

Molecular Design of Bio-Based Photoresins for Vat Photopolymerisation: Renewable Building Blocks, Network Architecture and Performance Trade-Offs

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Statement of Significance

Bio-based content is often discussed as if it were a direct predictor of vat-photopolymerisation performance. The primary literature does not support that simplification. Renewable feedstocks can generate soft elastomers, rigid glassy networks, thermoplastic-like printed parts, dynamic covalent networks and high-resolution DLP materials, depending on molecular architecture rather than feedstock origin alone. This review therefore reframes bio-based photoresin design around the variables that actually control the printed network: backbone rigidity and flexibility, reactive functionality, molecular weight, reactive-site spacing, intermolecular interactions, optical absorption, reactive-diluent fraction and dynamic-bond chemistry. A reporting framework is proposed to separate analytically measured biobased carbon content from formulation mass fraction, sustainability claims, biodegradability and circularity. The resulting architecture-process-property view provides a more rigorous basis for comparing renewable photoresins without assuming a universal mechanical penalty for increasing bio-based content.

Keywords: bio-based photoresins, vat photopolymerisation, DLP, SLA, renewable feedstocks, polyester acrylates, vegetable oils, isosorbide, itaconic acid, lignin, cardanol, rosin, dynamic covalent networks, biobased carbon, ASTM D6866

Abstract

Renewable building blocks are increasingly incorporated into photoresins for stereolithography, digital light processing and related vat-photopolymerisation processes. The field is chemically diverse: plant-oil acrylates provide flexible aliphatic segments and adjustable functionality; itaconate polyesters enable systematic control of double-bond density and backbone structure; isosorbide and biomass-derived aromatic units introduce rigidity; lignin-, vanillin-, guaiacol-, cardanol- and rosin-derived structures provide alternative aromatic or polycyclic motifs; and dynamic covalent chemistry adds reprocessability or chemical recovery as an orthogonal network function. Across these families, bio-based content alone does not determine viscosity, cure response, glass-transition temperature, modulus, toughness, resolution or recyclability. Instead, each property emerges from the interaction between molecular structure and the photopolymerisation process. This review synthesises primary studies from 2016-2026 and formal standards for biobased-carbon measurement to establish an architecture-centred framework for bio-based VPP materials. Particular attention is given to the distinction between radiocarbon-based biobased carbon content and formulation mass fraction; the effect of molecular functionality and reactive diluent on viscosity and conversion; architecture-dependent stiffness-toughness trade-offs; and the separation of renewable sourcing from biodegradability, circularity and life-cycle impact. A minimum reporting framework is proposed to improve cross-study comparability and to prevent unsupported extrapolation from feedstock origin to material performance or environmental benefit.

1. Introduction

1.1 From renewable feedstock substitution to molecular design

Vat photopolymerisation (VPP) converts a liquid, photo-reactive formulation into a spatially patterned polymer network. For conventional acrylate and methacrylate systems, the final part is therefore governed not only by the identity of the starting monomers or oligomers but also by functionality, molecular mobility, cure kinetics, optical attenuation, conversion, crosslink density and post-cure history. Replacing fossil-derived constituents with renewable analogues does not remove those constraints. It changes the molecular design space in which they must be solved.

Early bio-based VPP work already demonstrated the breadth of that design space. Soybean-oil epoxidized acrylate was used for stereolithographic scaffold printing and shape-responsive structures [3]. A later multi-scale optical-printing study used a bio-based resin across DLP and nonlinear laser lithography [4], while renewable polyester systems were adapted to functional DLP resins [5]. These examples are chemically dissimilar. Their commonality is renewable origin, not a common network architecture or performance envelope. Treating them as a single material class therefore obscures the molecular variables that determine printability and realised properties.

The central proposition of this review is that bio-based VPP should be treated as a molecular-architecture problem rather than as a single-axis substitution problem. Renewable feedstock content is an important compositional attribute, but it becomes an engineering variable only when linked to the structure of the reactive species and the network produced under defined printing and post-curing conditions. The primary literature provides enough contrasting examples to reject a universal relationship such as "higher bio-based content causes lower modulus". Isosorbide-rich systems can yield high-T_g, high-modulus materials [9]; cardanol-derived oligomers can form compact rigid networks [6]; lignin-derived methacrylates can be processed without reactive diluent using hot-lithography conditions [10]; and plant-oil architectures can deliberately target highly compliant elastomers [3].

1.2 Scope and boundary of the review

This review focuses on photoreactive renewable building blocks and resin architectures demonstrated in VPP or closely related photolithographic additive-manufacturing workflows. The primary scope includes SLA, DLP and masked stereolithography; hot-lithography studies are included where they reveal how viscosity limits can be shifted by process temperature. Two-photon studies are referenced only when they clarify material architecture rather than nanoscale optics as the principal subject.

