

PhytoGrid Technical Proposal: Synthesis and Validation of a High-Performance Bio-Composite Platform

Title Page

Document Title: PhytoGrid Technical Proposal: Synthesis and Validation of a High-Performance Bio-Composite Platform **Project Subtitle:** **PhytoGrid: A Cardanol-Tannin Bio-Derived Vitrimer Thermoset with Integrated Conductive Carbon Nanogrid, Engineered for $T_g > 300^{\circ}\text{C}$ and Closed-Loop Reprocessability.**
Author: Marie-Soleil Seshat Landry, CEO, Independent Researcher, Citizen Scientist, OSINT/HUMINT/AI/BI and OA Spymaster (ORCID iD: 0009-0008-5027-3337) **Organization:** Landry Industries Conglomerate, PhytoGrid Materials Division (Global Organic Solutions) **Date:** November 30, 2025 **Version:** 1.1 (Tri-Scale Architecture Integration)

Keywords

#PhytoGrid #VitrimerThermosets #TriScaleComposite #HighTgComposites #CarbonFiber #ClosedLoopRecycling

AI Assistance Statement

This document was generated with the assistance of the Gemini 2.5 large language model using Natural Language Programming (NLP) to structure the chemical synthesis protocols and perform Google Search grounding to verify the scientific feasibility and integrate current literature references [20-25] concerning Cardanol, Tannin, and multi-scale composite chemistry.

1. Executive Summary & Key Judgments

PhytoGrid is a novel, fully bio-based nanocomposite platform designed to replace conventional, non-recyclable petroleum-derived epoxy systems in high-stress, high-temperature applications (aerospace, defense, automotive). Our core innovation is the marriage of a high-performance, Cardanol-Tannin-derived polymer matrix with an integrated **tri-scale reinforcement system** (Nano, Micro, Macro) to ensure superior mechanical integrity and $T_g > 300^{\circ}\text{C}$ performance.

Key Deliverables & Target Performance:

Component	Function	Scale	Feedstock	Key Metric
A-Epoxy	Matrix Monomer	N/A	Cardanol (CNSL)	Bio-Content $\geq 90\%$
B-Hardener	Dynamic Curing	N/A	Tannin / Bio-Amine	Enables

Component	Function	Scale	Feedstock	Key Metric
	Agent			$\textbf{\text{T}_g > 300^{\circ}\text{C}}$
C-TCNM	Nano Reinforcement / Conductive Grid	Nano ($\text{approx } 10\text{ nm}$)	Tannin	Conductivity $\textbf{> } 100\text{ S/m}$
D-CTB	Fracture Toughener / Flow Control	Micro ($\text{approx } 10\text{ }\mu\text{m}$)	Cardanol/Tannin Biochar	Improves K_{IC} (Fracture Toughness)
E-TDCF	Structural Load Carrier	Macro ($\text{approx } 5\text{ }\mu\text{m fiber D}$)	Tannin	Ultimate Tensile Strength $\textbf{> } 1.0\text{ GPa}$

Key Judgments (Unfiltered): Implementing this tri-scale architecture necessitates precise control over two new variables: (1) The particle size distribution of the **CTB** (D-Component) to avoid viscosity spikes during infusion, and (2) The surface treatment of the **TDCF** (E-Component) to ensure covalent bonding with the bio-epoxy matrix for efficient load transfer. The Hemproxies precedent proves the tri-scale model is the required high-performance benchmark.

2. Component Specification (5-Component PhytoGrid Tri-Scale)

2.1. Component A: Cardanol-Derived Epoxy Resin (A-Epoxy)

- **Role:** Provides the main polymer backbone, replacing petrochemical monomers. The rigid phenolic ring structure of Cardanol is critical for high T_g [1.1].
- **Synthesis:** Cardanol is isolated, purified, and subjected to a two-step epoxidation process to form a multi-functional epoxy equivalent [2.1].
- **Target:** Epoxy Value $\text{approx } 0.45\text{ eq/100g}$.

2.2. Component B: Tannin-Derived Dynamic Amine Hardener (B-Hardener)

- **Role:** The curing agent that defines both the thermal performance (T_g) and the reprocessability (Vitrimers functionality) via dynamic bond exchange (transesterification) [3.3].
- **Synthesis:** Condensed Tannin is chemically modified via Mannich amination to introduce amine (NH_2) groups. A metal-free catalyst (DBU) is integrated to accelerate the bond exchange [5.1].
- **Target:** Amine Hydrogen Equivalent Weight (AHEW) precisely calculated for 1:1 stoichiometric ratio with the A-Epoxy.

2.3. Component C: Tannin-Derived Carbon Nanosheets (TCNM)

- **Role: Nano Reinforcement** for mechanical strength and the primary **conductive agent** to form the internal electrical nanogrid.
- **Synthesis:** Hydrothermal Carbonization (180°C) followed by high-temperature Pyrolysis (900°C) under inert atmosphere [4.1].
- **Target:** Conductivity $> 100\text{ S/m}$ at 3 wt% loading.

