

24.2 Manufacturing-route selection

Casting supports simple specimen and prototype development, provided sedimentation, gas entrapment, cure gradients and shrinkage are addressed. Compression molding may consolidate viscous material before cure or enable thermally assisted deformation of a verified dynamic network; pressure and equipment capacity require professional review. Nominal force $F = PA$ demonstrates the area dependence of press loads. A hypothetical 1 MPa over 0.04 m^2 gives 40 kN; these are not approved settings. Tooling and mold qualification must address thermal behavior, dimensional accuracy, compatibility and release.

Extrusion of uncured paste, reactive extrusion and deformation of a cured dynamic network are distinct research concepts. For ideal Newtonian capillary flow $Q = \pi R^4 \Delta P/(8\eta L)$, but viscosity changes, wall slip, entrance effects and premature network formation may invalidate the approximation. A mean residence time V_{hold}/Q obscures the actual residence-time distribution. There is no established compatibility with ordinary thermoplastic extrusion equipment. Direct ink writing would require validated deposition rheology and shape retention, as well as interlayer strength, anisotropy, cure and defect assessment. A thermal epoxy–acid formulation is not automatically a photopolymer; carbon absorptivity may impede light-driven processing. Large-format manufacturing cannot be inferred from small printed specimens.

24.3 Scale gates and quality

Stage	Required evidence
Bench to 1 kg	Independent conforming bench lots, approved thermal and mixing assessment, safety and defined quality windows.
1 kg to 10 kg	Temperature and mixing uniformity, viscosity, conversion, void content, yield, energy and process records.
Pilot development	Stable input supply, maintenance, trained personnel, documented acceptance, waste and exposure controls.
1–100 t/year	Cost and capacity scenarios only; no commissioned production capacity.

Map critical material attributes (EEW, assay, moisture and filler morphology) and critical process parameters (mass, mixing energy, temperature and time history, forming) to measured critical quality attributes. Use statistical process control only with a stable and sufficiently characterized process. Define saleable yield on a consistent basis. Separately record rejects, rework, recovered material and first-pass acceptance; never count waste as accepted output.

Source basis: v7 pilot engineering gates; v17 pp. 4–5; v18; v25 RT-12.

CHAPTER 25

Construction, transportation and functional applications

25.1 Application-first development

A material coupon is not a certified product. The recommended initial research targets are bounded non-safety-critical applications such as repairable industrial tooling, nonstructural panels, protective housings and selected noncritical transportation accessories. Terravitria and Landricus are proposed application initiatives associated with the research platform, not evidence of factories or product approval. Their role is to define customer function, comparator, geometry, exposure and mandatory criteria. RT-15 remains open. No product should be selected solely because a filler improves a favorable coupon metric.

25.2 Terravitria construction research

For a simply supported ideal slender beam under central load, $\delta = FL^3/(48EI)$ and for rectangular cross section $I = bh^3/12$. Equal coupon modulus does not imply equal component stiffness; geometry and connections matter. A nonstructural panel must be examined for flexure, impact, moisture, fastener behavior, dimensional stability, fire and emissions where applicable. A sandwich panel introduces separate face, core and interface failure modes. Building assemblies add weather, joints, air and vapor transport and fire-endurance requirements. Thermal resistance for ideal homogeneous layers is $R = L/k$; complete envelopes also involve interfaces, thermal bridges and moisture. Occupied housing, roads, bridges, towers and agricultural megastructures require separate engineering and procedural approvals; no claim of structural readiness is made. Indigenous cultural architecture and land use require appropriate consultation and respect for relevant rights.

25.3 Landricus transportation research

Initial component investigations should use bounded noncritical parts. Vehicle materials encounter vibration, fatigue, impact, temperature variation, moisture, chemicals, fire and aging. Structural transport requires assessment of joints, damage tolerance and actual component/assembly failure. Energy absorption $W = \int F(x)dx$ is specific to test geometry and loading. Battery-adjacent components require thermal, electrical and fire assessment, including unintended conduction pathways. Marine, rail, aerospace and orbital research carry further system-specific requirements. Vacuum outgassing, radiation and thermal cycling require separate mission-specific qualification. No roadworthy vehicle, flightworthy component or structural certification is established.

25.4 Electrical and tooling functions

For defined geometry, bulk conductivity $\kappa = L/(RA)$ is a possible primary endpoint for conductive grades; resistance changes under strain may support sensing only if repeatability, drift and hysteresis are measured. Conductive materials are not automatically safe

insulators. Percolation models of the form $\kappa \sim (\phi - \phi_c)^t$ require appropriate concentration coverage, identification of network behavior and uncertainty; the sparse screening grids do not establish ϕ_c. Energy storage is a separate electrochemical material pathway. A potential repairable tooling comparison should use a defined count of conforming manufacturing operations and dimensional tolerances, with repeated repair and thermal cycling evidence. Advance only where demonstrated material properties address the actual application problem.

Source basis: v7 application qualification matrix; v16–v18; v25 RT-15; application concepts from v30 draft, not existing products.

PART IX

Environmental performance and economics

Life-cycle inventory • carbon accounting • industrial economics

CHAPTER 26

Life-cycle assessment and carbon accounting

26.1 WP15A: goal, scope and functional equivalence

The original v7 methodology uses ISO 14040 and 14044 as candidate LCA frameworks and ISO 14067 for product carbon footprint. Obtain the applicable normative texts and amendments before claiming compliance. The initial screening functional unit is 1 kg of conforming cured material at factory gate. For a public comparative engineering claim, the decision unit is one functionally equivalent component delivering the same specified load, stiffness, environment and lifetime. Equal mass does not establish equal service. For an ideal stiffness-limited panel with equal width and boundary conditions, $E_1 h_1^3 = E_2 h_2^3$, so the mass ratio is $(\rho_2/\rho_1)(E_1/E_2)^{1/3}$; fire, impact, durability and other mandatory constraints still govern actual equivalence.

Cradle-to-gate includes cultivation, fertilizer and field emissions, drying, extraction, lignin and carbon conversion, reagents, catalyst, transportation, mixing, cure, rejects and relevant background utilities. Cradle-to-grave extends to use, repair, replacement, recovery and disposal. The original 80-row v7 inventory is embedded unchanged; all quantities remain unmeasured. Obtain actual geographic, temporal and technological representativeness, measure idle and active energy, include failed runs and cleaning. Record dry inputs, saleable outputs, heat, electricity, water, solvents, gases, wastewater, solids and emissions per batch. For multifunctional hemp systems, consider subdivision or system expansion before allocation; compare justified mass and economic allocation and avoid double counting substituted output. Impact categories include climate change, acidification, eutrophication, water and resource use and toxicity where sufficient data support them.

26.2 WP15B: mass and carbon balances

For a defined process boundary, dry mass closure $C_m = 100 \sum m_{out} / \sum m_{in}$ requires all relevant solid, gas and liquid streams on compatible bases, including chemical inputs. The inherited investigation trigger outside 95–105% is provisional and subject to uncertainty. Unmeasured streams are unresolved, not zero. Carbon closure is likewise $C_C = 100 \sum m_{out} x_{C,out} / \sum m_{in} x_{C,in}$. Account for carbon in gases and dissolved organic carbon where relevant. Neither closure statistic is a climate impact calculation.

For dry product mass m_p, elemental carbon mass fraction x_C, and biogenic carbon fraction f_B, the physical biogenic carbon stock expressed as corresponding CO_2 mass is

$$S_B = m_p x_C f_B \frac{44}{12}. \tag{26.1}$$

A hypothetical 1 kg product with $x_C = 0.60$ and $f_B = 0.80$ contains 0.48 kg biogenic elemental carbon, corresponding to 1.76 kg CO_2 mass. This stock is not a 1.76 kg CO_2e net-removal credit. Fossil carbon would be $m_p x_C(1 - f_B) = 0.12$ kg in the same example. Use a suitable radiocarbon method such as ASTM D6866 subject to scope and actual provenance; biogenic carbon fraction is a carbon-based denominator, not renewable mass fraction or organic certification.

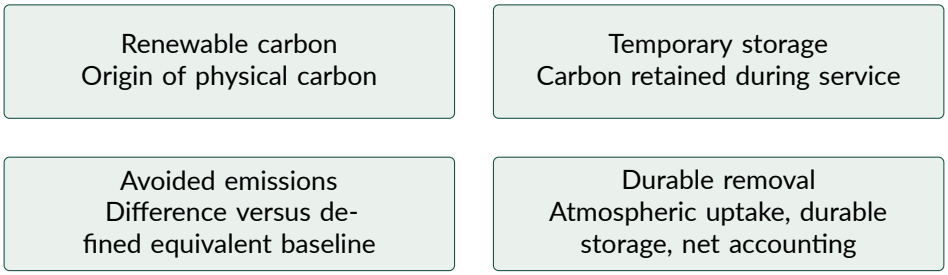


Figure 26.1: Four separate accounting concepts. None automatically establishes another.

26.3 Climate interpretation and uncertainty

A generalized impact model is $I_k = \sum_i q_i CF_{ik}$ for inventory flows q_i and specified characterization method. Report characterization horizon and treatment of biogenic uptake and releases consistently. Avoided emissions are $G_{baseline} - G_{candidate}$ for equivalent function, not physical atmospheric removal. Durable removal additionally requires an appropriate baseline, storage durability, treatment of reversal and leakage, and verified net accounting. Model actual product end-of-life, not indefinite storage. A first-order stock-decay scenario $S(t) = S_0 e^{-kt}$ has half-life $\ln 2/k$ but no measured rate is established. Do not apply soil-biochar permanence assumptions to composite materials without validation.

Assess agricultural fertilizer and field emissions, geographically appropriate energy factors, conversion and purification yields, solvent recovery, product lifetime, allocation and rejects. Keep attributional and consequential models distinct. Monte Carlo propagation requires justified input distributions, dependencies, seed, sample size and convergence; simulated uncertainty remains conditional on the assumptions. An uncertain yield denominator may dominate impact per saleable kg. Compare low/base/high scenarios as assumptions, not measurements. The programme requires independent critical review before public comparative claims.

Source basis: v7 WP15A/B; v9 pp. 8–9; v17; v18; v25 RT-12; inherited ISO/ASTM reference statuses.

CHAPTER 27

Techno-economic analysis and commercial feasibility

27.1 WP15C: capacity and unit cost

Model each formulation and plant scale independently. The inherited primary saleable-output scenarios are 1, 10 and 100 tonnes/year, not actual capacity. For rated input throughput q, scheduled hours H, utilization u and conforming yield Y, annual saleable output $Q = qHuY$ requires compatible mass bases and no double-counted availability loss. At hypothetical 10 kg gross output per cycle and 90% yield, one tonne/year would require at least 112 cycles, ten tonnes 1,112 and one hundred tonnes 11,112. This arithmetic illustrates scale mismatch, not a practical production design.

Operating cost includes feedstock, reagents, utilities, labor, maintenance, waste, quality and overhead. Record quantities, supplier quote sizes, freight, currency year, geography and sourcing status. Include qualified yield: for relevant input cost c per kg and yield Y, converted input cost per saleable kg is c/Y. For illustrative $c = 10$ CAD/kg and $Y = 0.75$, the contribution is 13.33 CAD/kg. Specialty filler cost at dry mass fraction w contributes approximately wc_f before losses and other process costs. These are sensitivity relationships and not quotes.

