

| DOCUMENT CONTROL & CORPORATE IDENTIFIERS |                                              |                   |                                       |  |
|------------------------------------------|----------------------------------------------|-------------------|---------------------------------------|--|
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Executive Governance & Sign-Off Matrix

| Governance Role            | Designated Name / Title     | Corporate Entity        | Status      | Date     |
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# 1. Executive Summary & Corporate Architecture

## 1.1 Strategic Mission & Corporate Positioning

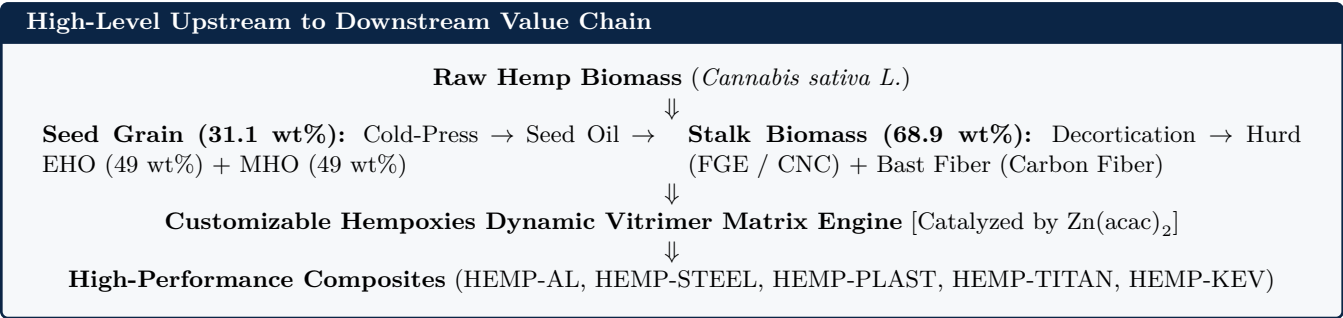
The Hempoxies Division of Landry Industries ([landryindustries.ca](http://landryindustries.ca)) commercializes a > 99% bio-based dynamic covalent vitrimer composite platform derived exclusively from *Cannabis sativa L.* monoculture biomass. The corporate mission is to advance this biomaterial platform from Technology Readiness Level (TRL) 1–2 (analytical proof-of-concept) to TRL 10 (multi-site continuous biorefining and global export) within a 36-to-60 month time-frame.

By displacing petroleum-derived diglycidyl ether of bisphenol A (DGEBA) matrices, non-recyclable fiberglass, and structural engineering metals (Aluminum 6061-T6, Titanium Ti-6Al-4V, Structural Steel), Hempoxies eliminates toxic chemical precursors (e.g., bisphenol A, epichlorohydrin, aromatic amines), solves end-of-life composite disposal, and lowers industrial Scope 1, 2, and 3 carbon compliance costs.

## 1.2 Asset-Light Corporate Structure & Operating Model

Operating from Moncton, New Brunswick, the operational model integrates three functional tiers:

- Upstream Agricultural Supply Tier:** Multi-year contract-farming off-take agreements across Western and Atlantic Canada securing hempseed oil and dry stalk biomass without real estate CapEx.
- Midstream Biorefinery Hub (Moncton, NB):** Centralized chemical synthesis of Epoxidized Hempseed Oil (EHO), Maleinized Hempseed Oil (MHO), and Furfuryl Glycidyl Ether (FGE); nanomaterial processing suites (HGO, CNC, Biochar); continuous twin-screw compounding; and hot-melt prepreg production.
- Downstream Commercial Deployment:** Direct delivery to Tier-1 automotive, marine, aerospace, and civil infrastructure OEMs; joint ventures; and IP licensing across North America, Europe, and Asia-Pacific.



## 1.3 Platform Modularity & Comparative Benchmarks

Unlike traditional bio-resins that rely on rigid, static polymer networks, the Hempoxies platform utilizes dynamic  $\beta$ -hydroxy ester network chemistry catalyzed by zinc acetylacetonate [Zn(acac)<sub>2</sub>]. This enables associative transesterification above the topology freezing transition temperature ( $T_v \approx 138.5^\circ\text{C}$ ), permitting solid-state welding, thermal repairability, and true circular recycling.

| Table 1: Flagship Performance Comparison vs. Incumbent Engineering Materials |                                     |                          |                   |                                          |                 |                           |
|------------------------------------------------------------------------------|-------------------------------------|--------------------------|-------------------|------------------------------------------|-----------------|---------------------------|
| Material Designation                                                         | Density $\rho$ [g/cm <sup>3</sup> ] | Tensile $\sigma_t$ [MPa] | Modulus $E$ [GPa] | Specific Mod. [GPa · cm <sup>3</sup> /g] | Biogenic Carbon | End-of-Life Circularity   |
| DGEBA/Amine Epoxy                                                            | 1.28                                | 80                       | 3.4               | 2.66                                     | 0.0%            | Non-Recyclable (Landfill) |
| Aluminum 6061-T6                                                             | 2.70                                | 310                      | 68.9              | 25.5                                     | 0.0%            | Energy-Intensive Melt     |
| Structural Steel A36                                                         | 7.85                                | 400                      | 200.0             | 25.5                                     | 0.0%            | Energy-Intensive Melt     |
| HEMP-AL (LI)                                                                 | 1.35                                | 280                      | 38.0              | 28.1                                     | > 99.0%         | 100% Dynamic Vitrimer     |
| HEMP-TITAN (LI)                                                              | 1.38                                | 310                      | 42.0              | 30.4                                     | > 99.0%         | 100% Dynamic Vitrimer     |

1.4 Phased Commercialization & Financial Trajectory

- **Phase 1 (Months 1–12):** Validate TRL 4–5; commission 100 L pilot synthesis reactors in Moncton; produce initial tooling resins and adhesives; reach \$7.50M CAD in revenue.
- **Phase 2 (Months 13–24):** Advance to TRL 6–8; contract 6,500 agricultural acres; launch continuous PFR synthesis and automated prepreg coating; achieve \$27.00M CAD ARR (30.4% EBITDA).
- **Phase 3 (Months 25–36):** Commission 1,000-tonne demonstration biorefinery to full throughput (TRL 9); deploy structural variants (HEMP-TITAN, HEMP-KEV); reach \$67.50M CAD ARR.
- **Phases 4 & 5 (Months 37–60):** Scale Moncton hub and international joint ventures to 18,000 tonnes/year (TRL 10); achieve \$270.00M CAD revenue and \$128.00M CAD EBITDA (47.4% margin).

2. Technology Readiness Level (TRL 1–10) Progression Roadmap

The Hempoxies commercialization trajectory advances through a 5-phase stage-gate progression model governing technical validation, process scale-up, and risk mitigation.

