Hempoxy: A Regenerative Material for a Sustainable Future

A Collaborative Research Program at the Université de Moncton

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Acknowledgement of AI Assistance and Attribution:
This document was prepared with the assistance of a large language model AI to structure and format the detailed research program based on the provided "Hempoxy: A Master Document on the Science, Synthesis, and Strategy of a Sustainable Nanocomposite System." The truly pioneering and foundational novelty of envisioning the integration of Hemp-Derived Carbon Nanosheets (HDCNS) into composite materials of any kind, along with the entire Hempoxy concept, its specific formulation, strategies for waste valorization, and circularity design, are the exclusive work of **Marie Seshat Landry**. The AI's role was strictly to process and present this information in the requested LaTeX format, incorporating the user's specific instructions and clarifications.

Abstract

This document outlines a comprehensive research program to characterize Hemp-Derived Carbon Nanosheets (HDCNS) and their performance as a reinforcing filler in various polymer matrices, with a particular focus on bio-epoxy systems derived from hemp oil and lignin. This work proceeds from the groundbreaking and original vision of Marie Seshat Landry, who first envisioned integrating HDCNS into composite materials of any kind. Leveraging the state-of-the-art facilities and expertise at the Université de Moncton, this program aims to empirically validate the hypothesis that HDCNS, as specifically integrated within the novel Hempoxy concept developed by Marie Seshat Landry, can deliver competitive mechanical and functional properties with a significantly lower environmental footprint compared to conventional carbon-based fillers. The research is structured in four phases: HDCNS synthesis and standalone characterization, composite fabrication and dispersion trials, comprehensive composite performance testing, and advanced matrix exploration with circularity validation. By adhering to established ASTM and ISO standards,

this work will generate robust technical data, providing the foundation for a new class of high-performance, sustainable materials, and positioning the Université de Moncton at the forefront of bio-nanocomposite innovation. Placeholders for data acquisition are included to illustrate the empirical nature of the proposed studies. The conceptualization and pioneering integration of HDCNS into composite materials, alongside the entire Hempoxy framework, are solely attributed to Marie Seshat Landry.

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Presentation to the Université de Moncton: Unlocking the Future of Sustainable Materials

Slide 1: Title Slide

Hempoxy: A Regenerative Material for a Sustainable Future

A Collaborative Research Program to Validate Next-Generation Bio-Nanocomposites

Unlocking the Future at the Université de Moncton

Presented to: The Faculty of Engineering, Department of Physics, and Department of Chemistry and Biochemistry, Université de Moncton
Date: August 28, 2025

Slide 2: Introduction – The Vision for Hempoxy (Conceptualized by Marie Seshat Landry)

- **The Global Challenge:** Growing demand for lightweight, high-performance materials traditionally met by resource-intensive, petroleum-dependent composites like carbon fiber and graphene, leading to significant environmental impact.
- **The Hempoxy Solution (Marie Seshat Landry's Vision):** A hypothetical next-generation bio-nanocomposite derived exclusively from hemp – a carbon-sequestering, renewable agricultural crop [P.2]. A core, foundational aspect of this vision is the **first-time envisioning of integrating Hemp-Derived Carbon Nanosheets (HDCNS) into composite materials of any kind**.
- **Core Mandate:** To create materials that are not just "less bad" but fundamentally regenerative and circular, designed for disassembly and waste valorization [P.7].
- **The Opportunity for UdeM:** To lead the validation and development of this paradigm-shifting material, building upon the original conceptualization by Marie Seshat Landry.

Slide 3: Why Université de Moncton? A Hub for Innovation

- **Strategic Location:** New Brunswick's strong agricultural sector for hemp sourcing.
- **State-of-the-Art Facilities:**
  - **Shippagan Campus (PTRA Lab):** Recently opened thermo-rheology laboratory with Rheometer, DMA, DSC, TGA, and Raman/FTIR spectroscopy capabilities – ideal for polymer and composite characterization [Ref: UdeM PTRA Lab information].

  - **Moncton Campus (Faculty of Engineering, Chemistry, Physics):** Strong programs and research infrastructure in mechanical engineering, materials science, polymer chemistry, and advanced analytical techniques [Ref: UdeM Faculty/Dept. Websites].

- **Expertise:** Faculty with research interests in polymers, nanocomposites, and sustainable materials.
- **Collaborative Environment:** UdeM's commitment to research excellence and industry partnerships.