27.2 Annualization and cash flow

For capital K, annual discount rate r and life n, an ideal annual capital recovery payment A satisfies $K = A[1-(1+r)^{-n}]/r$ (with appropriate limiting treatment when $r = 0$). Thus

$$CRF = \frac{r(1+r)^n}{(1+r)^n - 1}, \qquad C_{level} = \frac{KCRF + C_{fixed} + C_{variable} - C_{credits}}{Q}. \tag{27.1}$$

Only documented coproduct credits may be included. This expression is a screening levelized cost, not a full discounted cash-flow selling price. For initial investment I_0, net cash flows CF_t and residual value V_R (not counted elsewhere),

$$NPV = -I_0 + \sum_{t=1}^{n} \frac{CF_t}{(1+r)^t} + \frac{V_R}{(1+r)^n}. \tag{27.2}$$

Include tax, working capital, ramp-up, salvage, maintenance, capital structure treatment and real/nominal consistency where relevant. No investment return is established. If $p > v$ for selling price and variable cost per unit, break-even quantity under a simple linear model is $Q_{BE} = F/(p-v)$. Hypothetical $F = 60{,}000$, $p = 30$, $v = 18$ CAD imply 5,000 kg/year. Do not infer that fixed costs remain unchanged across hundredfold scale changes.

27.3 Commercialization and circularity

Use actual customer needs, benchmark, lifetime, specification, cost and willingness to pay. Potential first-use categories are repairable tooling and nonstructural components, followed by justified electrical or transportation functions. Contract manufacturing or

research collaboration may reduce up-front capital exposure but requires contractual quality, data and IP controls. Neither preliminary interest nor a proposed addressable market is contracted demand. Revenue from carbon credits is excluded absent a verified qualifying pathway. The 25,000 CAD Phase I planning budget is research funding, not an industrial production-cost estimate.

For environmental-economic comparisons, distinguish abatement cost from carbon removal cost. If $G_{baseline} > G_{candidate}$ on a common functional basis, incremental cost per avoided unit is $(C_{candidate} - C_{baseline})/(G_{baseline} - G_{candidate})$. Model repair and material recovery with actual additional energy, quality retention and replacement rates. Avoid repeated counting of recovered carbon. The TEA and LCA must reconcile to the same physical inventories; sensitivity should include energy price and emissions factor, feedstock cost, conversion yield, utilization, cycle time, rejection rates, labor, discount rate and service life.

Source basis: v7 WP15C; v17 pp. 4–5; v18; v19; v25 RT-12, RT-14, RT-15.

PART X

Laboratory execution, governance and commercialization

Commissioning • quality systems • risk controls • independent review

CHAPTER 28

Laboratory commissioning, procurement and funding

28.1 Immediate commissioning objective

The first commission is WP01 precursor qualification and WP05 neat-network feasibility. Seek a qualified laboratory willing to evaluate the proposed 27-preparation randomized design. If EHO cannot be sourced in qualified form, commission WP02 separately. Identify available staff, facility scope, equipment, safety systems, analytical capability and native data delivery. Quote facility access rather than purchasing all instruments by default. Required access may include calibrated balances, approved mixing and cure equipment, thermal monitoring, DSC, FTIR, DMA/rheometry and gel extraction capability. Method and exposure-control requirements must be reviewed by the actual facility. No appointment or accreditation is asserted.

28.2 Phase I staged request for quotation

Obtain separate written scope and costs for incoming assays, safety assessment, thermal scouts and controls, 27 independent preparations, specimen preparation, analytical work, native files, independent reporting and fresh confirmation. Separate freight, waste, storage, taxes and optional custom EHO synthesis. The v19 nineteen-row RFQ remains unquoted; unknown quantities and prices are not zero. Appendix D prints this register and preserves the original CSV. The illustrative 25,000 CAD envelope is a planning allocation from the consolidated programme, not a supplier quote or confirmed financing.

Planning category	CAD
Precursor qualification	3,500
Thermal scouting	3,000
27 independent preparations	6,000
Analytical characterization	6,500
Independent review and reporting	3,500
Contingency	2,500
Total	25,000

The contingency is 10%. Taxes, fresh confirmation, custom precursor synthesis and other unquoted needs may require additional financing. Authorize spending limits per stage; compare equivalent scope and accepted material cost rather than catalogue price. For purchase or synthesis, cost per accepted dry gram includes qualification, freight, waste and rework. Confirm signed terms before shipment and procurement. Commercial hemp

epoxy is a separate benchmark; do not substitute it for EHO without demonstrated equivalence and approved amendment.

28.3 Prospective collaboration strategy

The v20 register identifies CDCQ, RPC New Brunswick, UNB, NRC and ZILA BioWorks as potential technical or commercial leads, along with research and funding leads. Publicly described capabilities do not establish partner commitment, availability, stock or scope. Candidate funding routes include NRC IRAP, Mitacs and ACOA subject to current eligibility and terms. The preferred outreach sequence is days 1–7 tailored inquiries, days 8–14 one follow-up, days 15–30 comparison of complete bids, all relative planning targets. Reject unsafe proposals or bids failing mandatory data-access requirements before applying the proposed scoring weights: technical fit 35%, data quality 25%, total cost 20%, schedule 10%, IP terms 10%. Actual weights require approval.

A written research agreement should identify legal parties, scope, payment, staff, subcontracting, safety authority, data access, ownership and licensing of background/foreground IP, confidentiality, authorship, publication review, negative-result reporting, waste, sample custody, liability and termination. Obtain appropriate professional review. No confirmed sponsorship, funding, partner agreement or patent title is established.

28.4 Conditional schedule

Preserve the v19 planning allowances: weeks 1–4 for quotations/contracting and procurement arrangements after funding and partner agreement are in place as defined by the project; weeks 5–8 for incoming qualification, readiness and separately authorized thermal scouting; weeks 9–14 for the comparative campaign if released; weeks 15–18 for analysis and independent review. These are conditional calendar assumptions, not forecast supplier lead times; prerequisites and actual contracting sequence must be rebaselined at G01. Custom EHO synthesis or unavailable staff/methods may extend the schedule materially. Fresh confirmation must be priced and authorized before advancing beyond the foundational matrix. Subsequent 2027 work proceeds only as earlier milestones and funding permit.

Source basis: v19–v21; v26 illustrative budget; v24; v25 RT-07, RT-08, RT-14.

CHAPTER 29

Quality, authorization and master operating framework

29.1 Authority and readiness

The programme sponsor controls lawful funding and contractual scope. The laboratory PI and safety lead control physical execution and safety. The quality lead controls material disposition, the metrology lead method readiness, the statistician inference planning and the data steward genealogy and native records. Independent review evaluates the evidence; roles remain unassigned and any combination of roles requires conflict controls. A missing signature, method revision, limit, calibration or required data record means HOLD. No framework-level SOP in this monograph is a released operating recipe.

Gate / owner	Decision	Evidence
G01 / Funder / PI	Funding and contract	Signed scope, budget, payment and data terms
G02 / Lab safety officer	Laboratory and safety	Approved hazard assessment, containment, waste and emergency plan
G03 / Quality lead	Incoming materials	Released EHO, acid and catalyst lots; measured EEW and assay
G04 / Metrology lead	Method readiness	Approved methods, calibration, controls and uncertainty
G05 / Lab PI	Thermal scouting	Approved scale and cure window; scouting report
G06 / PI / statistician	Preregistration	Locked endpoints, thresholds, exclusions and analysis
G07 / Lab PI	Specimen allocation	Yield-based specimen plan, controls, custody and native data paths
G08 / PI and safety lead	Comparative campaign release	All preceding gates approved; signed release
G09 / Independent reviewer	Post-campaign review	Complete data, deviations, analysis and confirmatory plan

All nine original gates remain HOLD. Approver, approval date and evidence URI fields are unfilled. Source: v24 readiness register. The v24 comparative release is the logical conjunction of approved G01–G07 and signed G08. G09 is post-campaign review, not a prerequisite already completed before G08. A separate authorization for scout-specific scope and safety is necessary before any preliminary reactive work. Close applicable pre-release critical-risk evidence before execution and retain downstream closure requirements for G09 or later stages; do not require results that can only be obtained in authorized experiments as if they already existed.

29.2 Master quality system

Use original v22 requirement IDs P01-01 through P15-03 where applicable and v23 corresponding validation IDs. The complete 55-row specification and validation crosswalk is in Appendix B and original attachments. Quantitative and documentary acceptance

criteria, units, sampling, method revision, uncertainty and decision rules must be frozen. P01–P04 cover oil, EHO, acid and catalyst; later material categories address FGE, lignin, six carbon forms and two distinct commercial benchmark systems. Quarantine incoming lots; verify actual analytical data before disposition as RELEASED, REJECTED or HOLD for a specific use and revision. Supplier, lot, expiry, storage excursion or chemical changes require reassessment. A certificate of analysis is not an unrestricted release.

29.3 Safety and stop-work decision

Require qualified facilities, trained personnel, appropriate containment, ventilation, equipment limits, thermal-hazard assessment, waste procedures and emergency planning. Reactive synthesis, elevated-temperature carbon production and fine carbon processing are not home experiments. Halt on uncontrolled thermal excursion, failed containment, unsafe exposure, failed controls, material discrepancy, serious nonconformance or loss of traceability. Preserve evidence and obtain authorized restart after corrective action. Numerical operating ceilings and emergency procedures must be facility-specific and approved, not inferred from this document.

29.4 Master SOP architecture

Appendix F defines 124 supplementary master SOP IDs organized into governance, safety, procurement, precursor chemistry, carbon production, formulation, specimens, characterization, durability, statistics, environment/economics and data/publication. These index the proposed workflows, not 124 approved bench methods. Each operative SOP requires scope, personnel, hazards, equipment, approved conditions, QC, decision criteria, records, deviation actions, version and signatures. The inherited campaign-specific documents and original IDs remain authoritative for controlled design. Use the crosswalk to orchestrate procedures without multiplying preparation allocations.

29.5 Specimen allocation and integrity

For planned specimen counts n_i and actual measured or approved estimated masses m_i, calculate $M_s = \sum n_i m_i$, add nonduplicated controls, retained samples, machining, reserve and other relevant mass needs. If Y is appropriate forecast usable yield, require compatible input basis $M_{in} \geq M_{required}/Y$. Validate scale separately. Destructive testing cannot reuse failed coupons. Link every test unit to a physical parent preparation and source entry before release. The original 573-entry registry overlap remains open and must not be added to the 222 or 3,750 counts.

Source basis: v9 instrument worksheet; v22–v25; v30 master SOP concept.

CHAPTER 30

Research integrity, decision criteria and programme conclusion

30.1 The unresolved red-team register

All fifteen inherited findings remain OPEN, including seven critical. The complete original risk text, severity, source, owners, gates and closure evidence appear in Appendix C and the embedded v25 register. The immediate critical path is qualified precursor functionality (RT-01), distinguishing relaxation mechanisms (RT-02), separate scout safety (RT-03), appropriate statistical confirmation (RT-04), specimen yield and mass (RT-05), registry linkage (RT-06), and actual funding, methods, staff and authorization (RT-07). The remaining findings address precursor substitution, morphology confounding, empirical versus mechanistic synergy, the commercial bioepoxy gap, missing scale/cost/carbon evidence, bibliography, rights and undefined application requirements. A proposed mitigation is not evidence of closure.