The review is intentionally not a life-cycle assessment. Renewable carbon content, greenhouse-gas impact, toxicity, biodegradability, compostability and recyclability are separate propositions that require separate evidence. ASTM D6866-24a determines biobased carbon through radiocarbon analysis and explicitly does not establish product performance or environmental impact [1]. ISO 16620-2:2019 similarly specifies determination of biobased carbon content based on ^{14}C measurement for plastics and related materials [2]. These standards provide compositional metrology, not an environmental-performance score.

The review also avoids manufacturer-specific formulation mapping. Commercial products may contain renewable constituents, but proprietary composition is neither necessary nor appropriate for the scientific synthesis developed here. Quantitative comparisons are therefore drawn from cited primary literature and formal standards.

2. Terminology and measurement

2.1 Biobased carbon content is not formulation mass fraction

A recurring source of ambiguity is the use of "bio-based content" without stating what denominator is being used. Radiocarbon methods quantify the fraction of carbon attributable to contemporary biological sources relative to total organic carbon. By contrast, a formulation may report the mass fraction of a bio-derived ingredient, the renewable mass fraction of the complete formulation, the fraction of a synthesized oligomer derived from renewable precursors, or a calculated renewable-carbon contribution. These values are not interchangeable. A resin containing a high mass fraction of an oxygen-rich renewable component can have a different radiocarbon-based carbon percentage than its formulation mass percentage, and a partially bio-derived synthesized molecule may require explicit accounting of fossil and contemporary carbon atoms.

For cross-study comparison, the measurement basis should therefore accompany every numerical bio-based-content claim. ASTM D6866-24a is an active standard for radiocarbon-based biobased content [1], and ISO 16620-2:2019 remains current following its 2024 confirmation [2]. When a study instead calculates renewable mass fraction from known feedstocks, that result should be reported as such rather than presented as if it were a radiocarbon measurement.

Term	What it measures	Appropriate evidence	What it does not imply
Biobased carbon content	Fraction of carbon derived from contemporary biological sources	ASTM D6866 / ISO 16620-2 radiocarbon method	Lower environmental impact, biodegradability, safety or mechanical performance
Bio-based mass fraction	Mass fraction of ingredients or molecular content assigned to renewable origin	Transparent formulation accounting or validated mass-balance method	Radiocarbon result unless measured; life-cycle benefit
Renewable feedstock origin	Origin of precursor such as plant oil, lignin, itaconic acid, isosorbide, cardanol or rosin	Traceable raw-material and synthesis information	That the final network is biodegradable, recyclable or non-toxic
Biodegradability	Extent/rate of biological breakdown under a specified test environment	A defined biodegradation standard and test conditions	Compostability in another environment; renewable-carbon fraction
Recyclability / reprocessability	Ability to recover, reform or chemically recycle a cured network under defined conditions	Repeated processing, recovery yield and retained-property data	Low life-cycle impact or biodegradability
Life-cycle impact	Environmental burden over a defined functional unit and system boundary	Transparent LCA inventory, allocation and sensitivity analysis	Can be inferred from feedstock origin alone

Table 1. Terminology required to separate composition from performance and sustainability claims.

2.2 Why a single bio-content-performance slope is not defensible

A universal penalty such as a fixed percentage loss in modulus for every increment in biobased carbon is inconsistent with polymer-network physics and with the published VPP evidence. Modulus and T_g respond to segmental rigidity, molecular weight between crosslinks, functionality, secondary interactions, free volume, conversion and network defects. Bio-derived molecules span flexible aliphatic chains, rigid bicyclic isosorbide units, aromatic lignin-derived motifs, polycyclic rosin structures and multifunctional plant-oil derivatives. A compositional scalar cannot encode those structural differences.

The contrast between studies is instructive. Itaconate-based polyesters were deliberately varied in chemical structure and double-bond density, producing large shifts in stiffness and ductility [12]. Isosorbide methacrylate systems were developed specifically to access T_g values above 200 °C and modulus above 4 GPa in selected formulations [9]. Cardanol-derived methacrylate oligomers produced a compact network with high storage modulus and a measured T_g near 80 °C in that particular system [6]. In the opposite direction, cardanol-based thiol-ene polyesters were designed as soft degradable materials with Young moduli in the sub- to low-MPa range [24]. These are not contradictory observations; they are evidence that architecture, not the label "bio-based", controls the property envelope.

3. Architecture-to-process map

3.1 Reactive functionality, molecular weight and reactive-site spacing

Reactive functionality controls the number of polymerisable groups available per molecule, but functionality alone does not determine crosslink density. The spacing of those groups, their probability of reaction, intramolecular cyclisation, vitrification and final conversion all matter. Increasing functionality can accelerate gelation and raise network connectivity, but can also reduce molecular mobility early in cure, generate conversion gradients and increase shrinkage stress. Conversely, long flexible segments between reactive sites can lower T_g and modulus while increasing elongation and toughness.