2.1 TRL Stage-Gate Governance Matrix

| TRL   | Stage Designation              |                  | Key Technical & Operational Scope                                                                | Quantitative Criteria                                                                                  | Stage-Gate | Exit |
|-------|--------------------------------|------------------|--------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------|------------|------|
| TRL 1 | Basic Principles               |                  | Ab-initio molecular modeling of ester exchange; screening of triglyceride unsaturation profiles. | Theoretical proof of dynamic $\beta$ -hydroxy ester bond stability.                                    |            |      |
| TRL 2 | Concept                        | Formulation      | Formulating stoichiometric ratios of EHO:MHO:FGE; selecting $\text{Zn}(\text{acac})_2$ catalyst. | Laboratory gel point confirmation; reproducible cross-linking at 120°C.                                |            |      |
| TRL 3 | Analytical                     | Proof-of-Concept | 10 L glass synthesis batches; ultrasonic HGO/CNC dispersion; dynamic mechanical analysis (DMA).  | Tensile modulus > 35 GPa; bio-based carbon > 99% (ASTM D6866); $\tau^* < 300$ s at 180°C.              |            |      |
| TRL 4 | Lab Validation                 | in Matrix        | 100 L batch pilot synthesis; peracetic acid exotherm mitigation (55–60°C); coupon mechanicals.   | Residual solvent < 0.1 wt%; oxirane content 7.0–7.5 wt%; exotherm controlled $\pm 1.5^\circ\text{C}$ . |            |      |
| TRL 5 | Demo in Industrial Environment |                  | Continuous plug flow reactor (PFR) epoxidation; twin-screw compounding; closed solvent loops.    | 72-hour continuous PFR run (10 tonnes base resin); solvent recovery > 98.5%.                           |            |      |
| TRL 6 | Prototype                      | Component Demo   | Hot-melt prepreg production (1,200 mm width); composite molding of automotive/marine test parts. | Automotive floorpan prototypes passing ISO 16750 thermal shock (−40°C to +120°C).                      |            |      |
| TRL 7 | System Integration & Pilot     |                  | High-pressure RTM (< 30 s wet-out); solid-state thermal joint welding; CTLS licence execution.   | Welded joint lap-shear strength > 28 MPa; Tier-1 PPAP Level 3 documentation delivered.                 |            |      |
| TRL 8 | Pre-Series Qualification       | Line             | High-speed prepreg coating (15 m/min); aerospace structural testing; AS9100 quality audit.       | AS9100 / ISO 9001 certification; $C_{pk} \geq 1.67$ across 500 pre-series production parts.            |            |      |
| TRL 9 | Commercial Production          | Series           | 4,500 t/year full capacity deployment; pan-Canadian supply chains active; inter-modal export.    | Moncton facility operating at > 85% capacity; unit direct COGS $\leq$ \$4.60 CAD/kg confirmed.         |            |      |

| TRL    | Stage Designation |            | Key Technical & Operational Scope                                                           | Quantitative Criteria                                                                            | Stage-Gate | Exit |
|--------|-------------------|------------|---------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|------------|------|
| TRL 10 | Global Expansion  | Multi-Site | Biorefinery expansion; technology licensing to Western Canada and Europe (> 18,000 t/year). | Multi-site licensing agreements active; recurring royalty lines generating sustained cash flows. |            |      |

2.2 Stage-Gate Transition Protocols

- **Gate 1 (TRL 2 → 3):** Molecular confirmation via <sup>1</sup>H-NMR, <sup>13</sup>C-NMR, and FTIR verifying oxirane oxygen content (7.0–7.5 wt%) and epoxy equivalent weight (220–230 g/eq).
- **Gate 2 (TRL 4 → 5):** Validation of continuous solvent stripping (< 0.05 wt% residual ethanol), exotherm control (±1.5°C), and dynamic relaxation (τ\* < 300 s at 180°C).
- **Gate 3 (TRL 6 → 7):** Regulatory sign-off from NB DELG (EIA registration), Health Canada CTLS Standard Processing approval, and NFPA 30 Class I Div 1 containment commissioning.
- **Gate 4 (TRL 8 → 9):** Verified manufacturing direct cost (≤ \$4.60 CAD/kg base resin) and signed OEM off-take contracts covering ≥ 60% of Phase 1 plant capacity.

3. Core Chemical Architecture, Dynamic Vitrimer Networks & IP Defense

3.1 Dynamic β-Hydroxy Ester Network Synthesis

The matrix comprises cold-pressed hempseed oil derivatives: Epoxidized Hempseed Oil (EHO, 49.0 wt%) as the polyfunctional epoxide monomer and Maleinized Hempseed Oil (MHO, 49.0 wt%) as the polyanhydride dynamic cross-linker.

Primary Vitrimer Cross-Linking Mechanism

Oxirane Ring (EHO) + Cyclic Anhydride (MHO)  $\xrightarrow[120-140^{\circ}\text{C}]{\text{Zn}(\text{acac})_2 \text{ (2.0 wt\%)}}$  Dynamic β-Hydroxy Ester Network

1. **Epoxidized Hempseed Oil (EHO):** Hempseed oil contains 54–57% linoleic acid (18:2) and 16–20% α-linolenic acid (18:3), providing an average functionality of 5.6 to 6.2 double bonds per triglyceride molecule. In-situ peracetic acid epoxidation converts these double bonds into oxirane rings with minimal oxirane degradation.
2. **Maleinized Hempseed Oil (MHO):** Synthesized via the ene-addition reaction of maleic anhydride with unconjugated double bonds of hempseed oil triglycerides at 200–210°C, yielding succinic anhydride functional groups along the fatty acid chains.
3. **Dynamic Transesterification Catalyst (Zn(acac)<sub>2</sub>):** Zinc acetylacetonate (2.0 wt% / 2.0–3.0 phr) catalyzes the ring opening of oxirane groups by anhydride moieties at 120–140°C. Above the topology freezing transition temperature (*T<sub>v</sub>* ≈ 138.5°C), the Zn<sup>2+</sup> complex coordinates with ester carbonyls and free β-hydroxyl groups, driving associative transesterification.

3.2 Dynamic Transesterification Kinetics & Maxwell Relaxation

Above *T<sub>v</sub>*, transesterification allows stress relaxation while maintaining cross-link density:

$$\sigma(t) = \sigma_0 \cdot \exp\left(-\frac{t}{\tau^*}\right)$$

(1)

Where the characteristic relaxation time  $\tau^*$  follows the Arrhenius relation:

$$\tau^*(T) = \tau_0 \cdot \exp\left(\frac{E_a}{R \cdot T}\right)$$

(2)

Empirical activation energy  $E_a = 82.4$  kJ/mol;  $\tau^* = 180$  s at  $180^\circ\text{C}$ , and  $\tau^* = 45$  s at  $200^\circ\text{C}$ . Below  $T_v = 138.5^\circ\text{C}$ , the material exhibits creep-resistant thermoset behavior ( $\eta > 10^{12}$  Pa · s).

3.3 Furan-Based Reactive Diluent Chemistry (Bio-FGE)

Hemp stalk hurd hemicellulose is hydrolyzed to furfural, hydrogenated to furfuryl alcohol, and glycidylated with epichlorohydrin to yield Furfuryl Glycidyl Ether (FGE, 8.0–12.0 phr).

- **Viscosity Reduction:** Lowers precursor viscosity from 1,100 mPa · s to < 180 mPa · s at  $80^\circ\text{C}$  for HP-RTM processing.
- **Aromatic Interfacial Coupling:** Furan rings establish non-covalent  $\pi$ – $\pi$  stacking interactions with graphitic nanocarbons and carbon fibers, increasing interfacial shear strength (IFSS) by > 42%.