30.2 Research records and ethics

Preserve supplier lot, internal lot, preparation, specimen, measurement and report genealogy. Native files require calibration, method revision, timestamps, units, geometry, operator, environmental conditions, uncertainty and validity. Correct errors through an auditable record preserving old values, reasons and approval. Maintain versioned scripts, storage access controls, backup and restoration verification. File hashes identify bytes, not scientific validity. Simulation outputs must be classified apart from measured data. FAIR-style metadata supports findability and reuse under appropriate access conditions, without implying all proprietary data must be open.

AI-assisted writing, programming and model generation shall not fabricate observations, citations, procurement commitments or approval signatures. Authors and qualified reviewers remain accountable for source verification and validity. Disclose conflicts and relevant commercial interests. Appropriate agreements should preserve valid negative outcomes and define finite confidential review before publication. Maintain versioned public releases, source citations, contributor roles and correction history. Persistent identifiers are not peer review. Respect applicable occupational, environmental, Indigenous-rights and application-specific legal obligations. Prior-art searches and publication history do not establish legal inventorship, patentability or freedom to operate; consult qualified advisers.

30.3 Stop, redesign or advance

If qualified precursors fail network formation, investigate functionality, assay, stoichiometry and chemistry before adding reinforcements. If stress relaxation cannot be distinguished from degradation and residual cure, do not claim validated vitrimer behavior. If no carbon morphology provides meaningful benefits, stop or redesign rather than invent a hybrid synergy. Reject candidates failing mandatory service, creep, durability or safety

criteria even when initial stiffness is attractive. If manufacturing cost or life-cycle burden is unfavorable, investigate bounded alternatives; renewable origin cannot override evidence. Suspend unfunded or unsafe work and preserve all results and decisions. No evidence in this edition closes the original findings.

30.4 Final declaration

HEMPOXIES is a structured research platform for learning which hemp-derived molecular and carbon architectures, if any, can produce useful and reproducible engineering materials. The documentation has reached a consolidated planning stage; the experiments have not. The priority is therefore not further expansion of speculative formulations or increasingly long publications. It is a qualified laboratory feasibility assessment, funded and signed scoped agreement, precursor qualification, approved methods, separate thermal scouting and a scientifically controlled 27-preparation campaign. A result that refutes the foundational hypothesis is a legitimate outcome. Commercialization must follow verified function, process stability, safe manufacture, defensible environmental/economic data and applicable approvals.

Decision / release basis. Documentary consolidation complete. Original experimental baseline intact. All physical work, method approvals, material release, funding commitments and commercial claims remain HOLD or unconfirmed.

Source basis: v10, v18, v19–v25; all preceding research chapters.

APPENDIX A

Original preparation schedules

The following tables reproduce the original treatment assignments in registry order. All 222 slots are HOLD, with no actual physical batch manufacture established. Displayed calculated masses are planning quantities. Empty input-lot, condition, assay, recipe, result and authorization fields remain empty in the attached source files. The 36 replication slots are a separately proposed increment to the 186 screening slots.

A.1 v11 / WP05: neat network (27)

Original source: Hempoxies_Pilot_Batches_v11.csv. All allocations HOLD.

Batch	Block	Order	Acid/epoxy	Catalyst PHR	EHO g
NV-01-01	1	1	0.8	5	10
NV-01-02	1	2	0.8	0	10
NV-01-03	1	3	1	5	10
NV-01-04	1	4	1.2	5	10
NV-01-05	1	5	1.2	2	10
NV-01-06	1	6	1.2	0	10
NV-01-07	1	7	1	2	10
NV-01-08	1	8	1	0	10
NV-01-09	1	9	0.8	2	10
NV-02-01	2	1	1.2	0	10
NV-02-02	2	2	0.8	5	10
NV-02-03	2	3	1	2	10
NV-02-04	2	4	0.8	0	10
NV-02-05	2	5	0.8	2	10
NV-02-06	2	6	1	5	10
NV-02-07	2	7	1.2	5	10
NV-02-08	2	8	1	0	10
NV-02-09	2	9	1.2	2	10
NV-03-01	3	1	1.2	2	10
NV-03-02	3	2	0.8	0	10
NV-03-03	3	3	0.8	5	10
NV-03-04	3	4	1	5	10
NV-03-05	3	5	1	0	10
NV-03-06	3	6	1.2	5	10
NV-03-07	3	7	0.8	2	10
NV-03-08	3	8	1	2	10
NV-03-09	3	9	1.2	0	10

A.2 v12 / WP06: reactive diluent (36)

Original source: Hempoxies_FGE_Batches_v12.csv. All allocations HOLD.

Batch	Block	Order	FGE PHR	Acid/epoxy	EHO g	FGE g
FG-01-01	1	1	0	0.9	10	0.0
FG-01-02	1	2	0	1	10	0.0
FG-01-03	1	3	20	0.9	10	2.0
FG-01-04	1	4	30	1.1	10	3.0
FG-01-05	1	5	10	1	10	1.0
FG-01-06	1	6	10	1.1	10	1.0
FG-01-07	1	7	0	1.1	10	0.0
FG-01-08	1	8	20	1	10	2.0
FG-01-09	1	9	20	1.1	10	2.0
FG-01-10	1	10	30	1	10	3.0
FG-01-11	1	11	10	0.9	10	1.0
FG-01-12	1	12	30	0.9	10	3.0
FG-02-01	2	1	10	1	10	1.0
FG-02-02	2	2	20	0.9	10	2.0
FG-02-03	2	3	0	0.9	10	0.0
FG-02-04	2	4	0	1.1	10	0.0
FG-02-05	2	5	30	0.9	10	3.0
FG-02-06	2	6	20	1.1	10	2.0
FG-02-07	2	7	30	1.1	10	3.0
FG-02-08	2	8	30	1	10	3.0
FG-02-09	2	9	0	1	10	0.0
FG-02-10	2	10	20	1	10	2.0
FG-02-11	2	11	10	0.9	10	1.0
FG-02-12	2	12	10	1.1	10	1.0
FG-03-01	3	1	0	0.9	10	0.0
FG-03-02	3	2	20	0.9	10	2.0
FG-03-03	3	3	10	1.1	10	1.0
FG-03-04	3	4	30	1	10	3.0
FG-03-05	3	5	10	1	10	1.0
FG-03-06	3	6	20	1	10	2.0
FG-03-07	3	7	20	1.1	10	2.0
FG-03-08	3	8	30	0.9	10	3.0
FG-03-09	3	9	30	1.1	10	3.0
FG-03-10	3	10	0	1.1	10	0.0
FG-03-11	3	11	0	1	10	0.0
FG-03-12	3	12	10	0.9	10	1.0

A.3 v13 / WP05L: paired lignin (21)

Original source: Hempoxies_Lignin_Batches_v13.csv. All allocations HOLD.

Batch	Block	Order	Lignin type	Dry PHR	EHO g	Lignin g
LG-01-01	1	1	unmodified	10	10	1.0
LG-01-02	1	2	none	0	10	0.0
LG-01-03	1	3	epoxidized	5	10	0.5
LG-01-04	1	4	unmodified	15	10	1.5
LG-01-05	1	5	epoxidized	10	10	1.0
LG-01-06	1	6	epoxidized	15	10	1.5
LG-01-07	1	7	unmodified	5	10	0.5
LG-02-01	2	1	epoxidized	15	10	1.5
LG-02-02	2	2	epoxidized	10	10	1.0
LG-02-03	2	3	epoxidized	5	10	0.5
LG-02-04	2	4	unmodified	5	10	0.5
LG-02-05	2	5	unmodified	10	10	1.0
LG-02-06	2	6	unmodified	15	10	1.5
LG-02-07	2	7	none	0	10	0.0
LG-03-01	3	1	epoxidized	15	10	1.5
LG-03-02	3	2	epoxidized	10	10	1.0
LG-03-03	3	3	unmodified	10	10	1.0
LG-03-04	3	4	unmodified	5	10	0.5
LG-03-05	3	5	unmodified	15	10	1.5
LG-03-06	3	6	epoxidized	5	10	0.5
LG-03-07	3	7	none	0	10	0.0

A.4 v14 / WP07: individual carbon (57)

Original source: Hempoxies_Carbon_Batches_v14.csv. All allocations HOLD.

Batch	Block	Order	Morphology	Filler wt%	Matrix g	Filler g
HC-01-01	1	1	Reduced nanosheets	5	10	0.526316
HC-01-02	1	2	Short carbon fiber	2	10	0.204082
HC-01-03	1	3	Oxidized nanosheets	5	10	0.526316
HC-01-04	1	4	Activated biochar	2	10	0.204082
HC-01-05	1	5	Activated biochar	5	10	0.526316
HC-01-06	1	6	Reduced nanosheets	0.5	10	0.050251
HC-01-07	1	7	Biochar	5	10	0.526316
HC-01-08	1	8	Oxidized nanosheets	0.5	10	0.050251
HC-01-09	1	9	Biochar	0.5	10	0.050251
HC-01-10	1	10	Short carbon fiber	0.5	10	0.050251
HC-01-11	1	11	Porous nanosheets	5	10	0.526316
HC-01-12	1	12	Oxidized nanosheets	2	10	0.204082
HC-01-13	1	13	None	0	10	0.0
HC-01-14	1	14	Reduced nanosheets	2	10	0.204082
HC-01-15	1	15	Short carbon fiber	5	10	0.526316
HC-01-16	1	16	Activated biochar	0.5	10	0.050251
HC-01-17	1	17	Porous nanosheets	0.5	10	0.050251
HC-01-18	1	18	Porous nanosheets	2	10	0.204082
HC-01-19	1	19	Biochar	2	10	0.204082
HC-02-01	2	1	Porous nanosheets	5	10	0.526316
HC-02-02	2	2	Reduced nanosheets	2	10	0.204082
HC-02-03	2	3	Activated biochar	5	10	0.526316
HC-02-04	2	4	Oxidized nanosheets	5	10	0.526316
HC-02-05	2	5	Biochar	5	10	0.526316
HC-02-06	2	6	Short carbon fiber	2	10	0.204082
HC-02-07	2	7	Biochar	0.5	10	0.050251
HC-02-08	2	8	Porous nanosheets	2	10	0.204082
HC-02-09	2	9	Short carbon fiber	5	10	0.526316
HC-02-10	2	10	Activated biochar	2	10	0.204082
HC-02-11	2	11	Oxidized nanosheets	2	10	0.204082
HC-02-12	2	12	Short carbon fiber	0.5	10	0.050251
HC-02-13	2	13	Activated biochar	0.5	10	0.050251
HC-02-14	2	14	Biochar	2	10	0.204082
HC-02-15	2	15	None	0	10	0.0
HC-02-16	2	16	Oxidized nanosheets	0.5	10	0.050251
HC-02-17	2	17	Reduced nanosheets	5	10	0.526316
HC-02-18	2	18	Reduced nanosheets	0.5	10	0.050251
HC-02-19	2	19	Porous nanosheets	0.5	10	0.050251
HC-03-01	3	1	Biochar	5	10	0.526316
HC-03-02	3	2	Porous nanosheets	0.5	10	0.050251
HC-03-03	3	3	Biochar	0.5	10	0.050251
HC-03-04	3	4	Activated biochar	0.5	10	0.050251
HC-03-05	3	5	Activated biochar	2	10	0.204082
HC-03-06	3	6	Short carbon fiber	5	10	0.526316
HC-03-07	3	7	Short carbon fiber	2	10	0.204082
HC-03-08	3	8	Reduced nanosheets	2	10	0.204082
HC-03-09	3	9	Reduced nanosheets	5	10	0.526316
HC-03-10	3	10	None	0	10	0.0
HC-03-11	3	11	Oxidized nanosheets	5	10	0.526316
HC-03-12	3	12	Biochar	2	10	0.204082
HC-03-13	3	13	Porous nanosheets	2	10	0.204082
HC-03-14	3	14	Short carbon fiber	0.5	10	0.050251

Continued on next page

Batch	Block	Order	Morphology	Filler wt%	Matrix g	Filler g
HC-03-15	3	15	Oxidized nanosheets	0.5	10	0.050251
HC-03-16	3	16	Porous nanosheets	5	10	0.526316
HC-03-17	3	17	Activated biochar	5	10	0.526316
HC-03-18	3	18	Reduced nanosheets	0.5	10	0.050251
HC-03-19	3	19	Oxidized nanosheets	2	10	0.204082

A.5 v15 / WP08: hybrid carbon (45)

Original source: Hempoxies_Hybrid_Batches_v15.csv. All allocations HOLD.