The 2026 study by Jolly and co-workers explicitly tuned the functionality of an acrylated vegetable oil and observed systematic changes in the physicochemical behaviour of the printed network [29]. This type of controlled architecture study is more informative than comparing unrelated commercial resins at different nominal bio-based contents because it isolates a molecular variable while retaining a common feedstock platform. Similar logic is evident in itaconate-polyester studies where double-bond density and backbone chemistry were varied independently [11,12].

Molecular weight is coupled to processing. Oligomer-rich or lignin-rich systems can reduce the fraction of low-molecular-weight reactive species, but commonly raise viscosity. Keck and co-workers addressed this constraint by printing a liquid lignin-derived methacrylate without reactive diluents using hot lithography, a process adapted to higher viscosities [10]. The result illustrates a general point: a material that appears unprintable under an ambient-temperature desktop-VPP viscosity envelope may become processable under a heated or otherwise modified platform. Printability is therefore a material-process property, not an intrinsic binary property of the resin alone.

3.2 Backbone rigidity, flexibility and secondary interactions

Backbone architecture determines the energy scale for segmental motion and the ability of the network to redistribute stress. Flexible fatty-acid chains in plant-oil-derived systems can provide large deformation and low-temperature compliance, while cyclic and aromatic structures can raise Tg and stiffness. Isosorbide is a particularly clear example: its fused bicyclic structure provides conformational rigidity and has been used in high-Tg VPP resin systems [9]. Lignin-derived guaiacyl and syringyl structures similarly introduce aromatic rigidity, although their optical absorption and colour can become processing variables [8,10].

Secondary interactions provide an additional design axis. The 2024 dual-crosslinking polyester system of Huang et al. combined covalent photopolymerisation with Zn²⁺-carboxyl coordination, increasing strength in the studied network without relying solely on higher permanent covalent crosslink density [16]. Such systems show that the traditional binary distinction between flexible renewable segments and rigid fossil-derived networks is incomplete. Hydrogen bonding, ionic coordination, reversible bonds and supramolecular interactions can reinforce renewable architectures while retaining recovery or dissipation mechanisms.

3.3 Viscosity, cure response and optical behaviour

VPP requires a formulation to satisfy a coupled transport-optics-kinetics problem. Viscosity affects recoating, resin renewal and trapped-bubble removal; absorbance and scattering define the delivered optical field; photopolymerisation kinetics set the exposure required to reach gelation and adequate green strength; and conversion determines the state of the network available for post-cure. Renewable feedstocks can influence every term. Lignin-derived chromophores can alter optical penetration; aromatic and polycyclic units may change refractive index and absorbance; long oligomers raise viscosity; and less reactive itaconate double bonds can require different exposure conditions than acrylates.

Papadopoulos et al. demonstrated this coupling by varying reactive-diluent concentration in itaconic-acid-based polyester formulations and measuring the resulting effects on printing and material properties [11]. Cazin et al. similarly related polyester-resin structure to molecular weight, viscosity, cure kinetics and final thermomechanical performance [14]. The engineering implication is that reactive diluent is not merely a viscosity correction. It changes the reactive network composition and therefore shifts conversion, Tg, modulus and shrinkage. Any comparison between renewable oligomer architectures must report the complete reactive architecture rather than only the nominal oligomer family.

4. Major bio-based architecture families

4.1 Plant-oil acrylates and methacrylates

Vegetable oils provide abundant triglyceride-derived backbones with long aliphatic chains and multiple sites for chemical functionalisation. Acrylated epoxidized soybean oil and related derivatives are among the most established renewable photoresin building blocks. Their long fatty-acid segments naturally favour compliance and toughness, but the realised behaviour depends strongly on how many acrylate or methacrylate groups are introduced and what co-monomers or crosslinkers are used.

Miao et al. demonstrated stereolithographic printing of soybean-oil epoxidized acrylate for biomedical scaffold architectures [3]. More recent work has shifted from simply proving printability to controlling functionality and resolution. Wang et al. developed soybean-oil-derived UV-curable systems for high-resolution printing and reported a bio-based carbon content of 80.37% for the synthesized prepolymer, with approximately 40 micrometre XY features achieved in a formulation containing a commercial reactive diluent [18]. Bodhak et al. developed soybean-oil-derived acrylate/methacrylate ether chemistry for high-resolution additive manufacturing [20]. Jolly et al. then showed directly that changing acrylate functionality within a vegetable-oil platform changes the network properties [29]. These studies collectively support an architecture-centred rather than feedstock-centred classification.

Plant-oil chemistry also supports soft functional materials. A 2024 plant-oil-based elastomer study targeted large deformation and shape-memory/soft-robotics behaviour, showing that renewable feedstocks can be deliberately placed in a low-modulus design region rather than judged against a rigid engineering-plastic benchmark [21]. This is important for interpreting "performance penalty": a lower modulus is not a penalty if the application requires compliance.