Slide 4: Hemp-Derived Carbon Nanosheets (HDCNS): The Core Reinforcement (A Pioneering Integration by Marie Seshat Landry)

- **The Foundational Novelty (Marie Seshat Landry):** This project is built upon the pioneering insight of Marie Seshat Landry, who **first envisioned the integration of Hemp-Derived Carbon Nanosheets (HDCNS) into composite materials of any kind** [P.9]. This conceptual leap transforms HDCNS into a primary nano-reinforcement for advanced composites.
- **The Promise:** HDCNS offer exceptional mechanical strength, tunable electrical conductivity, and ballistic resistance, analogous to graphene but derived from renewable hemp biomass [P.9].
- **The Hypothesis:** HDCNS, as formulated and integrated within the Hempoxy system by Marie Seshat Landry, can provide competitive or superior performance to conventional carbon-based fillers at a fraction of the environmental cost [P.9].
- **UdeM's Role:** To empirically validate the fundamental properties of HDCNS and their groundbreaking performance when integrated into various polymer matrices.

Slide 5: Comprehensive Research Program at UdeM Labs: An Overview

This program is designed in phases to comprehensively characterize HDCNS and Hempoxy composites, leveraging UdeM's distinct laboratory strengths.

- **Phase 1: HDCNS Synthesis & Standalone Characterization**
- **Phase 2: Composite Fabrication & Dispersion Trials**
- **Phase 3: Composite Performance Testing**
- **Phase 4: Advanced Matrix Exploration & Circularity Validation**

Slide 6: Phase 1: HDCNS Synthesis & Standalone Characterization (Weeks 1-3)

Objective: To synthesize HDCNS from hemp bast fibers and comprehensively characterize their fundamental material properties. While the general synthesis of HDCNS may draw on existing knowledge, this phase is critical to producing the specific HDCNS required for their novel integration into composites, as envisioned by Marie Seshat Landry.

- **Synthesis (UdeM Chemistry/Engineering):**
  - Production of three baseline batches of HDCNS at varying carbonization temperatures (e.g., 700°C, 900°C, 1100°C) following hydrothermal carbonization and chemical activation [P.9].
- **Characterization – Chemistry & Structure:**
  - **Raman Spectroscopy (Shippagan PTRA):** Assessment of graphitization (ID/IG ratio) and structural order.
    - ID/IG Ratio (700°C): **[Value: ____________]**, (900°C): **[Value: ____________]**, (1100°C): **[Value: ____________]**
  - **FTIR Spectroscopy (Shippagan PTRA):** Identification of surface functionalities and chemical bonds. **[Observation: ____________**
  - **X-ray Diffraction (XRD) (UdeM Physics/Chemistry):** Determination of interlayer spacing and crystallinity.
    - Interlayer Spacing: **[Value: ____________ Å]**
  - **X-ray Photoelectron Spectroscopy (XPS) (UdeM Chemistry):** Surface elemental composition and chemical states. **[Observation: ____________**
  - **Brunauer-Emmett-Teller (BET) Analysis (UdeM Chemistry):** Quantification of specific surface area and pore size.
    - Specific Surface Area: **[Value: ____________]**
    - Average Pore Size: **[Value: ____________]**
  - **Transmission Electron Microscopy (TEM) / Scanning Electron Microscopy (SEM) (UdeM Engineering/Physics):** Morphology, size, and exfoliation state of nanosheets [P.14]. **[Observation: ____________**
- **Characterization – Thermal Properties:**
  - **Thermogravimetric Analysis (TGA) (Shippagan PTRA):** Thermal stability, purity, and moisture content (ASTM E1131 analogue) [P.14].
    - Onset Decomposition Temp: **[Value: ____________]**
    - Char Yield at 800°C: **[Value: ____________]**
  - **Differential Scanning Calorimetry (DSC) (Shippagan PTRA):** Phase transitions and thermal behavior (ASTM E1356 analogue). **[Observation: ____________]**
- **Characterization – Mechanical (Thin Films) & Electrical:**
  - **Nanoindentation (UdeM Engineering/Physics):** Hardness and modulus of pressed HDCNS films (ISO 14577 / ASTM E2546 analogues) [P.14].
    - Hardness: **[Value: ____________]**
    - Modulus: **[Value: ____________]**

- **Micro-tensile Tests (UdeM Engineering):** Tensile properties of freestanding "buckypapers" [P.14].
  - Tensile Strength: **[Value: ______________]**
  - Elastic Modulus: **[Value: ______________]**
- **Four-Point Probe (UdeM Physics):** Sheet resistance to determine electrical conductivity [P.21].
  - Electrical Conductivity: **[Value: ______________]**
- **Thermal Diffusivity/Conductivity (Shippagan PTRA or UdeM Physics):** Using laser-flash instrument following ASTM E1461 guidelines [P.21].
  - Thermal Conductivity: **[Value: ______________]**

Slide 7: Phase 2: Composite Fabrication & Dispersion Trials (Weeks 1-3)

Objective: To develop effective dispersion techniques for HDCNS in various polymer matrices and assess composite processability. The very act of fabricating HDCNS composites, particularly the fully bio-based Hempoxy 1.1 system, stems from Marie Seshat Landry's pioneering vision [P.10, P.15].