Batch	Block	Order	Filler wt%	A frac.	B frac.	C frac.	Filler g
HY-01-01	1	1	5	0.500000	0.500000	0.000000	0.526316
HY-01-02	1	2	5	0.333333	0.333333	0.333333	0.526316
HY-01-03	1	3	2	0.000000	1.000000	0.000000	0.204082
HY-01-04	1	4	2	0.500000	0.000000	0.500000	0.204082
HY-01-05	1	5	5	0.000000	1.000000	0.000000	0.526316
HY-01-06	1	6	2	1.000000	0.000000	0.000000	0.204082
HY-01-07	1	7	2	0.000000	0.500000	0.500000	0.204082
HY-01-08	1	8	2	0.500000	0.500000	0.000000	0.204082
HY-01-09	1	9	5	0.000000	0.000000	1.000000	0.526316
HY-01-10	1	10	5	0.500000	0.000000	0.500000	0.526316
HY-01-11	1	11	2	0.000000	0.000000	1.000000	0.204082
HY-01-12	1	12	5	1.000000	0.000000	0.000000	0.526316
HY-01-13	1	13	0	0.000000	0.000000	0.000000	0.000000
HY-01-14	1	14	5	0.000000	0.500000	0.500000	0.526316
HY-01-15	1	15	2	0.333333	0.333333	0.333333	0.204082
HY-02-01	2	1	5	0.500000	0.500000	0.000000	0.526316
HY-02-02	2	2	5	0.500000	0.000000	0.500000	0.526316
HY-02-03	2	3	2	0.333333	0.333333	0.333333	0.204082
HY-02-04	2	4	5	0.000000	0.500000	0.500000	0.526316
HY-02-05	2	5	5	0.333333	0.333333	0.333333	0.526316
HY-02-06	2	6	2	0.500000	0.000000	0.500000	0.204082
HY-02-07	2	7	2	0.000000	1.000000	0.000000	0.204082
HY-02-08	2	8	2	0.000000	0.000000	1.000000	0.204082
HY-02-09	2	9	0	0.000000	0.000000	0.000000	0.000000
HY-02-10	2	10	2	1.000000	0.000000	0.000000	0.204082
HY-02-11	2	11	5	0.000000	1.000000	0.000000	0.526316
HY-02-12	2	12	5	1.000000	0.000000	0.000000	0.526316
HY-02-13	2	13	5	0.000000	0.000000	1.000000	0.526316
HY-02-14	2	14	2	0.000000	0.500000	0.500000	0.204082
HY-02-15	2	15	2	0.500000	0.500000	0.000000	0.204082
HY-03-01	3	1	2	0.500000	0.500000	0.000000	0.204082
HY-03-02	3	2	5	0.333333	0.333333	0.333333	0.526316
HY-03-03	3	3	5	1.000000	0.000000	0.000000	0.526316
HY-03-04	3	4	2	0.000000	0.500000	0.500000	0.204082
HY-03-05	3	5	2	1.000000	0.000000	0.000000	0.204082
HY-03-06	3	6	5	0.000000	1.000000	0.000000	0.526316
HY-03-07	3	7	2	0.500000	0.000000	0.500000	0.204082
HY-03-08	3	8	2	0.000000	0.000000	1.000000	0.204082
HY-03-09	3	9	5	0.000000	0.500000	0.500000	0.526316
HY-03-10	3	10	5	0.000000	0.000000	1.000000	0.526316
HY-03-11	3	11	5	0.500000	0.000000	0.500000	0.526316
HY-03-12	3	12	2	0.000000	1.000000	0.000000	0.204082
HY-03-13	3	13	2	0.333333	0.333333	0.333333	0.204082
HY-03-14	3	14	0	0.000000	0.000000	0.000000	0.000000
HY-03-15	3	15	5	0.500000	0.500000	0.000000	0.526316

Fractions are relative to dry filler; displayed values rounded to six decimals. Exact source values and component masses remain in the attached original v15 CSV. Every slot has 10 g dry matrix basis.

A.6 v17: interlaboratory transfer (36)

Original source: Hempoxies_Replication_Registry_v17.csv. All allocations HOLD.

Run	Lab	Material group	Prep slot	Local order
V17-L1-001	L1	neat	1	8
V17-L1-002	L1	neat	2	9
V17-L1-003	L1	neat	3	12
V17-L1-004	L1	finalist A	1	11
V17-L1-005	L1	finalist A	2	7
V17-L1-006	L1	finalist A	3	4
V17-L1-007	L1	commercial epoxy	1	5
V17-L1-008	L1	commercial epoxy	2	1
V17-L1-009	L1	commercial epoxy	3	6
V17-L1-010	L1	commercial bioepoxy	1	2
V17-L1-011	L1	commercial bioepoxy	2	10
V17-L1-012	L1	commercial bioepoxy	3	3
V17-L2-013	L2	neat	1	4
V17-L2-014	L2	neat	2	2
V17-L2-015	L2	neat	3	8
V17-L2-016	L2	finalist A	1	6
V17-L2-017	L2	finalist A	2	1
V17-L2-018	L2	finalist A	3	9
V17-L2-019	L2	commercial epoxy	1	3
V17-L2-020	L2	commercial epoxy	2	11
V17-L2-021	L2	commercial epoxy	3	12
V17-L2-022	L2	commercial bioepoxy	1	7
V17-L2-023	L2	commercial bioepoxy	2	10
V17-L2-024	L2	commercial bioepoxy	3	5
V17-L3-025	L3	neat	1	11
V17-L3-026	L3	neat	2	8
V17-L3-027	L3	neat	3	9
V17-L3-028	L3	finalist A	1	3
V17-L3-029	L3	finalist A	2	7
V17-L3-030	L3	finalist A	3	4
V17-L3-031	L3	commercial epoxy	1	5
V17-L3-032	L3	commercial epoxy	2	12
V17-L3-033	L3	commercial epoxy	3	1
V17-L3-034	L3	commercial bioepoxy	1	2
V17-L3-035	L3	commercial bioepoxy	2	10
V17-L3-036	L3	commercial bioepoxy	3	6

APPENDIX B

Material specifications and method validation

All 55 inherited requirement IDs and corresponding v23 validation IDs are preserved below. The proposed method and validation route are quoted from the original CSVs. The specification limits, sample plan, units, method revisions, evidence and signatures remain unfilled. Blank limits do not authorize acceptance. Release decisions are lot- and intended-use-specific.

B.1 P01 • Hempseed oil

Requirement / validation ID	Proposed method	Proposed validation route
P01-01 / MV-P01-01	Identity/provenance review	Documentary verification; traceability and independent review
P01-02 / MV-P01-02	Iodine value titration	Quantitative or qualitative method: define measurand and verify fitness for use
P01-03 / MV-P01-03	Acid value titration	Quantitative or qualitative method: define measurand and verify fitness for use
P01-04 / MV-P01-04	Karl Fischer water	Quantitative or qualitative method: define measurand and verify fitness for use

B.2 P02 • Epoxidized hempseed oil

Requirement / validation ID	Proposed method	Proposed validation route
P02-01 / MV-P02-01	Identity/FTIR	Identity/structural assessment; reference patterns, specificity and operator agreement
P02-02 / MV-P02-02	Epoxy equivalent titration	Quantitative or qualitative method: define measurand and verify fitness for use
P02-03 / MV-P02-03	Karl Fischer water	Quantitative or qualitative method: define measurand and verify fitness for use
P02-04 / MV-P02-04	Acid value titration	Quantitative or qualitative method: define measurand and verify fitness for use

Continued on next page

Requirement / validation ID	Proposed method	Proposed validation route
P02-05 / MV-P02-05	Viscometry at specified temperature	Identity/structural assessment; reference patterns, specificity and operator agreement
P02-06 / MV-P02-06	Residual reagent assay	Quantitative or qualitative method: define measurand and verify fitness for use

B.3 P03 • Sebacic acid

Requirement / validation ID	Proposed method	Proposed validation route
P03-01 / MV-P03-01	Identity/CAS review	Documentary verification; traceability and independent review
P03-02 / MV-P03-02	Acid assay	Quantitative or qualitative method: define measurand and verify fitness for use
P03-03 / MV-P03-03	Karl Fischer water	Quantitative or qualitative method: define measurand and verify fitness for use
P03-04 / MV-P03-04	Provenance review	Documentary verification; traceability and independent review

B.4 P04 • Zinc acetylacetonate

Requirement / validation ID	Proposed method	Proposed validation route
P04-01 / MV-P04-01	Identity and chemical form	Identity/structural assessment; reference patterns, specificity and operator agreement
P04-02 / MV-P04-02	Hydration by validated method	Quantitative or qualitative method: define measurand and verify fitness for use
P04-03 / MV-P04-03	Assay	Quantitative or qualitative method: define measurand and verify fitness for use
P04-04 / MV-P04-04	Active loading calculation	Calculation verification; independent reference calculations and unit checks

B.5 P05 • Furfuryl glycidyl ether

Requirement / validation ID	Proposed method	Proposed validation route
P05-01 / MV-P05-01	Identity	Identity/structural assessment; reference patterns, specificity and operator agreement
P05-02 / MV-P05-02	Epoxy equivalent titration	Quantitative or qualitative method: define measurand and verify fitness for use
P05-03 / MV-P05-03	Purity by chromatography	Quantitative or qualitative method: define measurand and verify fitness for use
P05-04 / MV-P05-04	Water	Quantitative or qualitative method: define measurand and verify fitness for use
P05-05 / MV-P05-05	Inhibitor assay	Quantitative or qualitative method: define measurand and verify fitness for use

B.6 P06 • Hemp lignin

Requirement / validation ID	Proposed method	Proposed validation route
P06-01 / MV-P06-01	Provenance	Documentary verification; traceability and independent review
P06-02 / MV-P06-02	OH assay	Quantitative or qualitative method: define measurand and verify fitness for use
P06-03 / MV-P06-03	Ash by gravimetry	Quantitative or qualitative method: define measurand and verify fitness for use
P06-04 / MV-P06-04	Moisture	Quantitative or qualitative method: define measurand and verify fitness for use