2.4. Component D: Cardanol/Tannin-Derived Biochar (CTB) - Micro-Scale Reinforcement

- **Role: Micro Reinforcement.** Serves as a low-cost, rigid micro-filler to improve fracture toughness and modulate the resin flow characteristics, bridging the gap between nano and macro scales [4.3].
- **Synthesis:** Co-pyrolysis of Cardanol and Tannin precursors at 600°C (lower than TCNM) followed by milling and sieving to control particle size.
- **Target:** Particle Size: $1\text{ }\mu\text{m}$ to $10\text{ }\mu\text{m}$. Loading: 5-8 wt% in the matrix.

2.5. Component E: Tannin-Derived Carbon Fiber (TDCF) - Macro-Scale Reinforcement

- **Role: Macro Reinforcement.** The main load-bearing element, replacing conventional PAN-based carbon fiber. Essential for achieving the target mechanical modulus and structural integrity [7.2].
- **Synthesis:** Tannin dissolved in an appropriate solvent (e.g., DMSO) is electrospun or wet-spun into green fibers. These fibers are then stabilized and pyrolyzed at 1000°C to produce high-strength carbon fibers [7.3].
- **Target:** Fiber Diameter: $5\text{ }\mu\text{m}$ to $10\text{ }\mu\text{m}$. Tensile Strength $> 1.0\text{ GPa}$.

3. Protocol: PhytoGrid Nanocomposite Matrix Preparation

This matrix preparation now integrates the C and D components before the final curing step.

3.1. Stage 1: Cardanol-Epoxy (A-Epoxy) Synthesis (As per 2.1)

3.2. Stage 2: Tannin-Amine Dynamic Hardener (B-Hardener) Modification (As per 2.2)

3.3. Stage 3: Tri-Scale Filler Dispersion (Matrix Preparation)

1. **D-CTB Integration (Micro-Scale):** Disperse 5.0 wt% of the CTB powder into the Cardanol-Epoxy resin (A-Component). Mix using a high-shear impeller for 30 min at 80°C .
2. **C-TCNM Integration (Nano-Scale):** Add 3.0 wt% of the TCNM powder (C-Component). Follow with high-intensity probe sonication for 15 min with ice bath

- cooling to ensure de-agglomeration and formation of the conductive nanogrid [4.2].
3. **Resin Mixing:** Combine the filler-loaded A-Epoxy with the stoichiometric amount of B-Hardener (including DBU catalyst). Mix gently to avoid air entrainment.
 4. **Degassing:** Degas the final liquid resin blend under vacuum at 60°C for 15 min until all bubbles are removed. This ensures a void-free composite laminate.

4. Final Manufacturing Protocol: TDCF Layup and Consolidation

This step converts the liquid resin (A, B, C, D) and the macro-fiber (E) into the final structural composite laminate.

4.1. E-TDCF Fiber Pre-Treatment (Macro-Scale)

1. **Sizing Removal:** Wash the TDCF fabric/tow with acetone and deionized water to remove any residual processing aids (sizing) that could impede chemical bonding with the A/B matrix.
2. **Surface Activation:** Treat the cleaned TDCF with a mild plasma or ozone treatment for 5 min . This increases the surface functional groups (OH , COOH) for covalent bonding with the A-Epoxy resin [7.1].
3. **Drying:** Dry the activated TDCF at 100°C for 30 min to remove all moisture.

4.2. Composite Laminate Consolidation

1. **Layup:** Prepare a mold for a 4 mm thick laminate. Lay up 8 plies of the TDCF fabric in a $[0/90/0/90]_s$ symmetric orientation.
2. **Infusion (VARTM):** Employ the Vacuum Assisted Resin Transfer Molding (VARTM) technique. The degassed PhytoGrid resin is infused into the dry fiber preform under a vacuum of -0.9 bar . This ensures maximum fiber volume fraction ($V_f > 60\%$) and minimal void content.
3. **Curing Schedule (As per 3.3):**
 - **Pre-Cure:** 100°C for 2 hours .
 - **Post-Cure (T_g Max):** 180°C for 3 hours .
 - **Vitrimer Activation:** 250°C for 1 hour .

5. Characterization & Validation Targets

Metric	Test Method	Target Value	Strategic Purpose
Glass Transition Temp (T_g)	Dynamic Mechanical Analysis (DMA)	$> 300^{\circ}\text{C}$	Aerospace standard.
Reprocessability	Hot-press at 200°C (T_v analysis)	$\geq 85\%$ Mechanical Property Retention (after 5 cycles)	Validates closed-loop Vitrimer functionality [5.3].
Electrical Conductivity	Through-thickness Resistance	$> 100\text{ S/m}$	Confirms conductive TCNM Nanogrid is

Metric	Test Method	Target Value	Strategic Purpose
			formed.
Flexural Modulus	Three-Point Bending (ASTM \text{D}790)	$\mathbf{> 60\text{GPa}}$	<i>New Target</i> based on macro-fiber reinforcement.
Interlaminar Shear Strength (\text{ILSS})	Short Beam Shear (ASTM \text{D}2344)	$\mathbf{> 60\text{MPa}}$	Critical check for fiber-matrix adhesion (load transfer) [6.3].

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