

Purification and Reuse of Products from Triggered Photopolymer Depolymerisation: Composition, Functionality and Closed-Loop Evidence

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Abstract

Triggered depolymerisation can convert a printed network into soluble products, but network disappearance does not by itself establish a reusable feedstock. Published systems span thioester networks degraded to functional oligomers that can be repolymerised [1], deliberately recyclable photoresins that return functional material to later printing [2], and lipoate-based vat-photopolymer resins that were depolymerised, chemically characterised and reprinted across repeated cycles [3]. These routes differ in whether the recovered material is an oligomer, a monomer-like cyclic species or a compositionally mixed resin; in the fresh reactants required for the next cycle; and in the purification burden. ER-275 therefore owns the post-depolymerisation decision chain: identify all products, separate reusable from non-reusable fractions, quantify functionality and impurities, account for fresh inputs, demonstrate formulation and printing fitness, and report cycle-resolved retention. It does not prescribe a trigger chemistry or purification recipe and does not treat high isolated yield or successful reprinting as proof of chemical identity, closed-loop mass balance or environmental benefit.

Keywords: photopolymer depolymerisation; purification; recovered products; functionality; reprinting; closed-loop evidence; mass balance; vat photopolymerisation

1. Significance, scope and ownership

ER-275 begins after a deliberately triggered depolymerisation or deconstruction step has produced mobile products. ER-74 retains the chemistry and mechanism of programmed network disassembly, including whether the trigger actually cleaves the intended network [4]. ER-198 retains route-neutral end-to-end circularity evidence [5]. ER-111 to ER-113 retain their chemistry-specific reversible or degradable network families. ER-275 owns what happens after products exist: composition, purification, functional-group state, impurity control, storage, reformulation, reprinting and cycle-resolved evidence. ER-274 separately addresses recovery of pre-existing unreacted monomers and photoinitiators from waste; products created by depolymerisation are reaction products even if chemically similar to an original feedstock.

1.1 Corpus boundary

ER-74 retains programmed network disassembly, ER-198 retains route-neutral material-loop closure, and ER-111 to ER-113 retain their chemistry-specific reversible or degradable network families. ER-275 narrows the problem to recovered reaction products and asks when they become qualified secondary feedstocks. ER-274 is a current-series neighbour for recovery of pre-existing unreacted formulation components and is not used here as published evidentiary authority. ER-275 does not re-own the trigger mechanism, general LCA, mechanical recycling or waste-disposal decision.

2. Product identity precedes purification efficiency

A depolymerised liquid can contain target monomeric or oligomeric products, residual network fragments, catalyst, trigger reagent, solvent, photoinitiator residues, pigments, absorbers and side products. A gravimetric soluble fraction is therefore not a chemical identity measurement. Wang and co-workers demonstrated complete degradation of thioester-containing photopolymers to oligomers that were reused in repolymerisation [1]; the reusable entity was a functional oligomer population, not a recovered virgin monomer. The claimed feedstock identity must match the actual recovered species.

3. Purification is a component-resolved balance

Purification should be represented as a set of measured input-output fractions. For each target family, recovery yield, purity and residual-functionality fraction are separate quantities. A high recovered mass can coexist with low target purity, while a highly pure small fraction can represent poor overall recovery. Solvent, catalyst, sorbent, precipitant, membrane retentate, distillation residue and discarded fractions remain part of the material balance. ER-275 does not prescribe chromatography, precipitation, membrane separation, extraction or distillation; the operation is selected from measured properties of the actual product mixture.

4. Functional groups are the manufacturing currency

When recovered oligomers are reused through remaining thiol, hydroxyl, amine, alkene, disulfide or other reactive groups, functional-group concentration and stoichiometric accessibility determine what can be reformulated. Wang and co-workers showed that degradable thioester networks could yield oligomers subsequently used to form a nearly indistinguishable material [1]. That result does not imply that every depolymerised oligomer retains the functionality, molecular-mass distribution or inhibitor state required for a new photopolymer. Functionality must therefore be measured rather than inferred from solubility.

