Seshat's Bones: A Hemp-Based Composite Material Research and Development Roadmap

Author: Marie Seshat Landry, CEO, Marie Landry Spy Shop
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1. Executive Summary

Seshat's Bones is a forward-looking research and development project aimed at developing a novel **hemp-based composite material** capable of replacing graphene-enhanced epoxies in various industrial and defense-grade applications. This roadmap outlines a phased scientific development from basic testing to commercial deployment, culminating in a fully hemp-derived, biodegradable, and circular composite solution named **Hempoxy**. The project embodies a commitment to ecological science, ethical intelligence, and post-predatory economics, driving the **Organic Revolution of 2030** through sustainable infrastructure and military-grade sustainability.

2. Introduction

The demand for high-performance, sustainable materials is rapidly growing across industries, driven by environmental concerns and the need for resilient infrastructure. "Seshat's Bones" addresses this critical need by proposing a revolutionary approach to material science: the development of **Hempoxy**, a carbonized ballistic-grade hemp composite. This paper details the multi-version scientific framework for Hempoxy, tracing its evolution from initial characterization in synthetic matrices to a fully circular, waste-integrating, and commercially viable product. Each version builds upon the last, adding layers of sustainability, circularity, and advanced functionality, ultimately aiming to set new standards for material innovation and environmental stewardship.

3. Version 1.0 – Hemp Nanosheets in Synthetic Epoxy

This initial phase focuses on establishing the foundational properties of hemp-derived carbon allotrope nanosheets (H-CANs) within a known matrix.

3.1 Objective

To characterize the mechanical and electrical properties of **hemp-derived carbon allotrope nanosheets (H-CANs)** within conventional synthetic epoxy resin. This serves as a critical baseline for subsequent development of fully hemp-derived systems.

3.2 Scope

- Compare the performance of H-CAN-epoxy composite to traditional graphene-enhanced epoxy, identifying key advantages and areas for improvement.
- Characterize the composite's **tensile strength, flexural modulus, impact resistance, and electrical conductivity**.
- Validate nanosheet dispersion, bonding, and overall performance within the synthetic epoxy matrix.

3.3 Methods

- Nanosheet dispersion will be achieved via **ultrasonic agitation** to ensure uniform distribution within the resin.
- Composite molding will utilize **vacuum casting** to minimize voids and ensure material integrity.
- Testing protocols will adhere to **ASTM standards**: ASTM D638 (tensile), ASTM D790 (flexural), ASTM D256 (impact), and a four-point probe method for electrical conductivity. **Scanning Electron Microscopy (SEM)** and **Transmission Electron Microscopy (TEM)** will be employed for microstructural analysis, focusing on nanosheet dispersion and interfacial adhesion.

4. Version 1.1 – Fully Hemp-Derived Composite: Hempoxy + Hemp Nanosheets (Baseline High-Performance Bio-Nanocomposite)

This pivotal version marks the transition to a completely hemp-derived composite, synthesizing both the resin and fillers from hemp biomass.

4.1 Objective

To synthesize epoxy resin (**Hempoxy**) from hemp biomass and combine it with hemp nanosheets, achieving a **100% hemp-derived composite**. This establishes the core bio-nanocomposite system.

4.2 Scope

- Extract key chemical precursors such as **lignin, vanillic acid, and ferulic acid** from hemp biomass.
- Synthesize the Hempoxy epoxy monomer and develop suitable **bio-based hardeners** for optimal curing.
- Validate the mechanical integrity and crosslinking behavior of the fully bio-derived system.
- Address high resin viscosity to ensure ease of processing.

4.3 Methods

- **Green chemistry principles** will be strictly followed, emphasizing minimal solvent use and enzymatic catalysis for extraction and synthesis processes.
- Characterization techniques will include **Fourier-Transform Infrared Spectroscopy (FTIR), Nuclear Magnetic Resonance (NMR), Differential Scanning Calorimetry (DSC), and Thermogravimetric Analysis (TGA)** to confirm chemical structure, thermal properties, and crosslinking.
- Benchmarking will be conducted against the synthetic epoxy composite developed in Version 1.0 to assess performance parity or superiority.