4.2 Itaconate and bio-based polyester architectures

Itaconic acid is attractive because it combines renewable production routes with an unsaturated group that can participate directly or indirectly in photocurable network design. The architecture can be tuned by selecting co-diacids, diols, chain length and double-bond density. In the 2023 European Polymer Journal study, bio-based polyester structures ranging from more rigid cyclic/aromatic architectures to longer aliphatic chains produced correspondingly different Tg, modulus and elongation behaviour [12]. The same year, Papadopoulos et al. demonstrated that reactive-diluent concentration materially shifts both printability and cured properties [11].

The field has since expanded beyond conventional polyester crosslinking. Huang et al. introduced a carboxyl-terminated itaconate polyester with covalent and coordination crosslinks [16]. Maturi et al. used myrcene-itaconate Diels-Alder cycloadducts to create photocurable polyesters for fully biobased resin systems [17]. Carmenini et al. reported glycerol carbonate methyl itaconate as a renewable monofunctional building block incorporated into both soft and rigid formulations, reaching up to 77 wt% biobased content in the complete formulations [23]. The fact that the same renewable chemical family can support monofunctional diluent-like behaviour, multifunctional polyester networks and dual-crosslinked materials demonstrates again that molecular architecture is the controlling descriptor.

4.3 Isosorbide and other rigid cyclic renewable building blocks

Isosorbide is a rigid bicyclic diol derived from carbohydrate chemistry and is frequently used where thermal performance and stiffness are needed. Chu et al. developed isosorbide methacrylate resin systems for VPP with Tg values exceeding 200 °C and modulus above 4 GPa in selected systems [9]. A 2026 acrylic-isosorbide polyurethane study further demonstrated low-viscosity DLP-processable resins with dimensional errors of approximately 2% in the reported test geometries [28].

The design lesson is not that isosorbide always produces high-Tg networks. Rather, it supplies a rigid structural element whose contribution depends on its fraction, functionality, linking chemistry and co-monomers. In mixed systems, flexible components may be intentionally introduced to reduce brittleness, while isosorbide maintains a higher segmental-rigidity baseline. This architecture provides one clear route by which renewable content and high thermal performance can coexist.

4.4 Cardanol and rosin-derived aromatic or polycyclic architectures

Cardanol combines a phenolic ring with a long unsaturated C15 side chain. This dual character makes it unusually versatile: the aromatic ring can support rigidity and polarizability, while the aliphatic chain supports flexibility. Chen et al. synthesised cardanol-based methacrylate oligomers for DLP and reported a compact crosslinked network with tensile strength of 38.5 MPa, storage modulus of 5.37 GPa and Tg of 80.2 °C for the reported system [6]. In contrast, the 2025 cardanol-polyester thiol-ene study deliberately exploited cardanol-based aliphatic content to generate soft degradable networks with Tg around -20 °C and Young modulus of 0.2-2 MPa [24]. The two results are a useful controlled warning against assigning a single mechanical profile to a feedstock name.

Rosin contributes a different polycyclic motif. Recent rosin-epoxy-soybean-oil acrylate work increased reported bio-renewable carbon content while also increasing tensile performance within that specific formulation series [19]. This does not establish a universal strengthening role for rosin. The effect depends on derivative structure, loading, conversion and network topology. Claims that rosin automatically provides non-yellowing behaviour are similarly too strong without direct ageing and spectroscopy data, because rosin derivatives can contain conjugated structures and oxidation-sensitive motifs. Optical stability must be measured, not inferred from renewable origin.

4.5 Lignin, vanillin, guaiacol and other biomass-derived aromatic architectures

Lignin-derived chemistry is attractive because it offers aromatic carbon from a large biomass stream, but it is also one of the clearest examples of the architecture-processing trade-off. Native lignin has broad molecular-weight distribution and strong optical absorption, whereas molecularly defined lignin-deconstruction products can behave more like conventional monomers. Chin et al. used 4-propylguaiacyl acrylate and syringyl methacrylate derived from lignin-deconstruction chemistry to print materials spanning soft elastomers to rigid plastics, including thermoplastic-like parts that could be solvent-reprocessed [8]. This demonstrates the value of converting heterogeneous biomass into controlled reactive molecular units.

Keck et al. took a different route, synthesising a liquid lignin-based methacrylate containing approximately 26-39% lignin and printing it through hot lithography without reactive diluents [10]. The study is significant because it shifts the process window rather than forcing the material into a low-viscosity ambient-temperature formulation. More recent DLP work continues to optimise lignin modification and processing, including fully wood-derived composite formulations [30]. The appropriate engineering question is therefore not whether lignin is "printable", but which lignin architecture, modification degree, optical state and processing temperature create a usable exposure-viscosity window.

Vanillin and related aromatic aldehydes provide an additional route to dynamic networks. Cortes-Guzman et al. developed biobased photoresins using dynamic imine exchange [7], while a 2023 ACS Applied Materials & Interfaces study used vanillin-derived dynamic imine chemistry for rapid reprocessability [13]. These systems use biomass-derived aromaticity not only as a rigid structural component but also as a platform for reversible covalent chemistry.