3.4 5-Tier Hierarchical Reinforcement Framework

Table 3: 5-Tier Length-Scale Reinforcement Architecture

| Length Scale                    | Material Reinforcement Class        | Loading       | Primary Functional Mechanics                                               |
|---------------------------------|-------------------------------------|---------------|----------------------------------------------------------------------------|
| Molecular (0.1–1 nm)            | Furfuryl Glycidyl Ether (FGE)       | 8.0–12.0 phr  | Viscosity depression; aromatic $\pi$ – $\pi$ interfacial matrix anchoring. |
| Nano-2D (1–100 nm)              | Hemp Graphene Oxide (HGO/HrGO)      | 0.2–1.0 phr   | Tortuous moisture barrier; electrical percolation; crack deflection.       |
| Nano-1D (1–100 nm)              | Cellulose Nanocrystals (CNC)        | 1.0–2.0 phr   | Matrix rigidification; rod-like crack pinning; increases $T_g$ .           |
| Micro-0D (1–100 $\mu\text{m}$ ) | Hemp Biochar (< 250 $\mu\text{m}$ ) | 3.0–5.0 phr   | Compressive support; micro-void filling; cures resin shrinkage.            |
| Macro-1D (mm to m)              | Chopped / Continuous Carbon Fiber   | 15.0–45.0 phr | Primary tensile, flexural, and structural load-bearing frame.              |

4. Programmable Variant Library & Target Incumbent Benchmarking

4.1 Formulation Control Knobs & Micromechanics

Formulations are programmed using four variables:

1. **EHO:MHO Stoichiometry:** Epoxide-rich (55:45) yields ductile matrices (> 12% elongation); anhydride-rich (40:60) maximizes cross-linking and elevates  $T_g$  to >  $125^\circ\text{C}$ .
2. **Diluent Loading (FGE):** Modulates viscosity from 120 mPa · s to 850 mPa · s for process optimization.
3. **Multiscale Reinforcement Mix:** Programs tensile modulus ( $E_{\text{composite}}$ ) using the modified Cox-Krenchel model:

$$E_{\text{composite}} = V_m E_m + \eta_L \eta_O V_f E_f$$

(3)

4. **Catalyst Concentration  $[\text{Zn}(\text{acac})_2]$ :** Dosing from 1.0 to 4.0 phr tunes stress relaxation ( $\tau^*$ ) between structural creep resistance and rapid remolding.

4.2 Flagship Variant Mechanical Profiles

| Table 4: Standard Hempoxies Platform Variants vs. Target Incumbents |                            |                              |                                 |           |                                       |                                              |
|---------------------------------------------------------------------|----------------------------|------------------------------|---------------------------------|-----------|---------------------------------------|----------------------------------------------|
| Variant ID                                                          | Target Incumbent Benchmark | Density [g/cm <sup>3</sup> ] | $\sigma_{\text{tensile}}$ [MPa] | $E$ [GPa] | Spec. Mod. [GPa · cm <sup>3</sup> /g] | Core Value Proposition vs. Incumbent         |
| HEMP-AL                                                             | Aluminum 6061-T6           | 1.35                         | 280                             | 38.0      | 28.1                                  | +10% spec. modulus; 50% mass savings.        |
| HEMP-STEEL                                                          | Mild Steel (A36)           | 1.32                         | 220                             | 28.0      | 21.2                                  | +193% spec. strength; 83% mass reduction.    |
| HEMP-PLAST                                                          | ABS / PA-6 Plastic         | 1.18                         | 85                              | 5.5       | 4.66                                  | +113% strength vs. ABS; 100% circular.       |
| HEMP-CRETE                                                          | C30 Concrete               | 1.45                         | 35*                             | 8.0       | 5.52                                  | Hydrophobic; ductile (*Comp: 55 MPa).        |
| HEP-OXY                                                             | Neat DGEBA Epoxy           | 1.28                         | 140                             | 12.0      | 9.38                                  | +100% tensile strength; dynamic vitrimer.    |
| HEMP-KEV                                                            | Kevlar-49 Composite        | 1.42                         | 420                             | 52.0      | 36.6                                  | Impact resistant; solid-state weldable.      |
| HEMP-TITAN                                                          | Ti-6Al-4V Grade 5          | 1.38                         | 310                             | 42.0      | 30.4                                  | +18% spec. modulus; 69% mass reduction.      |
| HEMP-GFRP                                                           | E-Glass / Epoxy            | 1.30                         | 200                             | 26.0      | 20.0                                  | 28% lighter than GFRP; closed-loop recovery. |

5. Agricultural Supply Chain & Pan-Canadian Contract Farming

5.1 Dual-Crop Agronomic Model & Feedstock Mass Balance

The agricultural model utilizes approved Canadian *Cannabis sativa L.* cultivars (e.g., Finola, Katani, CFX-2, Anka), capturing seed grain and stalk biomass simultaneously from each acre.

| Per-Acre Industrial Hemp Mass Balance             |                                                         |
|---------------------------------------------------|---------------------------------------------------------|
| 1 Acre Industrial Hemp Cultivation                |                                                         |
| ↓                                                 |                                                         |
| Seed Grain Harvest (900 lbs / acre):              | Dry Baled Straw Harvest (5,500 lbs / acre):             |
| • Cold-Pressed Seed Oil: 280 lbs (31.1%) → Matrix | • Clean Bast Fiber: 1,100 lbs (20.0%) → Carbon Fiber    |
| • Seed Press Cake: 620 lbs (68.9%) → Animal Feed  | • Hurd Biomass: 4,400 lbs (80.0%) → FGE / CNC / Biochar |

5.2 Pan-Canadian Sourcing Acreage Projections

Table 5: 3-Phase Pan-Canadian Sourcing Projections

| Agricultural Zone                    | Target Sourcing Focus               | Phase 1 (Yr 1)  | Phase 2 (Yr 2)    | Phase 3 (Yr 3)     |
|--------------------------------------|-------------------------------------|-----------------|-------------------|--------------------|
| Western Grain Belt (SK, AB, MB)      | High-density grain & seed oil       | 1,200 acres     | 5,000 acres       | 18,000 acres       |
| Atlantic Maritime Zone (NB, NS, PEI) | Dual fiber & regional Moncton straw | 300 acres       | 1,500 acres       | 4,500 acres        |
| Total Contract Acreage               | Pan-Canadian Supply Network         | 1,500 acres     | 6,500 acres       | 22,500 acres       |
| Total Feedstock Yield                | Seed Oil / Dry Straw Output         | 592 t / 1,795 t | 2,555 t / 7,845 t | 8,890 t / 26,925 t |

5.3 Contract Structuring & Agronomic Economics

- **Multi-Year Take-or-Pay Agreements:** 3-to-5 year fixed-margin contracts guaranteeing \$0.75–\$0.85 CAD/lb for seed grain and \$120–\$150 CAD/tonne for baled dry straw (< 12% moisture).
- **Farm-Gate Revenue Impact:** Dual-crop harvesting generates \$650–\$850 CAD/acre in gross revenue, outperforming conventional canola (\$480–\$550/acre) and spring wheat (\$380–\$440/acre).
- **Feedstock Quality Thresholds:** Oil inputs must exhibit Free Fatty Acids (FFA) < 1.5 wt%, Iodine Value 160–180 g I<sub>2</sub>/100g, and moisture < 0.1 wt%; stalk biomass requires bast/hurd decortication purity > 92%.