B.7 P07 • Epoxidized hemp lignin

Requirement / validation ID	Proposed method	Proposed validation route
P07-01 / MV-P07-01	Parent lot review	Documentary verification; traceability and independent review
P07-02 / MV-P07-02	Epoxy equivalent assay	Quantitative or qualitative method: define measurand and verify fitness for use
P07-03 / MV-P07-03	Residual reagent assay	Quantitative or qualitative method: define measurand and verify fitness for use

B.8 P08 • Hemp biochar

Requirement / validation ID	Proposed method	Proposed validation route
P08-01 / MV-P08-01	Ash	Quantitative or qualitative method: define measurand and verify fitness for use
P08-02 / MV-P08-02	Elemental analysis	Quantitative or qualitative method: define measurand and verify fitness for use
P08-03 / MV-P08-03	Thermal history review	Documentary verification; traceability and independent review

B.9 P09 • Activated hemp biochar

Requirement / validation ID	Proposed method	Proposed validation route
P09-01 / MV-P09-01	BET	Quantitative or qualitative method: define measurand and verify fitness for use
P09-02 / MV-P09-02	Pore distribution	Quantitative or qualitative method: define measurand and verify fitness for use
P09-03 / MV-P09-03	Residual activation reagent assay	Quantitative or qualitative method: define measurand and verify fitness for use
P09-04 / MV-P09-04	Parent lot review	Documentary verification; traceability and independent review

B.10 P10 • Short hemp carbon fiber

Requirement / validation ID	Proposed method	Proposed validation route
P10-01 / MV-P10-01	SEM morphology	Identity/structural assessment; reference patterns, specificity and operator agreement
P10-02 / MV-P10-02	Aspect ratio distribution	Quantitative or qualitative method: define measurand and verify fitness for use
P10-03 / MV-P10-03	Elemental carbon	Quantitative or qualitative method: define measurand and verify fitness for use

B.11 P11 • Porous hemp carbon nanosheets

Requirement / validation ID	Proposed method	Proposed validation route
P11-01 / MV-P11-01	TEM/AFM	Identity/structural assessment; reference patterns, specificity and operator agreement
P11-02 / MV-P11-02	Raman	Identity/structural assessment; reference patterns, specificity and operator agreement
P11-03 / MV-P11-03	XRD	Identity/structural assessment; reference patterns, specificity and operator agreement
P11-04 / MV-P11-04	BET	Quantitative or qualitative method: define measurand and verify fitness for use

B.12 P12 ● Oxidized hemp nanosheets

Requirement / validation ID	Proposed method	Proposed validation route
P12-01 / MV-P12-01	Parent lot review	Documentary verification; traceability and independent review
P12-02 / MV-P12-02	XPS O/C	Quantitative or qualitative method: define measurand and verify fitness for use
P12-03 / MV-P12-03	Residual reagent assay	Quantitative or qualitative method: define measurand and verify fitness for use

B.13 P13 ● Reduced hemp nanosheets

Requirement / validation ID	Proposed method	Proposed validation route
P13-01 / MV-P13-01	Paired parent review	Documentary verification; traceability and independent review
P13-02 / MV-P13-02	XPS O/C	Quantitative or qualitative method: define measurand and verify fitness for use
P13-03 / MV-P13-03	Raman/TEM structure	Identity/structural assessment; reference patterns, specificity and operator agreement

B.14 P14 ● Conventional epoxy system

Requirement / validation ID	Proposed method	Proposed validation route
P14-01 / MV-P14-01	Resin/hardener identity	Identity/structural assessment; reference patterns, specificity and operator agreement
P14-02 / MV-P14-02	Cure schedule review	Documentary verification; traceability and independent review

B.15 P15 • Commercial bioepoxy system

Requirement / validation ID	Proposed method	Proposed validation route
P15-01 / MV-P15-01	TDS/SDS review	Documentary verification; traceability and independent review
P15-02 / MV-P15-02	Biobased content evidence	Documentary verification; traceability and independent review
P15-03 / MV-P15-03	Cure schedule review	Documentary verification; traceability and independent review

B.16 Blank release and verification record

Complete one controlled record for each applicable requirement. No limits are entered in this edition. Preserve the original templates in the attached files. **Lot ID and supplier lot**

Requirement ID and material use

Sample ID and sampling plan

Approved method revision and instrument

Approved acceptance limit and unit

Measured result and expanded uncertainty

Decision rule and raw data URI

Disposition (RELEASED / REJECTED / HOLD)

Reviewer, approval signature and date

APPENDIX C

Red-team register and authorization records

Original v25 findings reproduced below. Closure evidence describes required work, not evidence already obtained. All fifteen findings remain OPEN; seven are Critical and eight High.

C.1 RT-01 — Critical

Risk. EHO functionality distribution and residual acid/water may prevent robust network formation. EEW alone cannot establish functionality.

Required closure evidence. Measure lot chemistry and cure/gel response; establish feasibility before comparative release. **Proposed owner:** Lab PI **Gate:** G03/G05

Source: v11 pp1,3; v24 pp3–4 **Status: OPEN.**

C.2 RT-02 — Critical

Risk. Stress relaxation is not unique to associative exchange; degradation, residual cure and physical relaxation are alternatives.

Required closure evidence. Lock matched aging controls, repeated relaxation, gel retention and conversion; use orthogonal evidence and qualify terminology. **Proposed owner:** Polymer scientist **Gate:** G06/G09

Source: v11 p3; v24 p4 **Status: OPEN.**

C.3 RT-03 — Critical

Risk. Thermal scouting precedes comparative release but requires separate authorization.

Required closure evidence. Approve facility risk assessment and scout-specific limits before reactive work; document excursion and stop criteria. **Proposed owner:** Safety lead **Gate:** G02/G05

Source: v24 pp2–3 **Status: OPEN.**

C.4 RT-04 — Critical

Risk. Three preparations per arm are exploratory; no variance or meaningful effect threshold established.

Required closure evidence. Lock batch-level model and primary endpoint; use scout variance to size fresh confirmation. **Proposed owner:** Statistician **Gate:** G06/G09

Source: v11 p1; v24 p4 **Status: OPEN.**

C.5 RT-05 — Critical

Risk. 10 g EHO basis does not guarantee enough cured material for all tests and destructive controls.

Required closure evidence. Calculate yield, geometry, aliquot and witness needs; amend scale or allocate extra batches before release. **Proposed owner:** Lab PI **Gate:** G07

Source: v24 pp2,4; v19 p2 **Status: OPEN.**

C.6 RT-06 — Critical

Risk. Historical 573 entries overlap unresolved; parent links absent in qualification planning.

Required closure evidence. Reconcile genealogy before procurement or qualification; do not sum registry totals. **Proposed owner:** Data steward **Gate:** G07 / later

Source: v18 pp8,12; v16 CSV **Status: OPEN.**

C.7 RT-07 — Critical

Risk. No funded contract, released lots, approved methods or signed gates.

Required closure evidence. Obtain staged quote and signed scope, assign named accountable staff. **Proposed owner:** Sponsor / PI **Gate:** G01–G08

Source: v24 p2; v19 p2 **Status: OPEN.**

C.8 RT-08 — High

Risk. Commercial hemp epoxy is not interchangeable with EHO; supplier claims are insufficient.

Required closure evidence. Require lot-specific EEW, chemistry, assay and provenance; quote custom precursor if necessary. **Proposed owner:** Quality lead **Gate:** G03

Source: v21 pp1–2 **Status: OPEN.**

C.9 RT-09 — High

Risk. Carbon morphologies differ in surface chemistry and porosity, not just geometry; cure and dispersion may confound outcomes.

Required closure evidence. Characterize each lot; monitor viscosity, conversion, voids and dispersion; retain concurrent controls. **Proposed owner:** Composite lead **Gate:** Later

Source: v14 pp1–2; v18 p7 **Status: OPEN.**

C.10 RT-10 — High

Risk. Weighted single-filler reference is not a mechanistic synergy test.

Required closure evidence. Specify property direction, uncertainty and confirmation; avoid synergy claims without mechanism. **Proposed owner:** Statistician **Gate:** Later

Source: v15; v18 p7 **Status: OPEN.**

C.11 RT-11 — High

Risk. Bioepoxy absent from v16; v17 replication does not fill that gap. Equivalence margin unset.

Required closure evidence. Add separate approved allocation; define comparable cure and conditioning, margin and sample size. **Proposed owner:** Lab PI **Gate:** Later

Source: v18 pp8–9; v17 p3 **Status: OPEN.**

C.12 RT-12 — High

Risk. Scale, cost and carbon claims lack measured process and service-life data.

Required closure evidence. Use yield/energy/mass balance; compare equivalent function and service life; no carbon-negative claims. **Proposed owner:** Process/LCA lead **Gate:** Later

Source: v18 pp10–11; v17 pp4–5 **Status: OPEN.**

C.13 RT-13 — High

Risk. Literature and normative method editions not fully verified.

Required closure evidence. Check primary texts and applicability before publication or method approval. **Proposed owner:** Reviewer **Gate:** G04

Source: v18 pp3,12; v23 **Status: OPEN.**

C.14 RT-14 — High

Risk. Novelty, ownership and freedom to operate not established.

Required closure evidence. Separate prior art review from patent counsel and signed rights terms. **Proposed owner:** Sponsor **Gate:** G01

Source: v18 p12; v19 **Status: OPEN.**

C.15 RT-15 — High

Risk. No application-specific threshold or customer requirements.

Required closure evidence. Select a non-safety-critical first use after data; define benchmark and acceptance criteria. **Proposed owner:** Application owner **Gate:** Later

Source: v18 p10 **Status: OPEN.**

C.16 Gate register and decision record

Gate / owner	Decision	Evidence
G01 / Funder / PI	Funding and contract	Signed scope, budget, payment and data terms
G02 / Lab safety officer	Laboratory and safety	Approved hazard assessment, containment, waste and emergency plan
G03 / Quality lead	Incoming materials	Released EHO, acid and catalyst lots; measured EEW and assay
G04 / Metrology lead	Method readiness	Approved methods, calibration, controls and uncertainty
G05 / Lab PI	Thermal scouting	Approved scale and cure window; scouting report
G06 / PI / statistician	Preregistration	Locked endpoints, thresholds, exclusions and analysis
G07 / Lab PI	Specimen allocation	Yield-based specimen plan, controls, custody and native data paths
G08 / PI and safety lead	Comparative campaign release	All preceding gates approved; signed release
G09 / Independent reviewer	Post-campaign review	Complete data, deviations, analysis and confirmatory plan

All nine original gates remain HOLD. Approver, approval date and evidence URI fields are unfilled. Source: v24 readiness register. Use one signed record per gate. G01–G07 and signed G08 precede comparative runs; G09 is post-campaign. Scout-specific safety authorization precedes any reactive scouting. **Gate ID, scope and programme revision**

Evidence URI(s), method and registry revisions

Open deviations and residual risks

Decision and conditions of authorization

Named authority, signature and date

Expiry/reassessment triggers

APPENDIX D

Procurement, funding and collaboration registers

D.1 Nineteen-line Phase I request for quotation

The original v19 planning quantities and units are reproduced here. All supplier, quote, unit-price and extended-cost fields remain blank; all rows are UNQUOTED. Use the attached RFQ CSV to solicit comparable actual bids. The CAD 25,000 budget in the main chapter is illustrative, not a committed amount or total of these blank prices.