4.6 Bio-based urethane and non-isocyanate urethane architectures

Urethane chemistry is widely used in photoresins because hydrogen bonding and segment design provide broad control of toughness, flexibility and thermal behaviour. Bio-based urethane routes can substitute renewable polyols while retaining conventional isocyanate chemistry, or can pursue non-isocyanate pathways [26]. The architecture is particularly sensitive to soft-segment molecular weight, hard-segment content, functionality and hydrogen-bond density, making simplistic comparisons between "bio-based urethane acrylate" and another family unreliable.

Recent primary studies demonstrate this diversity. Acrylic-isosorbide polyurethane resins reported in 2026 combined a renewable rigid diol motif with aliphatic diisocyanates and methacrylate end groups for high-resolution DLP [28]. In parallel, dos Santos et al. reported a vegetable-oil-derived non-isocyanate urethane methacrylate using passion-fruit-seed-oil chemistry and CO₂-derived cyclic-carbonate chemistry, achieving up to 72% biobased carbon in the monomer platform and a broad viscosity window in the tested formulations [27]. Non-isocyanate routes therefore represent a chemical-design alternative, not merely a feedstock substitution.

Architecture family	Structural lever	Typical process consequence	Evidence-consistent interpretation
Plant-oil acrylates	Long aliphatic segments; tunable acrylate functionality	Often low Tg / high compliance; viscosity and cure depend on functionalisation	Can be soft or structurally reinforced; feedstock does not fix modulus
Itaconate polyesters	Diol/diacid selection, double-bond density, chain length	Reactive-diluent demand and exposure depend on backbone and unsaturation	Excellent platform for structure-property studies because architecture is systematically tunable
Isosorbide systems	Rigid fused bicyclic unit	Raises segmental rigidity; can support high Tg	High renewable content can coexist with high stiffness when architecture is rigid
Cardanol / rosin	Phenolic or polycyclic renewable motifs with hydrophobic segments	Potential viscosity, absorbance and conversion changes	Can reinforce or soften depending on derivative and network topology
Lignin / guaiacol / syringyl	Aromatic biomass structures; molecularly defined or heterogeneous	Optical absorption and viscosity can become dominant constraints	Processing route and degree of molecular definition are central

Architecture family	Structural lever	Typical process consequence	Evidence-consistent interpretation
Bio-based urethanes	Soft/hard segment balance, H-bonding, renewable polyol or NIPU route	Broad rheology and cure window; architecture-specific	No universal mechanical penalty; evaluate segment design and conversion
Dynamic networks	Imine, disulfide or other exchangeable bonds added to renewable backbone	Additional thermal/chemical recovery steps	Circularity is an independent network function and must be experimentally demonstrated

Table 2. Architecture families and the engineering variables they introduce.

5. Dynamic and reprocessable networks as an orthogonal design dimension

Renewable origin and network reversibility answer different questions. A resin can be highly bio-based and irreversibly crosslinked; a fossil-derived resin can be recyclable; and a renewable dynamic network can combine both attributes. Treating circularity as a direct consequence of renewable feedstock therefore creates a category error. The network must contain a mechanism that enables recovery, exchange, depolymerisation or reprocessing under defined conditions.

Dynamic imine chemistry has been demonstrated in DLP photoresins derived from vanillin-containing building blocks [7,13]. Kamble and Asha later combined imine and disulfide exchange in a biobased photopolymer composition and demonstrated reprinting and self-healing in a defined processing route [25]. In 2026, Liu et al. reported a eugenol/lipoic-acid-derived photopolymer in which UV fixation was followed by sulfur-mediated network reorganisation and chemical recovery, with DLP microfeatures in the 20-30 micrometre scale [31]. These examples show that reprocessability can be designed into a renewable photopolymer, but it is a network-chemistry result rather than a renewable-carbon result.

A useful reporting distinction is therefore: renewable sourcing describes where carbon originates; dynamic-network chemistry describes how the cured topology can change; chemical recovery describes what material is recovered and in what yield; and closed-loop recyclability requires proof that recovered material can return to an equivalent or defined secondary use. Each claim has a different evidentiary burden.

6. Structure-property-process trade-offs

6.1 Stiffness, toughness and elongation

The principal mechanical trade-off in photoresin design is not bio-based versus fossil-derived. It is the balance among network connectivity, segmental rigidity and mechanisms of energy dissipation. Highly connected rigid networks raise modulus and dimensional stability but can become brittle. Flexible aliphatic segments and reversible interactions can increase elongation and toughness but may reduce Tg or creep resistance. Renewable chemistry spans both extremes.

Lublin et al. used controlled monomer ratios in a biobased photopolymer system and applied multiscale mechanical characterisation, demonstrating that the local and bulk mechanical response changes with composition rather than following a simple renewable-content scalar [15]. The itaconate-polyester structure-property study reached the same conclusion through a different chemical family [12]. Consequently, a credible comparative paper should plot mechanical properties against chemically meaningful descriptors - functionality, molecular weight between crosslinks, aromatic/cyclic fraction, conversion - rather than against nominal BCC alone.