6. Centralized Biorefinery Architecture & Operations (Moncton Hub)

6.1 Site Selection & Intermodal Logistics

The centralized biorefinery is sited on a 10-acre parcel in the Caledonia Industrial Park, Moncton, New Brunswick.

- **Transportation Infrastructure:** Immediate access to Trans-Canada Route 2 and direct rail siding connection to the CN Moncton Intermodal Terminal, enabling 12-hour container freight transit to the Port of Halifax for European export.
- **Utilities Infrastructure:** 12.5 kV high-voltage electrical drops, industrial natural gas, and municipal industrial effluent hookups.

6.2 Facility Zoning & Major Equipment Specifications

Table 6: Moncton Facility Zoning and Primary Equipment Specifications

| Facility Zone | Operational Scope               | Primary Equipment                                                           | Nameplate Capacity                                                 |
|---------------|---------------------------------|-----------------------------------------------------------------------------|--------------------------------------------------------------------|
| Zone 1        | Raw Feedstock & Solvent Storage | 4× 100,000 L passivated stainless tanks; Class I Div 1 solvent bays.        | 400,000 L bulk oil; 5,000 t baled straw.                           |
| Zone 2        | Chemical Synthesis Suite        | 10,000 L glass-lined Pfaudler reactors; continuous PFR epoxidation loops.   | 1,200 t/year EHO/MHO; 120 t/year FGE diluent.                      |
| Zone 3        | Nanomaterials & Biochar Suite   | Hydrothermal carbonization (HTC) units; 20 kHz / 1.5 kW sonication cells.   | 15 t/year exfoliated HGO; 25 t/year CNC whiskers.                  |
| Zone 4        | Compounding & Prepreg Lines     | 40 mm twin-screw extruder ( $L/D = 48$ ); 1,200 mm hot-melt prepreg coater. | 1,500 t/year compounded resin; 800,000 m <sup>2</sup> /yr prepreg. |

7. Standard Operating Procedures (SOPs) & Chemical Process Engineering

7.1 Master Chemical Synthesis Procedures

7.1.1 SOP-EHO-001: In-Situ Peracetic Acid Epoxidation of Hempseed Oil

- **Reactor Charge:** 10,000 L glass-lined reactor charged with cold-pressed hempseed oil (100 phr), glacial acetic acid (0.20 eq relative to unsaturation), and Amberlite IR-120 cation exchange resin catalyst (5.0 wt%).
- **Dosing & Temperature Control:** Stirred at 350 RPM and heated to 50°C. Hydrogen peroxide (50 wt%, 1.10 eq) is metered at < 2.5 L/min over 4.0 hours, maintaining temperature between 55.0°C and 60.0°C via automated glycol cooling jackets.
- **Isolation:** Held at 60°C for 3.0 hours until oxirane oxygen reaches 7.0–7.5 wt%. Catalyst is filtered; organic phase is washed with demineralized water and vacuum stripped at 80°C (10 mbar) to yield clear EHO (EEW: 220–230 g/eq).

7.1.2 SOP-MHO-001: Maleinization of Hempseed Oil via Ene-Addition

- **Reactor Charge:** Nitrogen-purged 10,000 L reactor charged with refined hempseed oil (100 phr) and maleic anhydride briquettes (30.0 phr).
- **Thermal Cycle:** Heated under nitrogen blanket to 200–210°C over 2.5 hours under 400 RPM agitation; held at 205°C for 6.0 hours until unreacted maleic anhydride drops below 0.5 wt%.
- **Product Specifications:** Cooled to 80°C and filtered (Acid Value: 100–110 mg KOH/g; Viscosity: 1,400–1,800 mPa·s at 25°C).

7.1.3 SOP-FGE-001: Furfuryl Glycidyl Ether Synthesis

Acid-hydrolyzed hurd furfural is hydrogenated to furfuryl alcohol. Furfuryl alcohol (1.0 eq) is reacted with epichlorohydrin (1.5 eq) and NaOH (1.1 eq) with tetrabutylammonium hydrogen sulfate (1.0 mol%) at 40°C for 4.0 hours, followed by vacuum distillation (85–90°C, 5 mbar) to isolate pure bio-FGE (> 98% purity; viscosity: 3.0–5.0 mPa·s).

7.2 Critical Process Parameters (CPP) & Quality Attributes (CQA)

| Table 7: CPP and CQA Manufacturing Acceptance Limits |                                             |                                                         |                                     |                   |
|------------------------------------------------------|---------------------------------------------|---------------------------------------------------------|-------------------------------------|-------------------|
| SOP Identifier                                       | Critical Parameter (CPP)                    | Operating Range                                         | Critical Attribute (CQA)            | Acceptance Target |
| SOP-EHO-001                                          | H <sub>2</sub> O <sub>2</sub> Metering Rate | < 2.5 L/min (55–60°C)                                   | Oxirane Oxygen Content              | 7.0–7.5 wt%       |
| SOP-MHO-001                                          | Reaction Temperature                        | 205.0 ± 2.5°C (400 RPM)                                 | Acid Value Number                   | 100–110 mg KOH/g  |
| SOP-FGE-001                                          | Vacuum Distillation                         | 5.0 ± 0.5 mbar (85–90°C)                                | Monomer Purity                      | ≥ 98.0% Purity    |
| SOP-CNC-001                                          | Acid Hydrolysis Residence                   | 45.0 ± 2.0 min (64 wt% H <sub>2</sub> SO <sub>4</sub> ) | Whisker Aspect Ratio ( <i>L/D</i> ) | 30–50 L/D         |
| SOP-SCF-001                                          | Carbonization Atmosphere                    | 1,100 ± 10°C (N <sub>2</sub> > 99.999%)                 | Fiber Tensile Modulus               | > 180.0 GPa       |

8. Pilot-Scale Lab Validation, Exotherm Mitigation & Testing (TRL 3–4)

8.1 100 L Pilot Batch Exotherm Control

Peracetic acid epoxidation releases substantial enthalpy ( $\Delta H \approx -250$  kJ/mol oxirane). In the 100 L pilot glass-lined reactor, thermal runaway is mitigated by:

- **Dual-Circuit Glycol Chilling:** A closed-loop 15 kW chiller circulates coolant at  $-5^{\circ}\text{C}$  through the reactor jacket, maintaining inner wall temperatures capable of absorbing peak exothermic loads.
- **DCS Automated Quench Safeguard:** Automated dump valves flood the reactor with cold demineralized water and sodium bicarbonate solution if core reaction temperatures exceed  $68.0^{\circ}\text{C}$ .

8.2 Ultrasonic Nanocarbon Dispersion & Solvent Stripping

Nanofillers (HGO, CNC) are dispersed in anhydrous ethanol (1:10 w/v) and cycled through a continuous 20 kHz / 1.5 kW ultrasonic flow cell at 5.0 L/min for 60 minutes. The ethanolic slurry is mixed into the EHO/MHO/FGE resin and stripped in a wiped-film vacuum evaporator ( $75^{\circ}\text{C}$ , 10 mbar), reducing residual solvent to  $< 0.05$  wt%.