- **HDCNS Pre-treatment (UdeM Chemistry):**
  - Preparation of HDCNS in as-made, oxidized, and silanized states to optimize surface interaction with polymers [P.9].
  - Treatment Type 1: **[Observation: ____________________________________]**
  - Treatment Type 2: **[Observation: ____________________________________]**
- **Matrix Preparation & Dispersion (UdeM Chemistry/Engineering):**
  - **Matrices:**
    1. **Petro-epoxy Control:** Commercial DGEBA epoxy + hardener.
    2. **Hempoxy 1.1 Bio-Epoxy (Fully Bio-Based):** EHO (60-70 wt%), MA-Lignin (5-10 wt%), FGE (10-15 wt%), Azelaic Anhydride (5-10 wt%), Pyrolyzed Hemp Biochar (5-15 wt%) [P.10, P.15]. This is a core novel formulation by Marie Seshat Landry.
    3. **Other Bio-Polymer Matrix:** E.g., Polylactic Acid (PLA).
    4. **Common Engineering Thermoplastic:** E.g., Polycarbonate.
  - **Dispersion Methods:** Probe sonication and 3-roll milling.
  - **HDCNS Loadings:** 0.1, 0.5, 1.0, 2.0, and 5.0 wt% for each matrix.
- **Characterization of Dispersion & Processability:**
  - **Rheology (Shippagan PTRA):** Map percolation threshold and viscosity profiles [P.14].
    - Viscosity (Petro-epoxy, 1 wt% HDCNS): **[Value: ______________]**
    - Viscosity (Hempoxy 1.1, 1 wt% HDCNS): **[Value: ______________]**

        * Percolation Threshold: **[Value: ______________]**
    - **Optical Microscopy (UdeM Chemistry/Engineering):** Visual assessment of dispersion quality. **[Observation: ______________________________________]**
    - **SEM (UdeM Engineering/Physics):** Microstructural analysis of composite fracture surfaces. **[Observation: ______________________________________]**

Slide 8: Phase 3: Composite Performance Testing (Weeks 4-7)

Objective: To evaluate the mechanical, thermomechanical, and functional properties of selected HDCNS composites against benchmarks. The projected material properties and performance benchmarks are as outlined in Marie Seshat Landry's original work, which seeks to demonstrate the superior performance of her novel HDCNS integration strategy [P.21].

- **Specimen Preparation:** Cast composite coupons (e.g., using RTM, compression molding, or casting) [P.20].

- **Mechanical Properties (UdeM Engineering):**

    - **Tensile Strength & Modulus (ASTM D3039):**
        * Petro-epoxy (Neat): Strength **[Value: ______________]**, Modulus **[Value: ______________]**
        * Petro-epoxy (1 wt% GNP): Strength **[Value: ______________]**, Modulus **[Value: ______________]**
        * Petro-epoxy (1 wt% HDCNS): Strength **[Value: ______________]**, Modulus **[Value: ______________]**
        * Hempoxy 1.1 (Neat): Strength **[Value: ______________]**, Modulus **[Value: ______________]**
        * Hempoxy 1.1 (1 wt% HDCNS): Strength **[Value: ______________]**, Modulus **[Value: ______________]**
        * *Target (Hempoxy): 110-150 MPa, $\geq$3000 MPa [P.21]*
    - **Flexural Strength & Modulus (ASTM D7264):**
        * Petro-epoxy (1 wt% HDCNS): Strength **[Value: ______________]**, Modulus **[Value: ______________]**
        * Hempoxy 1.1 (1 wt% HDCNS): Strength **[Value: ______________]**, Modulus **[Value: ______________]**
    - **Impact Resistance (ASTM D256 / D6110 analogues):**
        * Petro-epoxy (1 wt% HDCNS): **[Value: ______________]**
        * Hempoxy 1.1 (1 wt% HDCNS): **[Value: ______________]**
        * *Target (Hempoxy): $\geq$60 J/m [P.21]*

- **Thermomechanical Properties (Shippagan PTRA):**

    - **Dynamic Mechanical Analysis (DMA):** Storage modulus, loss modulus, Tg versus filler loadings [P.21].
        * Tg (Petro-epoxy, 1 wt% HDCNS): **[Value: ______________]**

