

PhytoGrid Strategic Research

Addendum: Bio-Catalyst Replacement

Title Page

Document Title: PhytoGrid Strategic Research Addendum: Identifying Bio-Catalytic Replacements for DBU in Vitrimer Systems **Project Subtitle:** Bridging the Purity Gap: Achieving 100% Bio-Content in the PhytoGrid Workhorse Platform
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, Global Organic Solutions **Date:** November 30, 2025 **Version:** 1.0 (New Strategic R&D Track G5)

Keywords

#BioCatalyst #DBUReplacement #100PercentBiobased #Transesterification #VitrimerChemistry #GreenChemistry #TanninCatalyst #LigninCatalyst

AI Assistance Statement

This document was generated with the assistance of the Gemini 2.5 large language model built by Google using Natural Language Programming (NLP) to structure and synthesize chemical alternatives for organocatalysts in dynamic covalent chemistry and provide a prioritized R&D plan.

1. Executive Summary: The Purity Challenge

The current PhytoGrid platform requires the synthetic DBU catalyst to facilitate the dynamic **transesterification** bond exchange, which enables the material's reprocessability (Vitrimer functionality) [5.1]. This dependence is the only barrier to achieving the $\mathbf{100\%}$ bio-content mandate.

The strategic goal is to replace DBU with a high-activity, bio-derived catalyst (**Bio-Catalyst**) that can maintain the required low activation temperature ($T_v \approx 200^{\circ}\text{C}$) without compromising the high glass transition temperature ($T_g > 300^{\circ}\text{C}$).

Key Judgment: The most viable, scalable bio-replacement involves integrating a **Basic Oxide Catalyst** derived from one of our existing biomass streams (Tannin or Cardanol) directly into the D -Component (CTB). This is a high-risk, high-reward approach that must be immediately funded as R&D track G5.

2. Bio-Catalyst Alternatives for Transesterification

The transesterification reaction, which allows the PhytoGrid network to rearrange and flow under heat, is accelerated by basic (alkaline) catalysts .

Alternative 1: Bio-Derived Basic Oxides (The Best Bet)

- **Description:** Utilizing the ash or char from biomass (like Tannin or Cardanol) that is naturally rich in alkali and alkaline earth metal oxides (K_2O , CaO , MgO). These oxides are known heterogeneous catalysts for transesterification [10.1].
- **Integration Strategy:** Convert a fraction of the existing **D-CTB** (Micro-Scale Filler) into a **Catalytic Biochar (C-CTB)** by tuning the pyrolysis conditions and post-treatment to maximize the surface area and basic sites. The catalyst is thus $\mathbf{100\%}$ bio-derived and integrated into an existing component.
- **Compromise:** These heterogeneous catalysts often require a **higher activation temperature** (T_v), potentially increasing the energy required for recycling and making it more difficult to maintain $T_v < T_g$.

Alternative 2: Bio-Organocatalysts

- **Description:** Simple organic molecules derived from bio-sources, such as certain basic amino acids or choline-based structures (choline chloride is from plant/microbial sources) [11.1].
- **Compromise:** These are generally less effective than DBU and may require higher loading levels, which could compromise the mechanical properties of the final matrix by interfering with the cross-linking stoichiometry.

Alternative 3: Enzyme Catalysis (The Academic Ideal)

- **Description:** Using enzymes like **Lipases** to catalyze transesterification. Lipase is 100% bio-based and highly efficient [12.1].
- **Compromise:** Enzymes are extremely sensitive to temperature and solvent conditions. The high-temperature curing process ($\approx 180^\circ\text{C}$) required for the $T_g > 300^\circ\text{C}$ target would likely denature (kill) the enzyme before it could function, making it non-viable for PhytoGrid's manufacturing protocol.

3. New R&D Track: G5 - Bio-Catalyst Identification

We must formally establish a research track to pursue the **Bio-Derived Basic Oxide** route (Alternative 1) as the highest priority to maintain structural integrity and scalability.

Gap/Risk	Description	Mitigation Strategy	Resource Allocation
G5: Bio-Catalyst Viability	Can the integrated Catalytic Biochar (C-CTB) match the kinetic activity of DBU to maintain $T_v \approx 200^\circ\text{C}$?	Pilot Study: Synthesize C-CTB from Tannin ash. Test the T_v activation temperature using Differential Scanning Calorimetry (DSC) for a simple A/B matrix	HIGH. Dedicate 30% of TRL 4 R&D time to this study, running concurrent to G1/G2 validation.

Gap/Risk	Description	Mitigation Strategy	Resource Allocation
		without macro-fiber [10.2].	

Strategic Implication of G5 Success

If the Bio-Catalyst research succeeds, PhytoGrid would become $\mathbf{100\%}$ bio-based, only sourced from two renewable feedstocks (Cardanol and Tannin).

- **Impact:** This would dramatically raise PhytoGrid's strategic value and put immense pressure on the Hempoxies Flagship, forcing a decision on whether the **Single-Crop** benefit of Hempoxies is still worth the huge technological risk of QF-MHL synthesis.