6.2 Thermal performance

Tg and heat resistance are especially sensitive to backbone rigidity and crosslink topology. The high-Tg isosorbide systems [9] show that renewable building blocks can support engineering-grade thermal envelopes, while soft cardanol thiol-ene networks [24] demonstrate the opposite design direction. In both cases the result is intentional architecture. Thermal comparisons should therefore specify the metric (Tg, HDT, thermal decomposition or service temperature), the measurement method and the post-cure state. A high decomposition temperature does not substitute for a high Tg, and neither is equivalent to a service-temperature qualification.

6.3 Printability, resolution and dimensional fidelity

Printability is frequently reported as a photograph of a successful object, but architecture-level comparison requires more. At minimum, the uncured viscosity and temperature, exposure wavelength, irradiance or dose, layer thickness, optical attenuation strategy and post-cure should be reported. A highly viscous lignin or oligomer-rich resin printed in a heated system should not be compared directly with a low-viscosity ambient-temperature DLP formulation without acknowledging the process difference.

The 2024 soybean-oil study reporting approximately 40 micrometre XY resolution [18], the 2026 isosorbide-polyurethane study reporting dimensional errors of approximately 2% in its test geometries [28], and the 2026 sulfur-dynamic resin demonstrating 20-30 micrometre microfeatures [31] illustrate that renewable architectures can reach high geometric fidelity. These values remain system-specific; they should not be converted into feedstock-level promises. Resolution is an outcome of resin optics, kinetics, platform pixel/laser characteristics, exposure and geometry.

6.4 Reactive diluents, conversion and the hidden composition problem

Many renewable oligomers require a reactive diluent to enter a practical VPP viscosity window [22]. The diluent may be fossil-derived, partially bio-derived or renewable, and may contribute substantially to the final network. Reporting only the renewable oligomer fraction can therefore overstate the renewable content of the complete resin. Conversely, high-functionality bio-derived diluents or monomers can materially increase the renewable fraction while simultaneously changing network density and cure rate.

Papadopoulos et al. showed directly that diluent concentration changes both processing and cured properties in itaconate systems [11]. Carmenini et al. demonstrated that a renewable monofunctional GCI building block could be incorporated at high fraction but required exposure optimisation because itaconate reactivity differs from conventional acrylic chemistry [23]. These observations support a complete-formulation reporting convention: the renewable-content metric should refer to the final printable formulation, and all reactive components should be included in the architecture description.

Study	Renewable architecture	Demonstrated result	Architecture-level lesson
Miao et al., 2016 [3]	Soybean-oil epoxidized acrylate	SLA scaffolds and shape-responsive constructs	Plant-oil platforms can support printable, compliant functional networks
Skliutas et al., 2020 [4]	Bio-based optical resin	DLP and nonlinear optical printing	A renewable resin can be engineered across multiple optical fabrication scales
Chen et al., 2021 [6]	Cardanol methacrylate oligomer	Tg 80.2 °C; tensile 38.5 MPa in reported system	Phenolic rigidity can offset flexible side-chain effects
Chin et al., 2023 [8]	Lignin-deconstruction monomers	Soft-to-rigid thermoplastic-like printed parts	Defined molecular units can unlock behaviour not typical of crosslinked thermosets
Chu et al., 2023 [9]	Isosorbide methacrylate blends	Tg >200 °C and modulus >4 GPa in selected formulations	Rigid cyclic renewable structures can support high thermal/mechanical performance
Keck et al., 2023 [10]	Methacrylated lignin	Printed without reactive diluent using hot lithography	Process temperature can expand the viable viscosity window
Huang et al., 2024 [16]	Itaconate polyester + coordination network	High renewable fraction with dual-network reinforcement	Secondary interactions are independent reinforcement levers
Wang et al., 2024 [18]	Soybean-oil-derived UV resin	80.37% bio-carbon in the prepolymer; ~40 µm XY in a diluted formulation	High renewable content and fine features can coexist in a tuned system
Carmenini et al., 2025 [23]	Glycerol-carbonate methyl itaconate	Up to 77 wt% biobased formulation; soft/rigid property shifts	A renewable monomer can change mechanics differently in different host architectures
dos Santos et al., 2026 [27]	Vegetable-oil non-isocyanate urethane methacrylate	Up to 72% biobased carbon; broad viscosity and functional envelope	Renewable urethane design can move beyond conventional isocyanate routes
Liu et al., 2026 [31]	Eugenol/lipoic-acid sulfur-dynamic resin	20-30 µm microfeatures plus chemical recovery	Renewable sourcing and recoverable network design can be coupled but require separate validation

Table 3. Representative primary VPP studies showing why architecture is more informative than feedstock label.