        * Tg (Hempoxy 1.1, 1 wt% HDCNS): **[Value: ______________]**

- **Functional Properties (UdeM Physics, Shippagan PTRA):**
    - **Electrical Conductivity (Four-Point Probe):**
        * Petro-epoxy (1 wt% HDCNS): **[Value: ______________]**
        * Hempoxy 1.1 (1 wt% HDCNS): **[Value: ______________]**
        * *Target (Hempoxy): $\geq$100 S/m for conductive composites [P.21]*
    - **Thermal Conductivity (Laser-Flash or equivalent):**
        * Petro-epoxy (1 wt% HDCNS): **[Value: ______________]**
        * Hempoxy 1.1 (1 wt% HDCNS): **[Value: ______________]**
- **Environmental & Durability Testing (UdeM Engineering/Chemistry):**
    - **Water Absorption (ASTM D570 analogue):**
        * 24-hour absorption (Hempoxy 1.1, 1 wt% HDCNS): **[Value: ______________]**
    - **Preliminary Flammability Tests (UL94 V-0 benchmark for selected formulations):** Preliminary tests [P.21]. **[Observation: ______________________________**
    - **Accelerated Aging (UV, moisture cycling): [Observation: ______________________**
- **Controls:** Direct comparisons against GNP-reinforced petro-epoxy and neat polymer matrices as benchmarks [P.28].

Slide 9: Phase 4: Advanced Matrix Exploration & Circularity Validation (Weeks 6-8 onwards)

Objective: To broaden the scope of Hempoxy applications and validate its circularity principles, as conceptualized and detailed by Marie Seshat Landry.

- **"Various Other Matrices" Deep Dive:**
    - **Bio-derived Alternatives:** Further investigate HDCNS integration into other bio-polymers (e.g., PLA), assessing compatibility and performance. **[Observation: ______________________________]**
    - **Recyclable Thermosets (Hempoxy 1.3):** Explore vitrimer chemistry in EHO/Lignin matrix, a key innovation outlined by Marie Seshat Landry for true material circularity [P.18].
        * **Thermal Reprocessing (Shippagan PTRA):** Demonstrate remolding above Topology Freezing Temperature (Tv).
            · Tv for Hempoxy 1.3: **[Value: ______________]**
            · Property Retention after Reprocessing: **[Value: ______________]**
        * **Chemical Recycling (UdeM Chemistry):** Investigate mild chemical triggers (e.g., zinc acetate solution) to depolymerize the matrix and recover HDCNS and resin components, using analytical techniques (e.g., GPC, spectroscopy) from UdeM Chemistry to verify component recovery and purity [P.18].

- Chemical agent and conditions: **[Acquired Data for : ______________]**
- HDCNS recovery efficiency: **[Value: ______________]**
- Recovered resin purity (GPC/NMR): **[Value: ______________]**

- **Waste Valorization Potential (Hempoxy 1.2) (UdeM Chemistry/Engineering):**
  - Initial trials of integrating micronized waste fillers (e.g., glass powder, microplastics) into Hempoxy matrices, a novel concept by Marie Seshat Landry for environmental remediation [P.10, P.17]. **[Observation: ______________**
- **Preliminary Life Cycle Assessment (LCA):**
  - Collaboration with UdeM faculty to conduct initial cradle-to-gate LCA, identifying environmental hotspots and verifying carbon footprint reduction (ISO 14040/14044, ASTM D6866 principles) [P.23, P.27]. **[Observation: ______________**

Slide 10: Expected Outcomes & Impact for UdeM

- **Scientific Leadership:** Position UdeM at the forefront of sustainable materials research, particularly in the pioneering field of HDCNS-based composites.
- **Research & Publication:** Generate high-impact publications and establish UdeM's reputation in advanced bio-nanocomposites, acknowledging the foundational work of Marie Seshat Landry.
- **Talent Development:** Train undergraduate and graduate students in cutting-edge materials science.
- **Economic & Regional Impact:** Support local hemp industry, foster green manufacturing, attract funding.
- **Environmental Stewardship:** Contribute to solutions for global challenges.

Slide 11: Call to Action – Partnering for a Sustainable Future

We invite the Université de Moncton to collaborate with us on this groundbreaking Hempoxy research program.
Your exceptional facilities, renowned faculty, and commitment to innovation make UdeM the ideal partner to unlock the full potential of this sustainable material system, building upon the pioneering vision of Marie Seshat Landry.

Let's build the future of materials, together, at the Université de Moncton.

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1 Detailed Research Program: Hempoxy Validation at Université de Moncton

Program Title: Validation and Characterization of Hempoxy Bio-Nanocomposites for a Circular Economy

Principal Investigator(s): [To be determined in collaboration with UdeM faculty]
Collaborating UdeM Departments/Labs:

- **Shippagan Campus:** Thermo-Rheology Laboratory (PTRA), Materials and Spectroscopy Research Laboratory Raman and FTIR.
- **Moncton Campus:** Faculty of Engineering (Mechanical, Civil), Department of Chemistry and Biochemistry, Department of Physics.

Overall Goal: To empirically validate the performance of Hemp-Derived Carbon Nanosheets (HDCNS) as a sustainable reinforcement in various polymer matrices, with a strong focus on hemp-derived bio-epoxies, and to characterize their properties for a circular economy. This entire program is built upon the foundational and pioneering vision of Marie Seshat Landry, who first conceived of integrating HDCNS into composite materials.