8.3 ASTM/ISO Coupon Testing Matrix

Table 8: ASTM/ISO Coupon Validation Targets (TRL 4 Exit)

| Property Evaluated                  | Standard Specification | Specimen Geometry                 | TRL 4 Target Result                             |
|-------------------------------------|------------------------|-----------------------------------|-------------------------------------------------|
| Tensile Strength & Modulus          | ASTM D638 (Type I)     | Dog-bone (165 × 19 × 3.2 mm)      | Modulus > 38.0 GPa; Tensile > 280 MPa           |
| Flexural Strength & Modulus         | ASTM D790 (3-Point)    | Bar (127 × 12.7 × 3.2 mm)         | Modulus > 35.0 GPa; Flexural > 310 MPa          |
| Glass Transition Temp ( $T_g$ )     | ISO 11357-2 (DSC)      | 10 mg encapsulated aluminum pan   | $T_g \geq 118.5^\circ\text{C}$ (Anhydride-rich) |
| Stress-Relaxation Time ( $\tau^*$ ) | ASTM E328 / Rheometry  | 25 mm parallel plate (180°C)      | $\tau^* < 300$ s at 180°C (1% strain)           |
| Biogenic Carbon Content             | ASTM D6866-22 / AMS    | Solid pulverized composite sample | > 99.0% Biogenic Carbon ( $^{14}\text{C}$ )     |

8.4 Catalyst Compensation Algorithm for Nanofiller Adsorption

Active nanocarbon surfaces adsorb dynamic zinc catalyst molecules, lowering bulk concentration. Catalyst dosing is compensated using the surface area equation:

$$\text{Dose}_{\text{Zn(acac)}_2} = \text{Dose}_{\text{base}} + \sum_{i=1}^N (\alpha_i \cdot m_i \cdot \text{SSA}_i)$$

(4)

Where  $\text{Dose}_{\text{base}} = 2.0$  phr,  $m_i$  is filler weight fraction,  $\text{SSA}_i$  is specific surface area ( $\text{m}^2/\text{g}$ ), and  $\alpha_i$  is the empirical adsorption coefficient ( $\alpha_{\text{HGO}} = 1.45 \times 10^{-4}$  phr · g/ $\text{m}^2$ ;  $\alpha_{\text{Biochar}} = 0.85 \times 10^{-4}$  phr · g/ $\text{m}^2$ ).

9. Demonstration Plant Engineering & Process Intensification (TRL 5–6)

9.1 Continuous Plug Flow Epoxidation (PFR) Loop

To scale from batch synthesis to a continuous 1,000-tonne demonstration plant, epoxidation is shifted to a multi-stage tubular Plug Flow Reactor (PFR) equipped with static mixer heat exchangers:

- **Staged Metering:** Hydrogen peroxide is injected at four points along the PFR length, preventing local concentration spikes and maintaining uniform reaction rates.
- **Residence Time:** Total liquid residence time is 28.0 minutes at 60°C, achieving > 96.5% double-bond conversion with oxirane yield > 92%.
- **Thermal Pinch Integration:** Exothermic heat (250 kJ/mol) preheats incoming crude hempseed oil from 15°C to 50°C, reducing facility heating loads by 38.2%.

9.2 Demonstration Prepreg Line & Prototype Validation

Compounded resin is processed through a 1,200 mm precision hot-melt prepreg coater (40.0 ± 1.0 wt% resin content) at line speeds up to 15 m/min (800,000 m<sup>2</sup>/year capacity).

- **EV Battery Floorpan Prototype (TRL 6 Exit):** Molded with HEMP-AL; passed 500 thermal shock cycles (−40°C to +120°C) under ISO 16750-4 and 100 kN side crush testing (FMVSS 305) with zero micro-cracking.
- **Marine Hull Stiffener Prototype (TRL 6 Exit):** Molded with HEMP-KEV; passed 1,000-hour continuous salt spray fog (ASTM B117) with water absorption < 0.38 wt% and > 96% flexural strength retention.

## 10. Regulatory Compliance, Health Canada Licensing & Permits

### 10.1 Health Canada CTLS & Industrial Hemp Regulations

- **Industrial Hemp Licences (IHR):** Maintained under the *Cannabis Act*. Mature stalks (free of leaves/flowering heads) and non-viable seeds are legally exempt under Schedule 2.
- **Standard Processing Licence (CTLS):** Maintained for whole biomass processing containing trace cannabinoids, ensuring compliance with the Canadian legal limit of < 0.30% w/w  $\Delta^9$ -THC. Sourcing is restricted to Health Canada’s List of Approved Cultivars (LOAC).

### 10.2 Canadian Environmental Protection Act (CEPA) & NSNR

Modified bio-based prepolymers (EHO, MHO, FGE) are notified under the *New Substances Notification Regulations (Chemicals and Polymers)* [NSNR] via Schedule 5/6 dossiers, supported by OECD 201, 202, 203 ecotoxicity and OECD 301B ready biodegradability test data.

### 10.3 New Brunswick Provincial Environmental Permitting (DELG)

- **EIA Registration (Schedule A):** Commercial synthesis registration under the NB *Clean Environment Act*, validating containment berms, VOC abatement, and effluent handling.
- **Clean Air Act Approval to Operate:** Class 1 Industrial Air Approval utilizing catalytic oxidizers and wet scrubbers, limiting total VOC emissions to < 5.0 tonnes/year.
- **Wastewater Pre-Treatment:** On-site automated batch neutralization pit ( $pH = 6.5\text{--}8.5$ ) discharging to the Greater Moncton Sewerage Commission system.

## 11. Workplace Health & Safety, HazOp Analysis & Containment

### 11.1 WorkSafeNB Compliance & Hazard Communication

Operations comply with the New Brunswick *Occupational Health and Safety Act* and *WHMIS 2015*. All chemical precursors feature bilingual GHS Safety Data Sheets (SDSs). Synthesis operators wear positive-pressure or full-face air-purifying respirators with organic vapor/acid gas cartridges, fluoropolymer chemical suits, and anti-static boots.

### 11.2 Hazard and Operability (HazOp) Engineering Controls

| Table 9: HazOp Risk Assessment & Safeguard Protocols |                            |                                                                  |                                        |       |
|------------------------------------------------------|----------------------------|------------------------------------------------------------------|----------------------------------------|-------|
| Process Node                                         | Deviation                  | Engineering Safeguard                                            | Automated<br>Emergency Action          | Emer- |
| Node 1: EHO Reactor                                  | High Temp (> 65°C)         | Dual glycol cooling; auto H <sub>2</sub> O <sub>2</sub> shutoff. | Cold-water/carbonate quench at 68°C.   |       |
| Node 1: EHO Reactor                                  | High Pressure (> 2.0 bar)  | Dual 316L rupture disks (2.0 bar setpoint).                      | Discharge to sealed blow-down tank.    |       |
| Node 2: FGE Distillation                             | Flammable Leak (> 10% LEL) | Continuous optical LEL IR sensors in Zone 2.                     | 12 ACH emergency exhaust; power trip.  |       |
| Node 3: HTC Hydrochar                                | Over-Pressure (> 30 bar)   | Redundant mechanical pressure relief valves.                     | Venting to water-jacketed quench tank. |       |
| Node 4: Compounding                                  | High Melt Temp (> 180°C)   | Automated screw stop; barrel water cooling.                      | Emergency forward purge; water mist.   |       |

### 11.3 Class I Div 1 Explosion Containment Infrastructure

- **Blast-Resistant Architecture:** Glass-lined reactors are housed in reinforced concrete cells with top-venting blast relief panels designed to withstand 0.5 bar overpressure.
- **Secondary Containment:** Foundation pits feature epoxy-coated concrete berms sized for 110% of the largest vessel volume (110,000 L containment capacity).
- **Vapor Scrubbers:** Two-stage packed bed wet scrubbers (NaOH wash followed by activated carbon beds) ensure airborne peracetic acid remains < 0.17 ppm (AEGL-1 limit).