5. Closed-loop chemistry can still contain impurities

Machado and co-workers reported a lipoate-based DLP resin whose printed network was depolymerised to recovered resin at up to 98% yield in one route; the recovered resin showed an 85 mol% purity for the principal cyclic-disulfide material, with oligomeric material also detected [3]. Other formulations and cycles gave different recovered yields and cyclic-disulfide contents. These results demonstrate why yield, composition and purity must be reported separately and why one successful formulation cannot supply a universal purification target.

6. Fresh inputs define what has actually closed

Recovered functional products may require fresh complementary reactant, fresh initiator, catalyst, stabiliser or make-up resin. Lopez de Pariza and co-workers demonstrated a recyclable photoresin architecture in which chemically recycled material could be returned to printing [2], while ER-198 records the broader distinction between recovered fraction, recovered content in the next formulation and fresh material added per cycle. ER-275 requires every fresh input to be named and mass-accounted. Reuse remains useful even when the loop is not compositionally closed, but the narrower claim should be stated.

7. Storage and ageing occur between recovery and reuse

Recovered products can continue to oxidise, exchange, oligomerise, hydrolyse or lose inhibitor/catalyst balance during work-up and storage. Qualification therefore includes time, temperature, atmosphere, water content and container history between purification and reformulation. A recovered fraction tested immediately after isolation cannot automatically carry a shelf-life claim. Reanalysis is required at the point of reuse if storage can alter the reactive state.

8. Reprinting is a coupled formulation test

A recovered fraction enters a new formulation state. Before claiming printing equivalence, the formulation should be compared with an appropriate virgin or pristine control for viscosity/rheology, optical attenuation or working curve, cure conversion, dimensional response and at least one final-property endpoint relevant to use. Machado and co-workers directly demonstrated repeated printing after depolymerisation in a defined lipate system [3]. That observation is route-specific; it establishes the feasibility of coupled recovery-and-reprint evidence, not a generic process window.

9. Non-compensatory release gates

Gate	Minimum evidence	Blocking failure
Product identity	Resolved target species or bounded product family	Soluble mass called feedstock
Mass balance	All recovered, residue and discarded fractions accounted	Isolated yield without closure
Purity	Target fraction plus non-target profile	Yield substituted for purity
Functionality	Reactive-group concentration/state relevant to repolymerisation	Spectrum alone called reactivity
Fresh inputs	Every new reactive/process input quantified	Snowballing inventory hidden
Storage state	Time, temperature, atmosphere and stability markers	Freshly isolated state assumed durable
Print bridge	Matched cure, geometry and final-property comparison	Successful print called equivalence
Cycle history	Repeated recovery/reuse with composition tracking	Single recycle called closed loop

10. Minimum experiment

A minimum study begins with one chemically defined printed network and a predeclared depolymerisation trigger. All products and process aids are collected. The recovered mixture is characterised before purification, each purification output is weighed or volumetrically accounted, and the intended reusable fraction is analysed for identity, molecular-mass distribution where relevant, functional-group concentration, impurity profile and stability markers. The fraction is then used in a declared formulation with all fresh inputs recorded. A pristine control and at least one repeated recovery/reuse cycle are printed under measured cure conditions and compared for processability, geometry and use-relevant properties. The study must retain failed or discarded fractions in the balance.

11. Knowledge boundary

Direct studies establish that some designed photopolymer networks can be degraded to reusable oligomers or depolymerised to resin that is subsequently reprinted [1-3]. They do not establish one purification method, purity limit, fresh-input allowance or number of acceptable cycles for all VPP chemistries. ER-275 therefore supplies a route-neutral qualification architecture and does not infer a commercial process from any one chemistry.

12. Conclusions

The reusable object after triggered depolymerisation is whatever chemically defined product population the process actually produces, not whatever the starting formulation once contained. Credible reuse requires component-resolved recovery, purity, functionality, fresh-input accounting, storage control and a formulation-to-print bridge. Closed-loop evidence is strongest when the recovered composition remains bounded across repeated cycles; when it does not, the process should be described with the narrower recovery or open-loop reuse claim that the measurements support.

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