4.4 Formulation Details

The baseline formulation for this version includes:

- **Epoxidized Hemp Oil (EHO)**: The primary resin component, derived from hemp seeds and chemically modified to possess epoxide groups for crosslinking.
- **Furfuryl Glycidyl Ether (FGE)**: A bio-based reactive diluent used to reduce the viscosity of EHO, improving processability without compromising final properties.
- **Pyrolyzed Hemp Biochar**: Adds stiffness, reduces weight, and contributes to the composite's carbon footprint reduction.
- **Maleic Anhydride-Modified Hemp Lignin (MA-Lignin)**: Acts as a natural binder, enhancing interfacial bonding between the resin and fillers.
- **Carboxylated Hemp-Derived Carbon Nanosheets (HDCNS)**: Provides significant strength and potential conductivity enhancements, acting as graphene's bio-based counterpart.
- **Azelaic Anhydride**: A bio-based curing agent that facilitates the crosslinking reaction of the EHO.

4.5 Performance Targets

- **Tensile Strength:** ge110–150 MPa, demonstrating high-performance characteristics competitive with synthetic alternatives.

5. Version 1.2 – Pollution Upcycling Additives (Waste Sequestration Integration)

This version integrates waste materials into the composite, creating a dual-purpose material for structural strength and environmental remediation.

5.1 Objective

To integrate **upcycled waste** as functional fillers into the hemp composite matrix, creating a dual-purpose material for structural strength and **pollution sequestration**.

5.2 Scope

- Identify and process suitable waste streams for integration into the Hempoxy matrix.
- Optimize filler loading and surface treatment for compatibility and performance.
- Validate the composite's ability to encapsulate pollutants while maintaining mechanical integrity.

5.3 Composite Additives and Functions

- **Hemp Biochar (5–20%)**: Provides reinforcement and enhances thermal stability.
- **Fly Ash/Metakaolin (5–15%)**: Contributes to structural reinforcement and thermal control.
- **Microplastics (1–5%)**: Specifically, **Waste-Derived Functional Filler (WDF)**, such as ground-up microplastics and busted Styrofoam, will be encapsulated. These will be surface-treated, often pre-coated in lignin, to ensure compatibility and strong bonding within the Hempoxy matrix.

5.4 Processing Protocol

- All solid additives will be dried at 60^\\circC under vacuum to remove moisture.
- Solids will be dispersed into the Hempoxy resin using **ultrasonication** at 60^\\circC for 30–60 minutes to ensure homogeneous distribution.
- The curing agent will be added, thoroughly mixed, and the composite will be molded and cured at temperatures ranging from 80–150^\\circC for 2–6 hours, depending on the specific formulation.

5.5 Testing and Performance Metrics

- Mechanical testing will follow **ASTM standards** (D638 for tensile, D790 for flexural, D695 for compressive strength).
- Thermal behavior will be assessed using **TGA/DSC**.
- **SEM and FTIR** will be used to analyze dispersion, interfacial adhesion, and the chemical interactions between the matrix and additives.
- Additional tests will include moisture resistance, UV aging, and rigorous **pollutant leachate analysis** to confirm sequestration effectiveness.

5.6 Performance Targets

- **Waste Sequestration:** 99 of introduced WDF remains locked within the composite, preventing environmental release.

6. Version 1.3 – Biodegradable and Circular Composite (Controlled Degradation and Circularity)

This advanced version focuses on end-of-life solutions, enabling controlled degradation and full recyclability to close the material loop.

6.1 Objective

To develop a high-performance hemp-based composite capable of **controlled degradation and full recyclability**, aligning with circular economy principles.

6.2 Scientific Hypothesis

If **cleavable linkers** (photo-sensitive, thermally labile, enzymatically cleavable) are integrated into the Epoxidized Hemp Oil (EHO) matrix, then the composite will degrade under specific triggers, enabling material recovery without compromising performance during its intended use.

6.3 Formulation Enhancements

- **Cleavable Linkers:** Incorporation of specific chemical bonds such as Diels-Alder adducts, disulfide bonds, or ester-based linkages that can be broken under controlled conditions.
- **Trigger Mechanisms:** Activation of degradation through external stimuli such as UV light, specific pH levels, enzymatic action, or controlled thermal exposure.
- **Degradation Control:** Designing the matrix for controlled degradation while preserving valuable fillers for recovery and reuse.

These "Optional Chaos Modules" are crucial for enabling the composite's "afterlife planning."