Category	Service or material	Planning quantity	Unit
Qualification	Oil lot characterization	3	lot
Qualification	EHO EEW and incoming assays	—	lot
Qualification	Acid and catalyst qualification	—	lot
Procurement	EHO nominal screening requirement	270	g
Procurement	Sebacic acid	—	g
Procurement	Catalyst nominal screening requirement	6.3	g
Safety	Hazard review and SOP approval	1	service
Scouting	Thermal scouting and controls	—	batch
Screening	Independent preparations	27	batch
Testing	Specimen preparation	—	unit
Testing	DSC	—	test
Testing	FTIR	—	test
Testing	Gel fraction	—	test
Testing	DMA and relaxation	—	test
Testing	Thermal/degradation witnesses	—	test
Reporting	Native data and scientific report	1	service
Other	Shipping, waste, storage	—	service
Optional	WP02 EHO synthesis	—	service
Optional	Fresh confirmation batches	—	batch

D.2 Controlled sourcing register

These routes and acceptance evidence are from v21. Catalogue entries and research precedents do not establish availability or material release. All 15 sourcing rows remain HOLD; all quote and lot fields remain blank. Phase II–IV items are not part of the initial comparative campaign.

ID / phase	Material / route	Planning quantity	Required evidence
P01 / I	Hempseed oil; Buy or lab source	3 lots; quantity TBD	Identity, iodine value, acid value, water, origin

Continued on next page

ID / phase	Material / route	Planning quantity	Required evidence
P02 / I	Epoxidized hempseed oil; Custom synthesis or qualified purchase	270 g net; reserve TBD	EEW, water, acid value, viscosity, residual reagents
P03 / I	Sebacic acid; Fisher / TCI or Sigma	500 g pack candidate	CAS 111-20-6; assay, water, provenance
P04 / I	Zinc acetylacetonate; Lab chemical supplier RFQ	6.3 g nominal; reserve TBD	Identity, hydration, assay, active loading
P05 / II	Furfuryl glycidyl ether; Specialty chemical RFQ	TBD	EEW, purity, water, inhibitors
P06 / II	Hemp lignin; Custom isolation or supplier RFQ	TBD	Hemp provenance, OH content, ash, moisture
P07 / II	Epoxidized hemp lignin; Custom functionalization	TBD	EEW, residual reagents, parent lot
P08 / III	Hemp biochar; Buy or custom pyrolysis	TBD	Ash, elemental analysis, thermal history
P09 / III	Activated hemp biochar; Custom activation or purchase	TBD	BET, pores, residues, parent lot
P10 / III	Short hemp carbon fiber; Custom carbonization	TBD	SEM, aspect ratio, carbon content
P11 / III	Porous hemp carbon nanosheets; Academic sample or custom synthesis	TBD	TEM/AFM, Raman, XRD, BET
P12 / III	Oxidized hemp nanosheets; Custom functionalization	TBD	Parent lot, XPS O/C, residues
P13 / III	Reduced hemp nanosheets; Custom functionalization	TBD	Paired parent, XPS, structure
P14 / IV	Conventional epoxy system; Commercial benchmark RFQ	TBD	Resin/hardener identity and cure schedule
P15 / IV	Commercial bioepoxy system; ZILA inquiry or alternative	TBD	TDS, SDS, biobased content, cure schedule

D.3 Prospective collaboration register

The following source-derived leads were not contacted in v20. Any current contact, availability, affiliation, eligibility, sample or partner commitment requires independent confirmation.

Organization	Potential role / next action	Inherited verification
CDCQ	Composite development and testing; Phase I lead RFQ; confirm reactive chemistry and DMA	Verified public capability
RPC New Brunswick	Analytical chemistry; EEW, oil assays, FTIR; confirm custom validation	Verified public capability
UNB Nanocomposites and Mechanics Lab	Academic composite research; Seek PI review and later reinforcement collaboration	Verified public capability
NRC Boucherville	Polymer and composite processing; Later scale-up and testing inquiry	Verified public capability

Continued on next page

Organization	Potential role / next action	Inherited verification
ZILA BioWorks	Candidate commercial hemp epoxy; Request sample, SDS, CoA, EEW, availability and price; do not assume vitrimer	Unverified lead; confirm URL and product
David Mitlin / coauthors	Carbon nanosheet scientific review; Seek morphology advice and sample sourcing referral	Verified publication; current affiliation not checked
NRC IRAP	Funding and advisory; Check incorporation and commercial eligibility before applying	Verified general criteria
Mitacs Accelerate	Academic partnership funding; Ask academic partner to verify eligibility and contribution	Unverified programme lead
ACOA	Atlantic business development; Request eligibility screening; no award assumed	Unverified programme lead

D.4 Template inquiry for Phase I

Subject: HEMPOXIES Phase I — Feasibility assessment and staged quotation Dear Research Services Team, The HEMPOXIES research platform seeks a qualified laboratory to investigate whether a hempseed-oil-derived epoxy–acid network can be prepared reproducibly while maintaining chemical and thermal integrity. We request a staged, itemized feasibility proposal for incoming material qualification, approved thermal scouting and the original 27 independent neat-network preparations, with matched controls and appropriate chemical, rheological and thermal measurements. The comparative campaign remains HOLD until laboratory readiness and signed approval. Please quote native instrument data, batch and specimen genealogy, method versions, deviations, scientific review, retained material, shipping and waste, including separately priced custom precursor synthesis and fresh confirmation if needed. Please identify your capabilities, staff roles, scope exclusions, lead-time assumptions, data and IP terms and payment milestones. The platform is at the proposal stage; no experimental material performance or funding commitment is represented as established. Marie-Soleil Seshat Landry

HEMPOXIES Research Platform

ORCID 0009-0008-5027-3337

APPENDIX E

Source and bibliography audit

The literature register below preserves the 22 original reference identities and inherited v10 evidence classifications. Legacy entry 20 has an explicitly superseded DOI, preserved in the original attached CSV. An inherited classification describes what the historical source recorded, not a new independent verification in this edition. The main text cites internal revisions by name and section. Mandatory methods and current editions, all inherited literature metadata, full text and claims require final technical verification before normative use. **[1]** Montarnal D et al. (2011). Silica-like malleable materials from permanent organic networks. Science 334, 965–968.

10.1126/science.1212648; Secondary metadata corroboration.

[2] Capelot M et al. (2012). Metal-catalyzed transesterification for healing and assembling of thermosets. JACS 134, 7664–7667.

10.1021/ja302894k; Secondary metadata corroboration.

[3] Denissen W, Winne JM, Du Prez FE (2016). Vitrimers: permanent organic networks with glass-like fluidity. Chemical Science 7, 30–38.

10.1039/C5SC02223A; Direct source checked.

[4] Chong KL et al. (2022). A review on recent approaches to sustainable bio-based epoxy vitrimer from epoxidized vegetable oils. Industrial Crops and Products.

10.1016/j.indcrop.2022.115857; Inherited; recheck required.

[5] Lee CL et al. (2025). A review on the formulation and performance of epoxidized vegetable oil-based vitrimer. Royal Society Open Science 12, 250612.

10.1098/rsos.250612; Inherited; recheck required.

[6] Shuttleworth PS et al. (2017). Flexible bionanocomposites from epoxidized hemp seed oil thermosetting resin reinforced with halloysite nanotubes. J Phys Chem B 121, 2454–2467.

10.1021/acs.jpcb.7b00103; Publisher abstract and PubMed metadata checked.

[7] Effect of degumming and bleaching on the yield and quality of epoxidized hempseed oil (2025). ChemEngineering 9, 104.

10.3390/chemengineering9050104; Direct source checked.

[8] Wang H et al. (2013). Interconnected carbon nanosheets derived from hemp for ultrafast supercapacitors with high energy. ACS Nano 7, 5131–5141.

10.1021/nn400731g; Inherited; recheck required.

[9] Tailoring biomass-derived carbon nanoarchitectures for high-performance supercapacitors (2013). ChemElectroChem.

10.1002/celc.201300127; Inherited; recheck required.

[10] Callaway JC (2004). Hempseed as a nutritional resource: an overview. Euphytica 140, 65–72.

10.1007/s10681-004-4811-6; Inherited; recheck required.

[11] Kim S, Hwang HS (2024). Understanding the oxidation of hemp seed oil and improving its stability by encapsulation into protein microcapsules. J Food Sci 89, 6321–6334.

10.1111/1750-3841.17314; Inherited; recheck required.

[12] Industrial hemp response to nitrogen, phosphorus, and potassium fertilization (2015). Crop, Forage & Turfgrass Management.

10.2134/cftm2015.0159; Inherited; recheck required.

[13] Tang K et al. (2017). A comprehensive study of planting density and nitrogen fertilization effect on dual-purpose hemp cultivation. Industrial Crops and Products, 427–438.

10.1016/j.indcrop.2017.06.033; Inherited; recheck required.

[14] Yang Y et al. (2021). Effect of nitrogen supply on growth and nitrogen utilization in hemp. Agronomy 11, 2310.

10.3390/agronomy11112310; Inherited; recheck required.

[15] Kaur N et al. (2024). Nitrogen application and cultivar effects on industrial hemp yield dynamics. Agronomy Journal 116, 727–736.

10.1002/agj2.21537; Inherited; recheck required.

[16] Halpin JC, Kardos JL (1976). The Halpin–Tsai equations: a review. Polymer Engineering & Science 16, 344–352.

10.1002/pen.760160512; Inherited; recheck required.

[17] Habibi Y, Lucia LA, Rojas OJ (2010). Cellulose nanocrystals: chemistry, self-assembly, and applications. Chemical Reviews 110, 3479–3500.

10.1021/cr900339w; Direct source checked.

[18] Zhang Y, Enomoto Y, Iwata T (2023). Bio-based vitrimers from divanillic acid and epoxidized soybean oil. RSC Sustainability 1, 543–553.

10.1039/D2SU00140C; Inherited; recheck required.

[19] ASTM D638-22. Standard test method for tensile properties of plastics.

10.1520/D0638-22; Inherited; recheck required.

[20] ASTM D6866-10. Radiocarbon analysis of biobased content (historical edition; consult current edition).

10.1520/D6866-24A; Current ASTM catalogue checked; normative text not reviewed; supersedes historical DOI.

[21] Biobased vitrimeric epoxy networks (2024). Macromolecular Materials and Engineering 309, 2300371.

10.1002/mame.202300371; Inherited; recheck required.

[22] Research progress on bio-based epoxy vitrimers: a review (2026). Journal of Applied Polymer Science 143, e71187.

10.1002/app.71187; Publisher review table checked.