7. Critical examination of recurring claims

7.1 "Higher bio-based content necessarily reduces performance"

This claim is not supported as a general law. The literature contains high-Tg isosorbide systems [9], stiff cardanol networks [6], soft cardanol networks [24], tough plant-oil systems and a wide mechanical span within lignin-derived monomer families [8]. A performance trend can be established within a controlled formulation series, but it cannot be transferred across unrelated molecular architectures. Any reported slope between BCC and modulus should therefore be described as formulation-series-specific unless a broad, controlled dataset demonstrates generality.

7.2 "Bio-based" means biodegradable, recyclable or environmentally preferable

Renewable origin does not create a cleavage mechanism in a crosslinked network. Biodegradation depends on chemical bonds, network accessibility, water uptake, geometry, microbial or enzymatic environment and test conditions. Recyclability depends on thermoplasticity, dynamic exchange, selective cleavage or another recovery mechanism. Environmental preference requires a defined functional unit, system boundary and inventory. ASTM D6866 explicitly does not establish these outcomes [1]. Accordingly, a manuscript should not use high BCC as evidence for biodegradability, circularity or lower life-cycle impact.

7.3 "Natural aromatic or polycyclic feedstocks automatically improve UV stability"

Optical ageing depends on chromophore structure, oxidation pathways, photolysis products, stabilisers, wavelength and service environment. Lignin and rosin derivatives can contain strongly absorbing or oxidation-sensitive structures. Renewable aromaticity may improve stiffness or refractive behaviour in a given formulation, but non-yellowing or light-fastness claims require direct spectral and ageing measurements. This is a particularly important boundary because optical stability is often inferred from structural intuition without the necessary long-duration evidence.

7.4 "A successful print demonstrates material equivalence"

A successful geometry demonstrates process feasibility under one parameter set. It does not establish equivalence in mechanical properties, ageing, resolution, shrinkage, extractables or thermal service. Renewable formulations should therefore be benchmarked through matched specimen geometry, orientation, post-cure and test standards. Where a fossil-derived reference is used, the comparison should disclose whether viscosity, exposure and post-cure were re-optimised independently for each resin. Otherwise, the comparison can conflate formulation quality with process mismatch.

8. Proposed reporting framework for bio-based VPP materials

A minimum reporting framework can substantially improve comparability without requiring proprietary formulation disclosure. The goal is to identify the variables needed to interpret a result, not to demand exact commercial recipes. Ingredient identities can be reported at an appropriate chemical-family level where confidentiality is necessary, but the measurement basis and process state must remain explicit.

Reporting block	Minimum information	Reason
Renewable-content metric	ASTM D6866 / ISO 16620-2 result, or clearly labelled calculated mass fraction; denominator and sample state	Prevents confusion between radiocarbon BCC and formulation wt%
Architecture	Feedstock family, reactive functionality, approximate molecular-weight class, major reactive-diluent class, dynamic-bond chemistry if present	Connects composition to network physics without requiring proprietary percentages
Uncured-state processing	Viscosity with temperature; wavelength; irradiance/dose or exposure time; layer thickness; printer/process configuration	Defines the actual VPP process window
Cure state	Degree of conversion or other cure metric; wash; post-cure spectrum, time and temperature	Separates molecular design from under/over-cure effects

Reporting block	Minimum information	Reason
Geometric performance	Test geometry, nominal feature scale, measurement method, orientation and reported trueness/precision where possible	Makes resolution and dimensional claims comparable
Mechanical properties	Test standard, orientation, conditioning, specimen state and n; report modulus/strength/elongation as relevant	Avoids unsupported cross-study comparisons
Thermal properties	Metric and method: Tg, HDT, decomposition etc.; test conditions	Prevents substitution of one thermal metric for another
Circularity / degradability	Exact recovery/degradation protocol, mass balance, retained properties and number of cycles	Separates network functionality from renewable origin
Environmental claims	Functional unit, boundary and inventory if LCA is claimed	Prevents BCC from being used as a proxy for environmental performance

Table 4. Minimum reporting elements for a bio-based VPP study.

9. Research gaps

9.1 Matched architecture series across a broad renewable-content range

The strongest current studies vary one or several structural variables within a defined chemistry family, but few datasets span a broad renewable-content range while independently controlling functionality, molecular weight, viscosity and conversion. Such studies are needed to determine when a trend attributed to bio-based content is actually caused by architecture. A useful experimental design would hold the reactive functionality distribution and post-cure state approximately constant while varying renewable versus fossil-derived homologues with comparable structure.

9.2 Cross-platform process transfer

Many published renewable resins are demonstrated on a single DLP or SLA platform. Transfer to another irradiance, wavelength or resin-temperature regime is rarely quantified. This limits the ability to determine whether a material architecture is intrinsically robust or narrowly matched to one process. Reporting working-curve behaviour, viscosity-temperature dependence and conversion alongside print fidelity would allow more rigorous transfer studies.