6.4 Performance Targets

- **Tensile Strength:** ge90 MPa, ensuring high performance during the material's active lifespan.
- **Tunable Degradation:** Achieve a specified mass loss (X%) per defined time (Y hours) under controlled trigger conditions.
- **Filler Recovery:** geZ of valuable fillers recovered post-degradation.
- **Composite Recyclability:** geW of retained properties in re-fabricated samples after recycling.

6.5 Experimental Design

- Synthesis of cleavable monomers and their integration into the Hempoxy formulation.
- Detailed **degradation kinetics modeling** to predict and control the degradation process.

- Comprehensive recovery and recharacterization protocols for fillers to ensure their suitability for reuse.
- Validation of recyclability through the re-fabrication of samples from recovered materials and re-assessment of their properties.

7. Version 1.4 – Commercial Deployment: Hempoxy (Scalability and Life Cycle Dominance)

The final version focuses on bringing Hempoxy to market, ensuring scalable production and a fully validated, sustainable life cycle.

7.1 Objective

To finalize and commercialize the composite system as **Hempoxy**, ensuring scalable manufacturing, complete life-cycle validation, and industry readiness. This version positions Hempoxy as a "**Revolutionary Material**" that is "100% organic, from aeroponically grown hemp" and "stronger/lighter than steel."

7.2 Production Strategy

- Implement **continuous-flow synthesis** for Epoxidized Hemp Oil (EHO) and lignin to enable large-scale production.
- Utilize industrial processing techniques such as **twin-screw extrusion** and **compression molding** for efficient composite fabrication.
- Develop industrial-scale pyrolysis methods for hemp biomass and efficient nanosheet exfoliation for high-volume filler production.
- Optimize the integration of lignin-coated Waste-Derived Functional Filler (WDF) and refine curing protocols for consistent, high-quality output.

7.3 Life Cycle Assessment (LCA)

- Conduct a comprehensive **cradle-to-cradle Life Cycle Assessment** following ISO 14040/44 standards.
- Benchmark Hempoxy's environmental impact against conventional materials like aluminum and fiberglass.
- Key metrics for assessment will include embodied energy, carbon dioxide (CO$_2$) emissions, water consumption, waste generation, and toxicity.

7.4 Pilot-Scale Testing

- Conduct rigorous mechanical, functional, and recycling validation at pilot scale to confirm performance under real-world conditions.
- Perform detailed **economic feasibility studies** and **supply chain modeling** to ensure commercial viability and robust logistics.

7.5 Commercialization and Impact

Hempoxy is envisioned for widespread adoption in **defense and green infrastructure applications**. Commercialization strategies will include direct sales, intellectual property (IP) licensing, and the development of various end-products. The material's alignment with **NATO/UN Sustainable Development Goals (SDGs)** underscores its commitment to public-good stewardship and military-grade sustainability. The broader vision includes its potential for extraterrestrial development, such as in "**Mission: Mars**," where Hempoxy's properties would be invaluable for building habitats and infrastructure.

8. Conclusion

The "Seshat's Bones" roadmap culminates in **Hempoxy**: a regenerative, performance-engineered hemp composite fulfilling critical material science, environmental justice, and circular economy goals. From nano-scale innovation to industrial rollout, this roadmap embodies **Organic Law principles, public-good stewardship, and military-grade sustainability**. As a visionary project led by Marie Seshat Landry, CEO of Marie Landry Spy Shop, Hempoxy represents a paradigm shift in material development, promising a future where advanced materials are not only high-performing but also inherently sustainable and restorative to the planet.

Relevant Links:

- **Hemp-based Composites and Bioplastics:** This link from Springer Nature discusses the properties and applications of natural fiber-reinforced polymer composites, including hemp: https://link.springer.com/chapter/10.1007/978-981-19-6140-5_1
- **Bio-based Epoxies and Green Chemistry:** An article from MDPI's *Polymers* journal on recent advancements in bio-based epoxy resins, touching on green chemistry approaches: https://www.mdpi.com/2073-4360/14/19/4144
- **Circular Economy and Material Upcycling:** A resource from the Ellen MacArthur Foundation, a leading organization in promoting the circular economy, which aligns with your goals for material recovery and pollution upcycling: https://www.ellenmacarthurfoundation.org/topics/circular-economy-introduction/overview