E.1 Additional methodological reference families

The following are candidate resources for the laboratory and reviewers. Standard numbers and resource names identify a family or a publication; verify current editions and

the applicable clauses rather than claiming compliance. **Metrology and conformity.** ISO/IEC 17025; ISO 5725 series; JCGM 100 (GUM); JCGM 101 (Monte Carlo); JCGM 106 (conformity); Eurachem Fitness for Purpose of Analytical Methods and Quantifying Uncertainty in Analytical Measurement. **Chemical and carbon analysis.** ASTM D1652 / ISO 3001 (epoxy equivalents); ISO 660 (acid value); ISO 3961 (iodine value); ISO 8534 (water); ISO 9277 (BET); ISO/TS 21356-1 (graphene-related structural characterization); ISO 15472 (XPS energy calibration). **Thermal and rheological analysis.** ISO 11357 (DSC); ISO 11358 (TGA); ISO 6721 (dynamic mechanical properties); ISO 11359 (TMA); ISO 3219 (rheometry). **Mechanical and physical qualification.** ASTM D638, D695, D790, D256, D5045, D7791, D2990, D570, G154/G155 and D792; related ISO 527, 604, 178, 179, 13586, 899, 62, 4892 and 1183 series. Method scope, specimens and validity remain unresolved. **Environmental assessment.** ISO 14040, ISO 14044, ISO 14067; ASTM D6866 (use the v10 active DOI as inherited, verify current edition); IPCC 2019 Refinement and AR6 background; full lifecycle inventory needed. **Research integrity and reporting.** Canadian Tri-Agency Framework on Responsible Conduct of Research; Wilkinson et al., FAIR Guiding Principles (DOI 10.1038/sdata.2016.18); National Academies, Reproducibility and Replicability in Science (2019); CRediT contributor taxonomy; COPE guidance. **Statistical design and inference.** Montgomery, Design and Analysis of Experiments; Box, Hunter and Hunter, Statistics for Experimenters; Scheffé mixture designs; Dunnett multiple comparisons; equivalence testing (TOST). These are methodological leads, not exhaustive bibliography verification. **Prior art and rights.** US20140328006A1; US10170251B2; Canadian Intellectual Property Office; WIPO PATENTSCOPE. Patent claim scope, family, status, ownership and freedom to operate are unassessed.

E.2 Verification of the controlling source snapshot

The current original files were compared byte-for-byte by computing SHA-256 and checking the v25 design freeze manifest. All 15 listed source files match the recorded values. The v11 and v24 27-row designs agree on six controlling fields (batch ID, block, order, acid/epoxy ratio, catalyst PHR, nominal EHO mass). All source counts and statuses in the baseline were recomputed from the attached CSVs. Hash agreement establishes file identity, not authorization or validity of the scientific claims.

Hempoxies_First_Laboratory_Campaign_v11.pdf

`a3b5b07a30e46e4ca910f7a7e35a63d0e214611528b2d6527fc17be7d0a290bc`

Match; review snapshot only.

Hempoxies_Pilot_Batches_v11.csv

`46e74938746232e6a488537fef8bb99626b35eb437ba85a3c2d7f380f131d626`

Match; review snapshot only.

Hempoxies_Master_Dossier_v18.pdf

`857e2627722d142bc5921df74565e4e80cd93595d03a6c2d770f2806103b00a9`

Match; review snapshot only.

Hempoxies_Campaign_Index_v18.csv

`e9ffed88985be03e2162969c013d92527a87655ebb75b6d3b03da921c80b682d`

Match; review snapshot only.

Hempoxies_Qualification_Registry_v16.csv

`cf800f91ca9721fe058c807bcfad2b916240ffbaeec8d97a84fbde523c612f2e`

Match; review snapshot only.

Hempoxies_Execution_Funding_v19.pdf

`1b4e67f6ea11fdbdee9cc58a87894051fa4e5b6f2ce5cfc104de7081e4c789d6`

Match; review snapshot only.

Hempoxies_Procurement_Strategy_v21.pdf

`b3757027dff84ebe1523234fb58aba38531713e0f0016dc9936412c066a30429`

Match; review snapshot only.

Hempoxies_Method_Validation_v23.pdf

`424f9ae3de122752bdef2dd0c726d5e32179ebd5b552869366d2a7127bebed8d`

Match; review snapshot only.

Hempoxies_Controlled_Execution_v24.pdf

`1936dff0b4d076d6117dacb70c1d710e5c9990fe51ced407da4a0c5be8f8f2b5`

Match; review snapshot only.

Hempoxies_Readiness_Gates_v24.csv

`b7675b53cb286841c60bc211f1dc2dadaf81a846cb82513b55cf75343273a40a`

Match; review snapshot only.

Hempoxies_Batch_Record_v24.csv

`0780a7d30d4cefb1863ac9cfc35842fb0e50bd98a97dfd62ec9ce021acd4daea`

Match; review snapshot only.

Hempoxies_Carbon_Campaign_v14.pdf

`08d2f6e5a2aaa7a8bd347cf15ecc9482d104a9b1a62cf4dcf8a23ef0498f3c08`

Match; review snapshot only.

Hempoxies_Hybrid_Campaign_v15.pdf

`51173102ae9e1fe997b14bfa6384998e0a0ead5025af44474aff11f97c0571d7`

Match; review snapshot only.

Hempoxies_Replication_Campaign_v17.pdf

`bd4e750b7131f303c4f31378acd25c9172e707c5ce7ee65d1118faa84aca4397`

Match; review snapshot only.

Hempoxies_Method_Validation_Register_v23.csv

`a65349576c61b567aaacf3d432b62add4de444fc2bcc7e571501562d78538047`

Match; review snapshot only.

APPENDIX F

Master SOP crosswalk and commissioning forms

The following 124 proposed master procedure frameworks consolidate the v30 governance concept. They supplement, rather than supersede, the original campaign documents. Every row is DRAFT/HOLD. No chemical operating parameters, validated method revisions, acceptance limits or approvals are implied by these identifiers. The laboratory must assign applicable normative methods and approved local procedures.

F.1 Governance

Master ID	Procedure framework	Principal deliverable
M-GOV-01	Document control	Controlled revision history
M-GOV-02	Change management	Approved amendment
M-GOV-03	Gate authorization	Signed gate record
M-GOV-04	Risk management	Updated risk register
M-GOV-05	Personnel competence	Training and role records
M-GOV-06	Independent review	Reviewed evidence package

F.2 Safety

Master ID	Procedure framework	Principal deliverable
M-SAF-01	Hazard assessment	Approved risk assessment
M-SAF-02	Chemical storage	Compatibility and inventory record
M-SAF-03	Thermal scouting authorization	Approved scouting limits
M-SAF-04	Exposure and particulate control	Facility-approved controls
M-SAF-05	Emergency response	Approved emergency plan
M-SAF-06	Waste management	Traceable disposal pathway
M-SAF-07	Incident investigation	Corrective-action record
M-SAF-08	Stop-work and restart	Signed restart authorization

F.3 Procurement

Master ID	Procedure framework	Principal deliverable
M-PRO-01	Supplier qualification	Supplier assessment
M-PRO-02	RFQ management	Comparable quotations
M-PRO-03	Purchase approval	Authorized transaction
M-PRO-04	Incoming inspection	Receipt record

Continued on next page

Master ID	Procedure framework	Principal deliverable
M-PRO-05	Quarantine	Segregated material status
M-PRO-06	Sampling and retention	Traceable aliquots
M-PRO-07	Material disposition	Released, rejected or held lot

F.4 Precursor chemistry

Master ID	Procedure framework	Principal deliverable
M-CHEM-01	Hempseed oil qualification	P01 evidence
M-CHEM-02	Oil epoxidation development	Separately authorized synthesis evidence
M-CHEM-03	EHO qualification	P02 evidence
M-CHEM-04	Acid qualification	P03 evidence
M-CHEM-05	Catalyst qualification	P04 evidence
M-CHEM-06	FGE qualification	P05 evidence
M-CHEM-07	Hemp lignin qualification	P06 evidence
M-CHEM-08	Lignin functionalization	Controlled parent-to-product record
M-CHEM-09	Functionalized lignin qualification	P07 evidence

F.5 Carbon morphology

Master ID	Procedure framework	Principal deliverable
M-CARB-01	Biomass precursor qualification	Released feedstock
M-CARB-02	Biochar process development	Controlled material and yield record
M-CARB-03	Activated biochar development	Qualified activation product
M-CARB-04	Short carbon fiber development	Qualified morphology
M-CARB-05	Porous nanosheet development	Qualified nanosheet candidate
M-CARB-06	Nanosheet oxidation development	Traceable oxidized material
M-CARB-07	Nanosheet reduction development	Traceable reduced material
M-CARB-08	Carbon-material lot qualification	P08–P13 evidence

F.6 Formulation

Master ID	Procedure framework	Principal deliverable
M-FORM-01	Stoichiometric calculation	Reviewed formulation worksheet
M-FORM-02	Neat-network preparation	WP05 preparation record
M-FORM-03	Reactive diluent integration	WP06 preparation record
M-FORM-04	Lignin integration	WP05L preparation record

Continued on next page

Master ID	Procedure framework	Principal deliverable
M-FORM-05	Individual filler integration	WP07 preparation record
M-FORM-06	Hybrid filler integration	WP08 preparation record
M-FORM-07	Dispersion evaluation	Reviewed dispersion evidence
M-FORM-08	Cure control	Actual thermal and process history
M-FORM-09	Cured material disposition	Yield and validity record

F.7 Specimen management

Master ID	Procedure framework	Principal deliverable
M-SPEC-01	Mass allocation	Yield-based plan
M-SPEC-02	Specimen production	Traceable specimens
M-SPEC-03	Dimension measurement	Verified geometry
M-SPEC-04	Conditioning	Documented conditioning history
M-SPEC-05	Retained witnesses	Controlled witness inventory
M-SPEC-06	Destructive-test allocation	Specimen-use ledger
M-SPEC-07	Sample custody	Complete genealogy

F.8 Chemical and structural characterization

Master ID	Procedure framework	Principal deliverable
M-ANA-01	Epoxy equivalent measurement	Lot-specific EEW
M-ANA-02	Acid value and acid assay	Effective acid data
M-ANA-03	Water determination	Moisture result
M-ANA-04	FTIR	Chemical characterization
M-ANA-05	Raman spectroscopy	Structural spectral evidence
M-ANA-06	XPS	Surface chemistry
M-ANA-07	XRD	Structural diffraction evidence
M-ANA-08	SEM	Morphological evidence
M-ANA-09	TEM	High-resolution morphology
M-ANA-10	AFM	Surface and thickness information
M-ANA-11	BET and pore analysis	Accessible surface and porosity
M-ANA-12	Elemental analysis	Elemental composition
M-ANA-13	Residual reagent analysis	Residual chemistry
M-ANA-14	Radiocarbon analysis	Carbon-origin evidence

F.9 Thermal and rheological characterization

Master ID	Procedure framework	Principal deliverable
M-THERM-01	DSC	Thermal transitions and cure information
M-THERM-02	TGA	Mass-loss and thermal stability
M-THERM-03	DMA	Viscoelastic properties
M-THERM-04	Rheology	Flow and deformation behavior
M-THERM-05	Stress relaxation	Controlled relaxation response
M-THERM-06	Creep	Time-dependent deformation
M-THERM-07	Gel fraction	Operational insoluble fraction

F.10 Mechanical and physical characterization

Master ID	Procedure framework	Principal deliverable
M-MECH-01	Tensile testing	Strength, modulus and strain
M-MECH-02	Flexural testing	Flexural response
M-MECH-03	Compression testing	Compressive response
M-MECH-04	Fracture testing	Applicable fracture parameter
M-MECH-05	Impact testing	Defined impact performance
M-MECH-06	Fatigue testing	Cyclic performance
M-MECH-07	Density measurement	Material density
M-MECH-08	Void and porosity assessment	Relevant defect measurements
M-MECH-09	Electrical characterization	Conductivity or resistivity