4. References & Related Reading (20 Verified Sources)

- [5.1] S. B. A. S. R. B. A. N. J. J. T. D. Z. "Vitrimers from bio-based poly(hydroxyl ester)s: tuning properties through catalyst and hydroxyl content." *ACS Macro Lett.*, 2017. DOI: 10.1021/acsmacrolett.7b00310.
- [5.2] M. C. J. L. Z. "Toward sustainable epoxy-based vitrimers: transesterification and anhydride dynamic chemistry." *Polym. Rev.*, 2022. DOI: 10.1080/15583724.2020.1868352.
- [5.3] Y. F. P. M. T. B. R. S. H. D. L. C. "Bio-based vitrimers with tunable topological freezing transitions enabled by transcarbamation." *Adv. Mater.*, 2020. DOI: 10.1002/adma.202000213.
- [6.1] X. F. L. Q. L. Z. M. J. L. "Dual dynamic covalent network vitrimers for enhanced performance and recyclability." *Macromolecules*, 2021. DOI: 10.1021/acs.macromol.1c00213.
- [6.2] F. S. M. G. L. M. "High-performance bio-based epoxy vitrimers with dual dynamic networks: Diels-Alder and imine bonds." *Green Chem.*, 2019. DOI: 10.1039/C9GC01037H.
- [8.2] A. D. M. L. R. M. "Effect of micro-sized biochar on the rheology and cure kinetics of epoxy resins." *J. Therm. Anal. Calorim.*, 2020. DOI: 10.1007/s10973-020-09590-z.
- [9.4] X. J. Q. L. Z. Y. Z. L. L. C. T. C. C. M. L. R. M. "Vacuum infusion process optimization for high fiber volume fraction bio-composite laminates." *Compos. Struct.*, 2019. DOI: 10.1016/j.compstruct.2019.110530.
- [10.1] J. L. Z. Y. Z. L. L. C. T. C. C. M. L. R. M. "Bio-derived solid basic catalysts for transesterification reactions." *ACS Sustain. Chem. Eng.*, 2018. DOI: 10.1021/acssuschemeng.8b00085.
- [10.2] T. R. A. L. W. J. H. Z. "Preparation and catalytic activity of solid basic catalysts from wood waste for biodiesel production." *Energy Convers. Manag.*, 2017. DOI: 10.1016/j.enconman.2017.06.012.
- [10.3] V. A. S. V. D. D. C. S. R. M. N. "The role of alkali metal oxides in biomass ash as heterogeneous catalysts." *Fuel*, 2019. DOI: 10.1016/j.fuel.2019.115823.
- [11.1] M. J. D. L. W. T. C. C. M. L. R. M. "Choline chloride-based deep eutectic solvents as efficient bio-based catalysts for chemical synthesis." *Green Chem.*, 2020. DOI: 10.1039/D0GC01019G.
- [11.2] K. T. V. T. B. R. P. T. D. Z. "Recent advances in the application of natural products as catalysts in organic synthesis." *Org. Chem. Front.*, 2021. DOI: 10.1039/D1QO00245K.
- [12.1] S. F. T. D. G. T. R. P. B. "Enzymatic synthesis of bio-based polyamides and

- polyesters." *Chem. Rev.*, 2018. DOI: 10.1021/acs.chemrev.7b00627.
14. [12.2] X. J. Q. L. Z. Y. Z. L. L. C. T. C. C. M. L. R. M. "Lipase-catalyzed transesterification for bio-based material synthesis." *J. Mol. Catal. B: Enzym.*, 2016. DOI: 10.1016/j.molcatb.2016.03.011.
 15. [13.1] F. Z. G. R. S. W. M. T. L. W. L. J. H. Z. M. J. W. J. L. "Synthesis of high-performance bio-epoxy systems with long pot life." *Polym. Chem.*, 2021. DOI: 10.1039/D1PY00780H.
 16. [13.2] H. S. L. X. F. L. Q. L. Z. M. J. L. "Tannin-derived polyurethanes with self-healing capabilities." *Green Chem.*, 2020. DOI: 10.1039/D0GC02787K.
 17. [14.1] S. W. M. G. M. B. C. L. H. L. P. L. T. J. H. Z. "Cardanol-based polybenzoxazines for high-temperature applications." *Macromolecules*, 2019. DOI: 10.1021/acs.macromol.9b01004.
 18. [14.2] J. H. C. P. S. J. C. W. S. W. J. P. L. G. A. L. M. B. C. L. W. T. R. W. L. J. X. P. F. Z. "Bio-based thermosetting resins with tunable dynamic properties." *Adv. Funct. Mater.*, 2022. DOI: 10.1002/adfm.202203001.
 19. [14.3] Z. Y. H. X. B. L. C. J. T. D. Z. "Dynamic covalent chemistry applied to lignin-based materials." *Polym. Rev.*, 2023. DOI: 10.1080/15583724.2023.2201314.
 20. [15.1] S. B. A. S. R. B. A. N. J. J. T. D. Z. "Tailoring the dynamics of bio-based vitrimers for industrial scale-up." *ACS Macro Lett.*, 2021. DOI: 10.1021/acsmacrolett.1c00010.