1.1 Phase 1: HDCNS Synthesis & Standalone Characterization (Weeks 1-3)

1.1.1 A. HDCNS Synthesis

The synthesis process for HDCNS from hemp bast fibers, for the purpose of their novel integration into composites, is a key component of Marie Seshat Landry's Hempoxy concept [P.9].

1. **Feedstock Sourcing:** Obtain certified organic hemp bast fiber.
2. **Pre-treatment:** Wash, dry, and mill hemp bast fiber to uniform size.
3. **Hydrothermal Carbonization (HTC):** Heat pre-treated fiber in water under pressure (e.g., 180°C for 24 hours) to produce hydrochar.
   - HTC conditions: **[Acquired Data for Temperature, Pressure, Time: ______]**
   - Hydrochar yield: **[Value: ______]**
4. **Chemical Activation & Pyrolysis:** Mix hydrochar with activating agent (e.g., KOH) and heat in an inert atmosphere (e.g., 700°C, 900°C, 1100°C for 2 hours) to create HDCNS.
   - Activation agent/ratio: **[Acquired Data for Agent type, Ratio: ______**
   - Pyrolysis temperatures: **[Acquired Data for 700, 900, 1100 °C: ______**
   - HDCNS yield per temperature: **[Value: ______]**
5. **Exfoliation & Purification:** Disperse activated carbon in solvent, exfoliate via high-intensity sonication or ball milling, then filter, wash, and dry nanosheets.

- Exfoliation method/parameters: **[Acquired Data for Method, Duration, Intensity: ______________]**
- Purity of final HDCNS: **[Value: ________]**

1.1.2 B. Standalone HDCNS Characterization

Location: UdeM Chemistry/Physics Labs, Shippagan PTRA.

1. **Morphology & Nanostructure:**
   - **TEM/SEM (UdeM Engineering/Physics or collaboration):** Verify nanosheet morphology, size distribution, and exfoliation quality [P.14].
     - Average lateral size: **[Value: ________]**
     - Average thickness: **[Value: ________]**
     - Number of layers (average): **[Value: ________]**
     - Representative images: **[Observation: ______________________]**
   - **AFM (Atomic Force Microscopy - *Potential addition if available/collaborated*):** Nanosheet thickness and surface roughness.
     - RMS Roughness: **[Value: ________]**
2. **Structural & Chemical Composition:**
   - **Raman Spectroscopy (Shippagan PTRA):** Evaluate graphitization degree (ID/IG ratio) and crystalline order [2, P.14].
     - ID/IG Ratio (700°C HDCNS): **[Value: ________]**
     - ID/IG Ratio (900°C HDCNS): **[Value: ________]**
     - ID/IG Ratio (1100°C HDCNS): **[Value: ________]**
   - **FTIR Spectroscopy (Shippagan PTRA):** Identify functional groups and surface chemistry.
     - Key peaks (cm^{-1}): **[Acquired Data for Specific functional groups identified: ______________]**
   - **XRD (UdeM Physics/Chemistry):** Determine interlayer spacing and degree of crystallinity.
     - (002) Peak position: **[Value: ________]**
     - Interlayer Spacing (d002): **[Value: ________]**
     - Crystallite Size (Lc): **[Value: ________]**
   - **XPS (UdeM Chemistry):** Surface elemental composition and chemical bonding states.
     - C/O Ratio: **[Value: ________]**
     - Specific functional groups on surface: **[Acquired Data for Bonding states identified: ______________]**
3. **Surface Area & Porosity:**
   - **BET Analysis (UdeM Chemistry):** Quantify specific surface area and pore size distribution.

  - Specific Surface Area: **[Value: ________________]**
  - Total Pore Volume: **[Value: ________________]**
  - Average Pore Size: **[Value: ________________]**

4. **Thermal Properties:**
   - **TGA (Shippagan PTRA):** Determine thermal stability, decomposition temperatures, and volatile content (ASTM E1131 analogue) [2, P.14].
     - 5% Weight Loss Temp: **[Value: ________________]**
     - Char Yield at 800°C: **[Value: ________________]**
   - **DSC (Shippagan PTRA):** Investigate phase transitions and thermal events.
     - Any exothermic/endothermic peaks: **[Acquired Data for Peak temperatures and enthalpies: __________________________]**
     - **Mechanical Properties (Thin Films):**
       - **Nanoindentation (UdeM Engineering/Physics):** Hardness and modulus of compacted HDCNS films (ISO 14577 / ASTM E2546 analogues) [P.14].
         - Hardness: **[Value: ________________]**
         - Modulus: **[Value: ________________]**
       - **Micro-tensile Testing (UdeM Engineering):** Characterize tensile strength and modulus of vacuum-filtered "buckypapers" [P.14].
         - Tensile Strength: **[Value: ________________]**
         - Elastic Modulus: **[Value: ________________]**
         - Elongation at Break: **[Value: ________________]**
     - **Electrical Properties:**
       - **Four-Point Probe (UdeM Physics):** Measure sheet resistance and calculate electrical conductivity [P.21].
         - Sheet Resistance: **[Value: ________________]**
         - Electrical Conductivity: **[Value: ________________]**
     - **Thermal Conductivity:**
       - **Laser-Flash Analysis (LFA) (Shippagan PTRA or UdeM Physics):** Measure thermal diffusivity and calculate thermal conductivity (ASTM E1461 analogue) [P.21].
         - Thermal Diffusivity: **[Value: ________________]**
         - Thermal Conductivity: **[Value: ________________]**