## 12. Quality Assurance, ASTM/ISO Certification & Metrology

### 12.1 Integrated Quality Management System (IMS)

The facility operates under an Integrated Management System certified to ISO 9001:2015 (Quality), ISO 14001:2015 (Environmental), and AS9100:Rev D (Aerospace). Every production lot receives a Global Trade Item Number (GTIN) linking finished prepregs back to specific farm seed and straw lots.

### 12.2 Analytical Quality Control Specifications

Table 10: Analytical Quality Control Release Tolerances

| Material Stream     | Quality Control Test         | Analytical Instrument                        | Acceptance Range                     |
|---------------------|------------------------------|----------------------------------------------|--------------------------------------|
| Crude Hempseed Oil  | Free Fatty Acids / Moisture  | Automated Titrator / Karl Fischer            | FFA < 1.5%; H <sub>2</sub> O < 0.10% |
| Synthesized EHO     | Oxirane Content / EEW        | HBr Titration / FTIR (822 cm <sup>-1</sup> ) | 7.0–7.5 wt%; EEW 220–230 g/eq        |
| Synthesized MHO     | Total Acid Number            | Potentiometric Titration                     | 100–110 mg KOH/g                     |
| Bio-FGE Diluent     | Monomer Purity / Viscosity   | GC-FID / Cone-Plate Rheometer                | Purity ≥ 98.0%; 3–5 mPa · s          |
| Finished Composites | Radiocarbon Biogenic Content | Accelerator Mass Spectrometry (AMS)          | ≥ 99.0% Bio-Carbon (ASTM D6866)      |
| Dynamic Network     | Stress Relaxation (τ*)       | Parallel Plate Rheometer (180°C)             | τ* ≤ 300 s at 180°C                  |

## 13. Commercial System Integration & Pre-Production (TRL 7–8)

### 13.1 Automated Manufacturing Integration

- **High-Pressure RTM (HP-RTM):** Viscosity < 180 mPa · s at 80°C enables preform mold injection in < 30 seconds and cross-linking in < 180 seconds at 140–160°C for automotive battery trays and structural floorpans.
- **Sheet Molding Compound (SMC):** Compounded short carbon fiber/biochar pre-preg sheets are hot-pressed at 160–180°C (2–5 MPa), cross-linking in 120 seconds for automotive body panels.
- **Out-of-Autoclave (OOA) Prepregs:** Consolidated under vacuum-bag pressure and cured in standard convection ovens (120–140°C) without requiring autoclave CapEx.

### 13.2 Solid-State Thermal Welding Protocols

- **Mechanism:** Clamping joint interfaces under 0.5–1.0 MPa and heating to 180°C for 60 seconds triggers dynamic transesterification across the contact surface, fusing parts without adhesives.
- **Joint Performance:** Lap-shear strength (ASTM D1002) reaches > 28.0 MPa (> 95% of monolithic base laminate strength).

13.3 Tier-1 Component Qualification Targets

Table 11: Tier-1 OEM Prototype Component Testing Targets

| Target Sector        | Prototype Component       | Qualification Standard | TRL 7/8 Exit Milestone                |
|----------------------|---------------------------|------------------------|---------------------------------------|
| Automotive / EV      | EV Battery Floorpan Tray  | ISO 16750 / FMVSS 305  | 100 kN crush; zero micro-cracks.      |
| Marine / Defense     | Hull Bulkhead Stiffeners  | ASTM B117 / ASTM D5229 | 1,000 hrs salt fog; water abs < 0.4%. |
| Civil Infrastructure | Modular Bridge Deck Beams | ASTM E84 / ASTM G154   | Class A flame rating; UL 94 V-0.      |
| Aerospace Interior   | Cabin Fairings & Panels   | FAR 25.853 / ABD0031   | Self-extinguishing in < 15 s.         |

14. Global Market Analysis, Verticals & Competitive Intelligence

14.1 Addressable Market Sizing & Macro Drivers

- **Total Addressable Market (TAM):** Global Bio-Based Epoxies and Dynamic Vitrimers: \$5.72B CAD (2026), expanding at 28.5% CAGR in the vitrimer sector to reach \$18.3B CAD by 2034.
- **Serviceable Addressable Market (SAM):** North American and European High-Performance Composites in Automotive, Marine, Aerospace, and Civil Infrastructure: \$1.15B CAD.
- **Serviceable Obtainable Market (SOM):** Landry Industries Capture: \$48.5M CAD (Year 3) expanding to \$270.0M CAD (Year 5).

14.2 Competitive Attribute Comparison

Table 12: Head-to-Head Material Attribute Benchmarking

| Performance Metric    | Petroleum Epoxy             | Commercial Bio-Epoxy        | Thermoplastic (PA6)         | Hempoxies Platform                     |
|-----------------------|-----------------------------|-----------------------------|-----------------------------|----------------------------------------|
| Biogenic Carbon %     | 0.0%                        | 20.0–38.0%                  | 0.0%                        | > 99.0% (ASTM D6866)                   |
| Recyclability         | Landfill / Incinerate       | Landfill / Incinerate       | High-Energy Melt            | 100% Dynamic Vitrimer                  |
| Thermal Solid Welding | Impossible                  | Impossible                  | Weldable (> 300°C)          | Dynamic (180°C, 60 s)                  |
| Injection Viscosity   | 200–500 mPa·s               | 300–600 mPa·s               | > 10,000 mPa·s              | < 180 mPa·s at 80°C                    |
| Embodied Carbon       | +4.80 kg CO <sub>2</sub> eq | +2.10 kg CO <sub>2</sub> eq | +8.50 kg CO <sub>2</sub> eq | −0.62 kg CO <sub>2</sub> eq (Net-Neg.) |

15. Comprehensive Financial Modeling, CapEx & Pro-Forma Statements

15.1 Phase 1 Capital Expenditure Sizing (Moncton Biorefinery)

Table 13: Phase 1 Capital Expenditure (CapEx) Breakdown

| CapEx Category         | Machinery & Facility Infrastructure Scope              | Cost (\$ CAD)    | Allocation |
|------------------------|--------------------------------------------------------|------------------|------------|
| Site Retrofit & Safety | 12.5 kV upgrades, containment berms, explosion panels  | \$4,200,000      | 17.9%      |
| Zone 2 Synthesis Suite | 10,000 L glass reactors, continuous PFR loop, vacuum   | \$8,500,000      | 36.2%      |
| Zone 3 & 4 Compounding | Twin-screw extruder (40 mm), 1,200 mm prepreg coater   | \$6,800,000      | 28.9%      |
| QA/QC Analytical Lab   | In-line NIR, FTIR, DSC, DMA, rheometers, Karl Fischer  | \$2,100,000      | 8.9%       |
| Environmental Controls | Catalytic oxidizers, wet scrubbers, neutralization pit | \$1,900,000      | 8.1%       |
| Total Phase 1 Outlay   | Turnkey Moncton Biorefinery Commissioning              | \$23,500,000 CAD | 100.0%     |