F.11 Durability and recovery

Master ID	Procedure framework	Principal deliverable
M-DUR-01	Moisture exposure	Property-retention evidence
M-DUR-02	Thermal aging	Aging response
M-DUR-03	Ultraviolet exposure	Weathering response
M-DUR-04	Chemical exposure	Compatibility evidence
M-DUR-05	Repair evaluation	Functional recovery
M-DUR-06	Reprocessing	Recovery and quality yield
M-DUR-07	Repeated-cycle testing	Cumulative degradation record
M-DUR-08	Failure analysis	Mechanism assessment

F.12 Statistics and metrology

Master ID	Procedure framework	Principal deliverable
M-STAT-01	Experimental preregistration	Frozen analysis plan
M-STAT-02	Randomization	Controlled treatment schedule

Continued on next page

Master ID	Procedure framework	Principal deliverable
M-STAT-03	Blinding	Controlled identification key
M-STAT-04	Method validation	Approved validation report
M-STAT-05	Uncertainty evaluation	Measurement uncertainty budget
M-STAT-06	Factorial analysis	Batch-level statistical results
M-STAT-07	Multiple comparisons	Controlled inference
M-STAT-08	Confirmation design	Justified independent sample size
M-STAT-09	Interlaboratory comparison	Transfer and equivalence evidence
M-STAT-10	Missing-data and deviation review	Transparent validity assessment

F.13 Environmental assessment

Master ID	Procedure framework	Principal deliverable
M-ENV-01	Life-cycle scope definition	Approved functional unit
M-ENV-02	Agricultural inventory	Traceable upstream data
M-ENV-03	Mass and carbon balances	Reconciled physical inventory
M-ENV-04	Energy and water inventory	Resource-use measurements
M-ENV-05	Coproduct allocation	Approved allocation method
M-ENV-06	Climate assessment	Reviewed climate-impact model
M-ENV-07	End-of-life assessment	Recovery and disposal scenarios
M-ENV-08	Environmental uncertainty	Probabilistic assessment

F.14 Economics

Master ID	Procedure framework	Principal deliverable
M-ECON-01	Capital estimation	Documented capital scenarios
M-ECON-02	Operating cost estimation	Traceable operating inventory
M-ECON-03	Industrial capacity assessment	Capacity and yield model
M-ECON-04	Discounted cash flow	Financial scenarios
M-ECON-05	Integrated LCA–TEA review	Reconciled assessment

F.15 Data management

Master ID	Procedure framework	Principal deliverable
M-DATA-01	Native data preservation	Protected original files
M-DATA-02	File integrity verification	Hash manifest
M-DATA-03	Registry validation	Reconciled identifiers
M-DATA-04	Backup and restoration	Tested recovery arrangements
M-DATA-05	Analysis reproducibility	Versioned scripts and results

F.16 Publication and rights

Master ID	Procedure framework	Principal deliverable
M-PUB-01	Reference verification	Audited bibliography
M-PUB-02	Intellectual-property review	Documented rights assessment
M-PUB-03	Scientific reporting	Evidence-linked publication
M-PUB-04	Correction and withdrawal	Controlled publication history

F.17 SOP and method authorization template

Before executing a procedure, the responsible laboratory shall convert a framework into a controlled method: purpose, intended use, matrix, method revision, personnel, hazards, equipment, release conditions, actual operating procedure, QC and calibration, acceptance decision, uncertainty, deviations, sample genealogy, data requirements and signatures. The following fields must be completed by the assigned laboratory. **Method/SOP ID, revision and scope**

Applicable normative document and verified applicability

Required competence, facility and hazard assessment

Material lots, apparatus and calibration

Approved operating bounds and controls

Acceptance criteria, measurement uncertainty and stop limits

Records and native data location

Reviewers, approver, signature and date

F.18 Phase I readiness checklist

Contract and safety

- ☐ G01 signed scope, funding and data/IP terms
- ☐ G02 hazard assessment, training, containment, waste and emergency plan
- ☐ Separate scout authorization before reactive work

Material and method readiness

☐ G03 released EHO, acid and catalyst lots; measured EEW, assay and hydrate/chemical form

☐ G04 approved methods and applicable normative documents; controls, calibration and uncertainty

☐ G05 thermal scouting report and approved safe scale/cure window

Design and specimen release

☐ G06 frozen endpoints, meaningful effect, constraints, validity and analysis plan

☐ Original v11/v24 registry and treatment order verified

☐ G07 measured or justified yield-based mass allocation, controls and specimen genealogy

☐ Applicable pre-release critical-risk evidence reviewed

☐ G08 signed comparative release by PI and safety lead

Independent review

☐ Complete batch and native instrument data, controls and deviations preserved

☐ Reproducible analysis and limitations documented

☐ G09 independent disposition and fresh confirmation plan

F.19 Preregistration and release worksheet

Primary normalized-stress endpoint: temperature, time and strain

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Minimum meaningful effect and statistical model

Gel, conversion, residual-cure and thermal stability criteria

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Matched thermal witnesses and other controls

Specimen count, geometry, parent genealogy and mass budget

Missingness, multiplicity and exclusion rules

Confirmation sample-size rationale

PI / safety / statistician sign-off, dates and registry hash

F.20 Post-campaign deliverables and independent review

Require all original native measurements, calibrated metadata, approved method revisions, complete preparation and specimen lineage, material certificates and release decisions, mass/yield records, protocol deviations and failed observations, reproducible analysis scripts, effect estimates and uncertainty, mechanistic limitations, raw file integrity manifest, retained specimens, and a signed decision. A negative or inconclusive outcome is acceptable. No automatic downstream release.

APPENDIX G

Qualification allocation and embedded records

G.1 Qualification registry counts

The 3,750 rows in the original v16 qualification CSV are preserved byte-for-byte as an embedded attachment. All specimen IDs are distinct; all parent batch and source-entry fields are unassigned and all result fields blank. The historical v8 registry and instrument worksheets are retained separately as traceability aids, not new allocation counts. The following summaries are calculated directly from the v16 CSV.

Material description (source)	Allocated units
catalyst free	36
commercial epoxy	387
finalist A	1077
finalist B	777
finalist C	396
neat	1077

Test label (source)	Allocated units
DMA	30
DSC	432
TGA	30
TMA	30
compression	75
creep	180
electrical conductivity	30
fatigue	135
flexure	75
fracture	75
gel fraction	168
impact	75
recovery mass balance	120
relaxation	120
tensile	2085
thermal conductivity	30
thermal witness	60

G.2 Package-by-material allocation

Zeros in this cross-tabulation indicate absent allocations, not measurements. The actual original IDs and individual conditions remain in the attached registry.

WP	Neat	Commercial epoxy	Catalyst free	Finalist A	Finalist B	Finalist C	Total
09	75	75	0	75	75	75	375
09F	27	27	0	27	27	27	135
10	36	36	0	36	36	36	180
11	36	0	36	36	36	36	180
11C	36	36	0	36	36	36	180
12	300	0	0	300	0	0	600
12R	81	81	0	81	81	81	405
13	108	108	0	108	108	0	432
13R	24	24	0	24	24	24	120
13W	81	0	0	81	81	81	324
14	273	0	0	273	273	0	819

G.3 First and last registry identifiers by package

Identifier extrema are locator aids only; not every integer between the extremes belongs to a given work package. The attached file is authoritative.

Package	First ID (sorted)	Last ID (sorted)	Count
09	V5-S00001	V5-S00543	375
09F	V6-S00001	V6-S00135	135
10	V5-S00026	V5-S00555	180
11	V5-S00556	V5-S00735	180
11C	V6-S00136	V6-S00315	180
12	V5-S00736	V5-S01335	600
12R	V6-S00316	V6-S00720	405
13	V5-S01336	V5-S01767	432
13R	V6-S01045	V6-S01164	120
13W	V6-S00721	V6-S01044	324
14	V5-S01768	V5-S02586	819

G.4 Embedded archive and retrieval

This consolidated PDF includes 48 embedded source files and a SHA-256 manifest. Open the PDF with an attachment-capable viewer to extract the individual PDF and CSV records. This edition prints all 222 preparation assignments, the 55 quality requirements, nine gates, 15 risk findings, and the 124 master procedure frameworks. The complete 3,750-row qualification register and full original source documents are embedded rather than reprinted. Attachments remain original snapshots except for the explicitly labeled v31 supplementary SOP register and generated manifest. Historical settings may be superseded and must not be treated as approved instructions.

Original programme PDFs

Hempoxies_Master_Programme_v9.pdf

Hempoxies_Controlled_Baseline_v10.pdf

Hempoxies_First_Laboratory_Campaign_v11.pdf

Hempoxies_FGE_Campaign_v12.pdf
Hempoxies_Lignin_Campaign_v13.pdf
Hempoxies_Carbon_Campaign_v14.pdf
Hempoxies_Hybrid_Campaign_v15.pdf
Hempoxies_Qualification_Campaign_v16.pdf
Hempoxies_Replication_Campaign_v17.pdf
Hempoxies_Master_Dossier_v18.pdf
Hempoxies_Execution_Funding_v19.pdf
Hempoxies_Partnership_Strategy_v20.pdf
Hempoxies_Procurement_Strategy_v21.pdf
Hempoxies_Quality_Assurance_v22.pdf
Hempoxies_Method_Validation_v23.pdf
Hempoxies_Controlled_Execution_v24.pdf
Hempoxies_Scientific_Red_Team_v25.pdf
Hempoxies_Master_Programme_v7.pdf
Hempoxies_Fact_Checked_Research_Proposal.pdf

Original machine-readable registers

Hempoxies_Pilot_Batches_v11.csv
Hempoxies_FGE_Batches_v12.csv
Hempoxies_Lignin_Batches_v13.csv
Hempoxies_Carbon_Batches_v14.csv
Hempoxies_Hybrid_Batches_v15.csv
Hempoxies_Qualification_Registry_v16.csv
Hempoxies_Replication_Registry_v17.csv
Hempoxies_Campaign_Index_v18.csv
Hempoxies_Phase_I_RFQ_Budget_v19.csv
Hempoxies_Partner_Register_v20.csv
Hempoxies_Procurement_Register_v21.csv
Hempoxies_Material_Specifications_v22.csv
Hempoxies_Lot_Release_Template_v22.csv
Hempoxies_Nonconformance_Template_v22.csv
Hempoxies_Method_Validation_Register_v23.csv
Hempoxies_Validation_Observation_Template_v23.csv
Hempoxies_Readiness_Gates_v24.csv
Hempoxies_Batch_Record_v24.csv
Hempoxies_Red_Team_Register_v25.csv
Hempoxies_Design_Freeze_Manifest_v25.csv
Hempoxies_Evidence_Register_v10.csv
Hempoxies_Run_Registry_v8.csv
Hempoxies_Specimen_Registry_v8.csv
Hempoxies_Instrument_Worksheet_v9.csv
Hempoxies_Mass_Budget_v6.csv

Hempoxies_LCA_TEA_Inventory_v7.csv
Hempoxies_Specimen_Allocation_v5.csv
Hempoxies_Specimen_Allocation_v6.csv

Supplementary v31 records

HEMPOXIES_Master_SOP_Register_v31.csv
attachment_manifest.csv

End of controlled research proposal. Documentary consolidation only; physical execution remains HOLD.