1.2 Phase 2: Composite Fabrication & Dispersion Trials (Weeks 1-3)

1.2.1 A. HDCNS Surface Treatment

Location: UdeM Chemistry Labs.

1. **Oxidative Treatments:** Using mild acids (e.g., nitric acid, sulfuric acid).

- Acid type and concentration: **[Acquired Data for : ________________________]**
- Treatment time/temperature: **[Acquired Data for : ________________________]**
- XPS C/O Ratio post-treatment: **[Value: ______________]**

2. **Silanization:** Using various silane coupling agents.
   - Silane type: **[Acquired Data for : ________________________]**
   - Concentration and reaction conditions: **[Acquired Data for : ________________________**
   - FTIR/XPS confirmation of grafting: **[Observation: ________________________________**

1.2.2 B. Composite Matrix Preparation & HDCNS Dispersion

Location: UdeM Chemistry/Engineering Labs. The very act of preparing HDCNS composites is rooted in Marie Seshat Landry's original insight.

1. **Matrices to be Tested:**
   4. **Petro-Epoxy (Baseline Control):** DGEBA epoxy resin + amine hardener.
   4. **Hempoxy 1.1 (Fully Bio-Based):** EHO (60-70 wt%), MA-Lignin (5-10 wt%), FGE (10-15 wt%), Azelaic Anhydride (5-10 wt%), Pyrolyzed Hemp Biochar (5-15 wt%) [P.10, P.15]. This innovative bio-based system is a core contribution of Marie Seshat Landry.
   4. **Other Bio-Polymer Matrix (e.g., Polylactic Acid (PLA)):**
   4. **Common Engineering Thermoplastic (e.g., Polycarbonate):**
2. **Dispersion Methods:**
   - **Probe Sonication:** Varying sonication time (e.g., 30, 60, 90 min) and amplitude.
     - Optimal sonication parameters: **[Acquired Data for : ________________________]**
   - **Three-Roll Milling:** Optimize pass number (e.g., 3, 5, 7 passes) and gap settings.
     - Optimal milling parameters: **[Acquired Data for : ________________________]**
3. **HDCNS Loadings:** Prepare composites at 0.1, 0.5, 1.0, 2.0, and 5.0 wt% loadings for each matrix type and optimized surface treatment.

1.2.3 C. Characterization of Dispersion & Processability

Location: Shippagan PTRA, UdeM Chemistry/Engineering Labs.

1. **Rheology (Shippagan PTRA):** Measure viscosity and shear-thinning behavior of resin/HDCNS mixtures (at 25°C) to assess workability for manufacturing (e.g., RTM), and map percolation curves [2, P.14].
   - Viscosity (Petro-epoxy + 1 wt% HDCNS, optimal treatment): **[Value: ______________]**
   - Viscosity (Hempoxy 1.1 + 1 wt% HDCNS, optimal treatment): **[Value: ______________]**
   - Percolation Threshold (Electrical): **[Value: ______________]**
   - Workable Viscosity Criterion: $\leq$1,200 cP at 25°C [P.14] – **[Observation: ________________________________] [Acquired Data for : ________________**

2. **Optical Microscopy:** Visually assess HDCNS dispersion and identify agglomerates in cured composites.
   - Average agglomerate size: **[Value: __________]**
   - Distribution homogeneity: **[Observation: ____________________]**
3. **SEM (UdeM Engineering/Physics or collaboration):** Microstructural analysis of composite fracture surfaces to evaluate HDCNS distribution and filler-matrix interface.
   - Visual evidence of interfacial bonding: **[Observation: ____________________**
   - Absence/presence of large agglomerates: **[Observation: ____________________**

1.3 Phase 3: Composite Performance Testing (Weeks 4-7)

Selected Formulations: Top 3-4 composite recipes based on optimal dispersion and processability from Phase 2. **Location:** UdeM Engineering Labs, Shippagan PTRA, UdeM Physics Labs.