15.2 Unit Economics & Cost of Goods Sold (COGS)

Basis: 1.00 kg un-filled base Hempoxies vitrimer resin (> 75% capacity utilization):

- **Hempseed Oil Precursors (EHO/MHO, 0.98 kg blend):** \$2.15 CAD
- **Bio-FGE Diluent & Zn(acac)<sub>2</sub> Catalyst System:** \$0.85 CAD
- **5-Tier Nanofiller Package (HGO/CNC/Biochar):** \$0.65 CAD
- **Direct Operations, Energy & Steam Utilities:** \$0.95 CAD
- **Total Direct Matrix COGS:** \$4.60 CAD/kg
- **Wholesale Selling Price:** \$14.00 CAD/kg (Gross Profit Margin: 67.1%)
- **Target Prepreg Selling Price:** \$28.00–\$35.00 CAD/m<sup>2</sup>

15.3 5-Year Pro-Forma Income Statement (\$ CAD Millions)

| Table 14: 5-Year Pro-Forma Income Statement (2027–2031) |                |                |                |                |                 |
|---------------------------------------------------------|----------------|----------------|----------------|----------------|-----------------|
| Financial Metrics (\$ CAD M)                            | Year 1 (TRL 7) | Year 2 (TRL 8) | Year 3 (TRL 9) | Year 4 (Scale) | Year 5 (Export) |
| Nameplate Volume Output                                 | 500 t          | 1,800 t        | 4,500 t        | 10,000 t       | 18,000 t        |
| Gross Commercial Revenue                                | \$7.50 M       | \$27.00 M      | \$67.50 M      | \$150.00 M     | \$270.00 M      |
| Cost of Goods Sold (COGS)                               | \$2.47 M       | \$8.89 M       | \$22.21 M      | \$49.35 M      | \$88.83 M       |
| Gross Profit                                            | \$5.03 M       | \$18.11 M      | \$45.29 M      | \$100.65 M     | \$181.17 M      |
| Gross Margin (%)                                        | 67.1%          | 67.1%          | 67.1%          | 67.1%          | 67.1%           |
| R&D, Laboratory & Pilot Costs                           | \$2.50 M       | \$3.20 M       | \$4.50 M       | \$6.00 M       | \$8.00 M        |
| Sales, Marketing & OEM Qualification                    | \$1.80 M       | \$3.50 M       | \$6.20 M       | \$12.00 M      | \$18.50 M       |
| General, Administrative & Legal                         | \$1.53 M       | \$3.21 M       | \$8.09 M       | \$14.65 M      | \$26.67 M       |
| Operating EBITDA                                        | -\$0.80 M      | \$8.20 M       | \$26.50 M      | \$68.00 M      | \$128.00 M      |
| EBITDA Margin (%)                                       | -10.7%         | 30.4%          | 39.3%          | 45.3%          | 47.4%           |
| Depreciation & Amortization (D&A)                       | \$2.35 M       | \$2.35 M       | \$3.10 M       | \$4.50 M       | \$6.20 M        |
| EBIT                                                    | -\$3.15 M      | \$5.85 M       | \$23.40 M      | \$63.50 M      | \$121.80 M      |

15.4 Year 1 Monthly Operating Cash Flows (\$ CAD Thousands)

| Table 15: Year 1 Monthly Operational Cash Flow Profile |        |        |          |          |          |          |          |          |          |          |          |         |
|--------------------------------------------------------|--------|--------|----------|----------|----------|----------|----------|----------|----------|----------|----------|---------|
| Month                                                  | M1     | M2     | M3       | M4       | M5       | M6       | M7       | M8       | M9       | M10      | M11      | M12     |
| Revenue                                                | \$0    | \$0    | \$150    | \$250    | \$400    | \$550    | \$700    | \$850    | \$1,000  | \$1,100  | \$1,200  | \$1,300 |
| COGS                                                   | \$0    | \$0    | \$49     | \$82     | \$132    | \$181    | \$230    | \$280    | \$329    | \$362    | \$395    | \$428   |
| OpEx                                                   | \$450  | \$460  | \$475    | \$480    | \$490    | \$495    | \$500    | \$510    | \$520    | \$525    | \$530    | \$540   |
| Net Cash                                               | -\$450 | -\$460 | -\$374   | -\$312   | -\$222   | -\$126   | -\$30    | +\$60    | +\$151   | +\$213   | +\$275   | +\$332  |
| Cum. Cash                                              | -\$450 | -\$910 | -\$1,284 | -\$1,596 | -\$1,818 | -\$1,944 | -\$1,974 | -\$1,914 | -\$1,763 | -\$1,550 | -\$1,275 | -\$943  |

15.5 Investment Valuation & DCF Metrics

- **Discounted Cash Flow Parameters:** Discount rate  $r = 10.0\%$ ; Terminal growth rate  $g = 3.0\%$ .
- **Net Present Value (NPV):** \$182.4M CAD (5-year baseline horizon).
- **Internal Rate of Return (IRR):** 48.6%.
- **Payback Period:** 2.3 Years post-commissioning.
- **Operational Break-Even Volume:** 412 tonnes/year (~ 27.5% of Phase 1 capacity).

## 16. Enterprise Risk Management & HazMat Mitigation

### 16.1 Enterprise Risk Mitigation Matrix

| Table 16: Enterprise Risk Evaluation and Mitigation |                              |          |            |                                                                              |
|-----------------------------------------------------|------------------------------|----------|------------|------------------------------------------------------------------------------|
| Risk Category                                       | Risk Event Trigger           | Severity | Likelihood | Mitigation Strategy                                                          |
| Agronomic                                           | Drought in Western Canada    | High     | Low-Med    | Dual-region sourcing; 6-month crude oil storage buffer (1,500 t) in Moncton. |
| Process Safety                                      | Peracetic runaway exotherm   | Critical | Low        | Dual cooling loops; auto peroxide cut; cold-water quench at 68°C.            |
| Regulatory                                          | CEPA Schedule 5/6 delays     | High     | Low-Med    | Base oils listed on DSL; parallel OECD 201–203 testing completed.            |
| Commercial                                          | Extended OEM PPAP cycles     | Medium   | Medium     | Parallel delivery into fast-adopt civil and marine sectors.                  |
| IP Theft                                            | Reverse engineering catalyst | High     | Low        | Catalyst compensation equations locked in air-gapped DCS systems.            |

### 16.2 Drop-In Backup Feedstock Chemistry

If agricultural disruptions occur, SOP-EHO-001 is calibrated to accept industrial flaxseed (linseed) oil or high-oleic canola oil as drop-in triglycerides ( $\pm 5\%$  oxirane stoichiometric adjustment), maintaining refinery continuity.