9.3 Optical ageing and colour stability

Renewable aromatic systems create opportunities for rigid, high-refractive-index networks but also raise optical questions. Long-term UV/visible ageing, yellowing index, absorbance evolution and post-cure colour changes are under-reported relative to mechanical testing. This gap is especially important for optical, dental and consumer-facing applications where appearance is part of functional performance.

9.4 Quantitative separation of renewable sourcing and end-of-life function

Dynamic networks are expanding rapidly, but terminology remains inconsistent. Reprocessing, recycling, chemical recovery, self-healing, welding and reprinting are distinct phenomena. Future studies should report recovery yield, molecular or network state of the recovered fraction, number of cycles, retained mechanical performance and whether the recovered material returns to the same printing process or to a secondary process. The 2025-2026 dynamic-network studies [25,31] provide useful proof-of-concept platforms but also show how strongly the outcome depends on the specific exchange chemistry and recovery protocol.

9.5 Standardised reporting of biobased content in the final printable formulation

A final gap is surprisingly basic: many papers report renewable content for a synthesized oligomer or monomer but not for the complete printable resin after addition of reactive diluents, crosslinkers and other carbon-containing components. Because those additions can dominate the total formulation mass, a high renewable fraction in the core oligomer does not necessarily translate to an equally high BCC in the final resin. Radiocarbon measurement on the finished formulation, or transparent complete-formulation mass accounting, would materially improve comparability.

3Dresyns implementation examples

Current 3Dresyns products provide commercial examples of the renewable-content design space discussed in this review. The stated bio-based contents below are product-specific documentation values and should not be extrapolated to other formulations or interpreted as proof of biodegradability, recyclability or lower environmental impact.

3Dresyn Bio Soya1. Manufacturer documentation reports approximately 82% total bio-based content. This product-specific composition attribute should not be interpreted as proof of biodegradability, recyclability or lower environmental impact [M1].

3Dresyn Bio Bamboo. Manufacturer documentation reports approximately 88% total bio-based content. This value is product-specific and does not establish environmental performance or end-of-life behaviour [M2].

3Dresyn Bio Corn. Manufacturer documentation reports approximately 88% total bio-based content. This value is product-specific and does not establish environmental performance or end-of-life behaviour [M3].

Source basis: current 3Dresyns product and Technical Data Sheet documentation, August 2026. These commercial examples are included to connect the review framework to implementation and are not substitutes for independent application-specific validation.

10. Conclusions

The primary literature from 2016-2026 supports a clear reframing of bio-based vat photopolymerisation. Renewable feedstock origin is a compositional attribute; material performance is an architecture-process outcome. Plant-oil, itaconate, isosorbide, cardanol, rosin, lignin and vanillin-derived systems occupy very different regions of the molecular design space. Within those families, reactive functionality, molecular weight, backbone rigidity, reactive-site spacing, optical behaviour, secondary interactions, dynamic bonds and reactive-diluent fraction determine how the resin cures and what network is ultimately produced.

No universal mechanical penalty can therefore be assigned to increasing bio-based content across VPP materials. Controlled formulation series may exhibit monotonic trends, but those trends remain specific to their architecture and processing conditions. High renewable content can coexist with high Tg and stiffness, with compliant elastomeric behaviour, with high-resolution printing, or with chemical recovery, depending on the design objective and the chemistry used to reach it.

A second conclusion is metrological. Biobased carbon content measured by ASTM D6866 or ISO 16620-2 should not be conflated with formulation mass fraction, sustainability, biodegradability or circularity. These are separate quantities and claims. Publishing them separately - together with uncured viscosity, exposure conditions, cure state, post-processing and standardised property measurements - would substantially strengthen cross-study comparison.

The most productive next stage for the field is therefore not to maximise a single renewable-content number in isolation. It is to design molecular architectures in which renewable sourcing is integrated with the required rheology, optical cure response, network mechanics, thermal performance, ageing and end-of-life function, and to report those dimensions with sufficient detail that performance can be reproduced and compared.

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Limitations

This review is a narrative engineering synthesis rather than a preregistered systematic review or meta-analysis. Reported renewable-content metrics, cure conditions and property-test methods vary across studies, so quantitative values are interpreted within their original measurement basis rather than pooled into a universal performance relationship.

Author contributions

Juan Seguro: conceptualisation, literature synthesis, engineering framework, writing and critical review.

Competing interests

The author is affiliated with 3Dresyns by Resyner Technologies S.L. Commercial 3Dresyns formulations are not used as the quantitative evidentiary basis of this review. No proprietary formulation composition is disclosed.

Data availability

No new experimental dataset was generated for this review. Quantitative values discussed in the text are taken from the cited primary literature or formal standards and remain subject to the conditions and methods reported in those sources.

Company information

Legal company name: 3Dresyns by Resyner Technologies S.L. Registered tax address: General Etxague 15B, 20003 Donostia / San Sebastián, Gipuzkoa, Spain VAT number: ESB24827511 Contact email: info@3Dresyns.com Company website: www.3Dresyns.com

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