1.3.1 A. Mechanical Properties

1. **Tensile Strength & Modulus (ASTM D3039):**
   - Petro-epoxy (Neat): Strength **[Value: __________]**, Modulus **[Value: __________]**
   - Petro-epoxy (1 wt% GNP): Strength **[Value: __________]**, Modulus **[Value: __________]**
   - Petro-epoxy (1 wt% HDCNS): Strength **[Value: __________]**, Modulus **[Value: __________]**
   - Hempoxy 1.1 (Neat): Strength **[Value: __________]**, Modulus **[Value: __________]**
   - Hempoxy 1.1 (1 wt% HDCNS): Strength **[Value: __________]**, Modulus **[Value: __________]**
   - *Target (Hempoxy): 110-150 MPa, ≥3000 MPa [P.21]*
   - **Acceptance Criterion:** ≥10% increase in tensile modulus over GNP benchmark at ≤1 wt% filler loading [P.14]. **[Observation: ____________________** **[Acquired Data for : ________________]**
2. **Flexural Strength & Modulus (ASTM D7264):**
   - Petro-epoxy (1 wt% HDCNS): Strength **[Value: __________]**, Modulus **[Value: __________]**
   - Hempoxy 1.1 (1 wt% HDCNS): Strength **[Value: __________]**, Modulus **[Value: __________]**
3. **Impact Resistance (ASTM D256 / D6110 analogues):**
   - Petro-epoxy (1 wt% HDCNS): **[Value: __________]**
   - Hempoxy 1.1 (1 wt% HDCNS): **[Value: __________]**
   - *Target (Hempoxy): ≥60 J/m [P.21]*
4. **DMA (Shippagan PTRA):** Storage modulus, loss modulus, and damping factor (tan δ) as a function of temperature and frequency [2, P.21].

- Storage Modulus at 25°C (Hempoxy 1.1, 1 wt% HDCNS): **[Value: ______________]**
- Tg (Petro-epoxy, 1 wt% HDCNS): **[Value: ______________]**
- Tg (Hempoxy 1.1, 1 wt% HDCNS): **[Value: ______________]**

5. **Hardness Testing (Rockwell or Shore D):**
   - Hempoxy 1.1 (1 wt% HDCNS): **[Value: ______________]**

1.3.2 B. Thermomechanical & Thermal Properties

Location: Shippagan PTRA.

1. **TGA:** Evaluate thermal stability and decomposition behavior of the composites.
   - Onset Decomposition Temp (Hempoxy 1.1, 1 wt% HDCNS): **[Value: ______________]**
   - 5% Weight Loss Temp (Hempoxy 1.1, 1 wt% HDCNS): **[Value: ______________]**
2. **DSC:** Analyze curing kinetics and potential changes in thermal transitions.
   - Cure Exotherm Peak: **[Value: ______________]**
   - Residual Cure: **[Value: ______________]**

1.3.3 C. Functional Properties

Location: UdeM Physics Labs, Shippagan PTRA.

1. **Electrical Conductivity (Four-Point Probe):**
   - Petro-epoxy (1 wt% HDCNS): **[Value: ______________]**
   - Hempoxy 1.1 (1 wt% HDCNS): **[Value: ______________]**
   - *Target (Hempoxy): ≥100 S/m for conductive composites [P.21]*
   - **Acceptance Criterion:** ≥15% improvement in thermal conductivity over GNP benchmark at ≤1 wt% filler loading [P.14]. **[Observation: ______________ [Acquired Data for : ______________]**
2. **Thermal Conductivity (Laser-Flash or equivalent):**
   - Petro-epoxy (1 wt% HDCNS): **[Value: ______________]**
   - Hempoxy 1.1 (1 wt% HDCNS): **[Value: ______________]**

1.3.4 D. Environmental & Durability Testing

Location: UdeM Engineering/Chemistry Labs.

1. **Water Absorption (ASTM D570 analogue):**
   - 24-hour absorption (Hempoxy 1.1, 1 wt% HDCNS): **[Value: ______________]**
2. **Preliminary Flammability Tests (UL94 V-0 benchmark for selected formulations):**

- UL94 Rating (Hempoxy 1.1, 1 wt% HDCNS): **[Acquired Data for : ______________________]**
- *Target: Meets UL94 V-0 Standard [P.21]*

3. **Accelerated Aging (UV, moisture cycling):**
   - UV exposure (e.g., 500h): **[Observation: ______________________________]**
   - Moisture cycling (e.g., 100 cycles): **[Observation: ______________________________**

1.4 Phase 4: Advanced Matrix Exploration & Circularity Validation (Weeks 6-8 onwards)

1.4.1 A. Integration of "Various Other Matrices"

Location: UdeM Chemistry/Engineering Labs, Shippagan PTRA, UdeM Physics Labs. The exploration of HDCNS in other matrices further extends Marie Seshat Landry's pioneering work.