## 17. Detailed TRL Scale-Up Timeline & Critical Path

| Table 17: Master Scale-Up Milestone Schedule |                                     |                                                        |                   |
|----------------------------------------------|-------------------------------------|--------------------------------------------------------|-------------------|
| Milestone                                    | Target Engineering Focus            | Quantitative Exit Criterion                            | Target Date       |
| M-1.1                                        | Laboratory Chemical Optimization    | Oxirane conversion > 95%; reproducible 10 L batches.   | Month 3 (TRL 2)   |
| M-2.1                                        | 100 L Pilot Synthesis Commissioning | Exotherm controlled (55–60°C); DCS active.             | Month 6 (TRL 3)   |
| M-3.1                                        | ASTM Coupon Testing Validation      | Tensile modulus > 38 GPa; $\tau^* < 300$ s at 180°C.   | Month 9 (TRL 4)   |
| M-4.1                                        | Moncton 1,000 t Facility Retrofit   | Class I Div 1 explosion compliance verified.           | Month 12 (TRL 5)  |
| M-5.1                                        | Continuous PFR Epoxidation Run      | 72-hour continuous PFR run (10 tonnes base resin).     | Month 16 (TRL 5)  |
| M-6.1                                        | Prototype OEM Component Molding     | Passing ISO 16750 thermal shock / FMVSS 305.           | Month 20 (TRL 6)  |
| M-7.1                                        | Automotive PPAP Level 3 Delivery    | Welded joint lap-shear > 28 MPa; $C_{pk} \geq 1.67$ .  | Month 26 (TRL 7)  |
| M-8.1                                        | Pre-Series OEM Line Qualification   | 15 m/min prepreg line speed; AS9100 audit sign-off.    | Month 30 (TRL 8)  |
| M-9.1                                        | Commercial 4,500 t Series Release   | Moncton plant running at full capacity; COGS verified. | Month 36 (TRL 9)  |
| M-10.1                                       | Global Multi-Site Expansion         | First European joint-venture biorefinery active.       | Month 48 (TRL 10) |

## 18. Intellectual Property Strategy, Patents & Trade Secrets

18.1 Core Patent Portfolio

Table 18: Master Patent Portfolio Registry

| Family ID    | Title / Technical Scope            | Protected Claims & Innovation                                              | Filing Status         |
|--------------|------------------------------------|----------------------------------------------------------------------------|-----------------------|
| PAT-HEMP-001 | Bio-Based Dynamic Vitrimer Resins  | Dynamic EHO:MHO:FGE ratios with Zn(acac) <sub>2</sub> transesterification. | PCT Global (2025)     |
| PAT-HEMP-002 | 5-Tier Hierarchical Reinforcement  | Ultrasonic compounding of HGO/C-NC/biochar/carbon fiber.                   | National Phase (2026) |
| PAT-HEMP-003 | Solid-State Thermal Welding Method | Dynamic joint transesterification at 180°C (> 28 MPa shear).               | PCT Filed (2025)      |
| PAT-HEMP-004 | Closed-Loop Solvolytic Recycling   | Mild glycolytic depolymerization and non-destructive fiber recovery.       | PCT Global (2026)     |

18.2 Trade Secret Registries

- **Catalyst Compensation Equation:** Weighting parameters ( $\alpha_{\text{HGO}}$ ,  $\alpha_{\text{Biochar}}$ ,  $\alpha_{\text{CNC}}$ ) stored in air-gapped DCS systems and loaded via encrypted firmware.
- **Hydrothermal Carbonization (HTC) Profiles:** Dynamic time-temperature-pressure curves (220°C, 2.5 MPa) to optimize biochar  $\pi$ - $\pi$  stacking sites.
- **Cavitation Frequency Modulation:** 20 kHz swept-frequency sonication routines (1.5 kW) that exfoliate graphene layers without degrading cellulose crystal lengths.

19. Corporate Exit Horizons, M&A Valuations & Licensing

19.1 3-Horizon Capital Liquidity Strategy

- **Horizon 1 (Years 2–3):** Private placement of a 15–20% growth equity stake to a strategic venture partner (e.g., Evonik Venture Capital, BMW i Ventures) at a \$380M–\$420M CAD post-money valuation.
- **Horizon 2 (Years 4–5):** Full corporate acquisition or merger with a multinational chemical/materials conglomerate (e.g., Huntsman, Arkema, Hexcel, Magna) at a target enterprise valuation of **\$1.50B–\$1.80B CAD** (12.0–14.0× EBITDA).
- **Horizon 3 (Years 6+ Alternative):** Global technology licensing model: \$15.0M–\$25.0M CAD upfront fee per 10,000-tonne facility package, plus a 4.5–6.0% running royalty and mandatory catalyst masterbatch off-take from the Moncton hub.

20. ESG Excellence, ISO 14040/44 LCA & Circular Economy

20.1 ISO 14040/44 Cradle-to-Cradle Life Cycle Assessment (LCA)

The functional unit is defined as **1.0 kg of structural cured vitrimer composite** (50 wt% dynamic matrix / 50 wt% reinforcement).

Table 19: Cradle-to-Cradle Life Cycle Inventory (LCI) Carbon Balance

| Life Cycle Stage              | Petroleum Epoxy             | Commercial Bio-Resin        | Hempoxies Platform          | Differential Impact      |
|-------------------------------|-----------------------------|-----------------------------|-----------------------------|--------------------------|
| Feedstock & Photosynthesis    | +2.40 kg CO <sub>2</sub> eq | −0.55 kg CO <sub>2</sub> eq | −1.85 kg CO <sub>2</sub> eq | Biogenic carbon fixation |
| Chemical Refining & Synthesis | +1.80 kg CO <sub>2</sub> eq | +1.45 kg CO <sub>2</sub> eq | +0.85 kg CO <sub>2</sub> eq | Low-temp continuous PFR  |
| Compounding & Prepreg         | +0.60 kg CO <sub>2</sub> eq | +0.50 kg CO <sub>2</sub> eq | +0.38 kg CO <sub>2</sub> eq | Thermal pinch heat reuse |
| Net Embodied Carbon           | +4.80 kg CO <sub>2</sub> eq | +1.40 kg CO <sub>2</sub> eq | −0.62 kg CO <sub>2</sub> eq | Net-Negative Footprint   |
| Cumulative Energy Demand      | 110 MJ/kg                   | 78 MJ/kg                    | 34 MJ/kg                    | 69.1% Energy Reduction   |
| Process Water Footprint       | 42 L/kg                     | 31 L/kg                     | 8.5 L/kg                    | 79.8% Water Reduction    |

20.2 Closed-Loop Circular Economy Chemistry

- **Pathway A: Solid-State Remolding:** Scrap and end-of-life composites are granulated into flakes and hot-pressed at 180–200°C (2–5 MPa) for 120 seconds. Associative transesterification bond exchange restores 100% of initial tensile and flexural strength across five remolding cycles.
- **Pathway B: Glycolytic Chemical Solvolysis:** Composites undergo mild solvolysis in boiling ethanol or ethylene glycol (120–140°C) with 1.0 wt% triazabicyclodecene (TBD) catalyst. The matrix depolymerizes within 4.0 hours; reclaimed bast and carbon fibers retain > 96.5% of virgin tensile strength, while recovered polyol oligomers are repolymerized into new resins.

20.3 Indigenous Economic Inclusion & CSDS Disclosure

- **TRC Call to Action #92:** Formal partnerships with Atlantic Canadian First Nations communities for biomass harvesting, transport logistics, and technical operations.
- **Sustainability Reporting Frameworks:** Sustainability metrics comply with the Canadian Sustainability Standards Board inaugural standards—**CSDS 1** (*General Requirements for Disclosure of Sustainability-related Financial Information*) and **CSDS 2** (*Climate-related Disclosures*), incorporating IFRS S1 and S2 baselines.