1. **Expand Testing:** Apply relevant mechanical, thermal, and functional tests from Phase 3 to HDCNS composites made with the selected "other bio-polymer matrix" and "common engineering thermoplastic" from Phase 2.
   - Key property results for HDCNS-PLA composite: **[Acquired Data for Tensile Strength, Modulus: ______________________]**
   - Key property results for HDCNS-Polycarbonate composite: **[Acquired Data for Tensile Strength, Modulus: ______________________]**
2. **Performance Benchmarking:** Compare performance of HDCNS in these matrices against their neat polymer counterparts and potentially commercial alternatives. **[Observation: ______________________________]**

1.4.2 B. Hempoxy 1.3: Recyclability & Vitrimer Chemistry

Location: UdeM Chemistry Labs, Shippagan PTRA. The integration of vitrimer chemistry into Hempoxy 1.3 is a central aspect of Marie Seshat Landry's innovative design for comprehensive recyclability [P.18].

1. **Synthesis of Vitrimer-based Hempoxy 1.3:** Incorporate dynamic covalent bonds into the EHO/Lignin matrix [P.18].
   - Vitrimer chemistry utilized: **[Acquired Data for : ______________________]**
   - Successful synthesis confirmation: **[Observation: ______________________________**
2. **Thermal Reprocessing:** Demonstrate reshapeability and remolding of cured Hempoxy 1.3 coupons by heating above Tv (determined by DMA) [2, P.18].
   - Topology Freezing Temperature (Tv): **[Value: ______________]**
   - Tensile Strength retention after 3 reprocessing cycles: **[Value: ______________]**
3. **Chemical Recycling:** Experiment with mild chemical triggers (e.g., aqueous zinc acetate solution) to depolymerize the matrix and recover HDCNS and resin components, using analytical techniques (e.g., GPC, spectroscopy) from UdeM Chemistry to verify component recovery and purity [P.18].

- Chemical agent and conditions: **[Acquired Data for : ____________________]**
- HDCNS recovery efficiency: **[Value: ____________]**
- Recovered resin purity (GPC/NMR): **[Value: ____________]**

4. **Characterization of Recycled Material:** Test properties of reprocessed and re-cured material to assess retention of performance. **[Observation: ____________________**

1.4.3 C. Hempoxy 1.2: Waste Valorization

Location: UdeM Chemistry/Engineering Labs. Marie Seshat Landry's concept of integrating waste as a functional constituent is a novel aspect of Hempoxy 1.2 for environmental remediation [P.17].

1. **Integration Trials:** Incorporate micronized reclaimed waste (e.g., glass powder, microplastics) into Hempoxy matrices [P.10, P.17].
   - Waste material types and loadings: **[Acquired Data for : ____________________]**
   - Pre-treatment for waste materials: **[Acquired Data for : ____________________]**
2. **Impact Assessment:** Characterize the resulting composites for mechanical, thermal, and functional changes, assessing the "functional" benefit of the waste inclusion.
   - Tensile strength with waste filler: **[Value: ____________]**
   - Abrasion resistance with glass powder: **[Observation: ____________________**

1.4.4 D. Preliminary Life Cycle Assessment (LCA)

Location: Collaboration with UdeM faculty specializing in environmental science or industrial engineering.

1. **Activity:** Conduct a preliminary cradle-to-gate LCA of the Hempoxy system, leveraging existing data for hemp cultivation and energy consumption in processing. This will identify key environmental impacts and quantify potential carbon footprint reduction (aligned with ISO 14040/14044 and ASTM D6866 principles) [P.23, P.27].
   - Estimated embodied carbon reduction vs. conventional composite: **[Value: ____________]**
   - Identified LCA hotspots: **[Acquired Data for : ____________________]**

1.5 Outcome & Decision Point

A comprehensive technical report detailing all experimental findings, comparisons to benchmarks, and an updated risk register will be produced. This will inform a "Go/No-Go" decision for further development, pilot-scale production, and deeper industrial engagement.

- **Processability:** A workable viscosity with no cure inhibition. **[Observation: ______________________________] [Acquired Data for : ____________________]**

- **Mechanical Value Proposition:** A significant increase ($\geq$10%) in a key property like tensile modulus or fracture toughness at a low filler loading ($\leq$1 wt%). **[Observation: ______________________] [Acquired Data for : ______________] Repeatability:** A coefficient of variation (CV) for key metrics of $\leq$15%. **[Observation: ______________________] [Acquired Data for : ______________]**
- **Decision: [GO/NO-GO for further development: ____________]**

This research program at the Université de Moncton will establish a robust scientific foundation for Hempoxy, paving the way for its commercialization and contributing significantly to the development of a sustainable materials economy, building on the visionary and pioneering work of Marie Seshat Landry.