

Pyrolysis and Thermochemical Recovery of Photopolymer Waste: Product Distribution, Fillers, Emissions and Energy Balance

Qualification of thermochemical routes that convert photopolymer waste into gas, liquid and solid recovery streams

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Abstract

Pyrolysis can process crosslinked photopolymer waste that is difficult to remelt or dissolve, but its outputs are multiple streams rather than a regenerated resin. Temperature history, atmosphere, fillers and additives determine the distribution and quality of gases, condensable products and solid residues. This review defines a qualification framework for thermochemical recovery of photopolymer waste, including feedstock identity, reactor conditions, product yields, recovered filler state, emission control, energy demand and realistic valorisation of each fraction.

Keywords: pyrolysis; thermoset waste; photopolymer; thermochemical recycling; fillers; emissions; energy balance; product distribution

1. Significance and scope

Thermosetting waste is difficult to reprocess mechanically, which makes pyrolysis one possible route for recovering chemical value, energy or inorganic reinforcement. Reviews of thermoset pyrolysis emphasise both its versatility and its dependence on feedstock and operating conditions [1].

This review owns thermochemical treatment of photopolymer waste. ER-452 and ER-453 own lower-temperature chemical recovery routes; pyrolysis intentionally accepts deeper molecular destruction and a different product hierarchy.

2. Pyrolysis produces several products, not one recycled material

A pyrolysis experiment should start from a defined waste stream: neat resin, filled resin, fibre composite, support waste, mixed prints or wash-derived residue. Different additives and fillers change heat transfer, char formation and product composition.

Temperature, heating rate, residence time, pressure and atmosphere control cracking pathways. Reporting only a peak temperature is insufficient when comparing product yields or emissions.

Feedstock pretreatment should be recorded because drying, grinding and size reduction alter heat transfer and residence-time distribution. Comparisons across studies are weak when one route processes dense parts and another finely divided waste.

Temperature history should be reported as more than a nominal set point. Heating rate, peak temperature, vapour residence time and local heat transfer influence secondary cracking, char formation and the partition between gas, liquid and solid products.

3. Feedstock identity controls decomposition

The output should be closed by mass balance into gas, condensable liquid and solid fractions. Unrecovered mass should be reported rather than silently assigned to one stream.

A systematic review of thermosetting waste highlights that process optimisation must consider energy demand, emissions and variability rather than only conversion of the polymer [1].

4. Fillers and reinforcement remain in the solid fraction

Fillers, glass fibres, carbon fibres, pigments and mineral flame retardants largely report to the solid fraction, but their surface state and contamination can change. Recovery mass is not equivalent to recovered functionality.

Work on polyester-based composite waste shows that solid residues can retain useful inorganic or fibrous content while condensable and gaseous products have very different compositions and valorisation options [2].

Reinforcement recovery therefore requires ash, char and surface-state characterisation. A fibre may survive geometrically yet lose interfacial performance in a new composite.

Reactor deposits and carryover should be included in cleaning and maintenance requirements. Fouling can change heat transfer and product composition over repeated batches even when nominal operating settings remain unchanged.

Filler recovery should distinguish physical survival from functional retention. Mineral or fibre solids can remain after polymer destruction while carrying char, surface oxidation or metal contamination that changes their suitability for a new photocurable composite.

5. Emissions and energy determine process credibility

Thermoset-composite recycling reviews show why mechanical, thermal and chemical routes should be compared by recovered-value pathway rather than by waste disappearance [3]. For photopolymers, this includes whether fillers can be reused in a new resin without degrading cure.

Gas and liquid streams require chemical identification and contaminant control before they can be described as fuels or feedstocks. Halogens, nitrogen-containing additives and metals can alter treatment requirements.

Energy balance must include pre-drying, reactor heat, inert gas, condensation and post-treatment. Autothermal claims require measured energy recovery rather than the calorific value of one product fraction alone.

Axis	Measurement	Failure mode
Feedstock	resin, fillers, contamination	mixed waste treated as defined input
Reactor	temperature, time, atmosphere	peak temperature treated as process
Products	gas/liquid/solid mass balance	conversion treated as recovery
Fillers	surface, char, retained function	solid residue treated as reusable
Energy/emissions	inputs, gas treatment, hazards	waste diversion treated as circularity

Table 1. Domain-specific qualification matrix for pyrolysis and thermochemical recovery of photopolymer waste.

6. Device-level verification of recovered streams

Device-level verification should take recovered fillers or carbonaceous products into a realistic second-use formulation and compare processing and performance with an appropriate reference.

For liquid products, qualification should state whether the target is fuel, chemical feedstock or further upgrading. Each target has different purity and stability requirements.

Failure modes include unstable product distribution, excessive char, contaminated reinforcement, corrosive or toxic emissions, high parasitic energy and a low-value output that cannot displace virgin material.

Device-level qualification of a thermochemical route should close both material and energy balances over a representative waste mixture. Product yields without condensate losses, off-gas accounting and reactor energy cannot support a factory-level recovery claim.

7. Minimum qualification framework

Report feedstock composition, moisture, particle size, reactor type, temperature-time history, atmosphere, mass of each product fraction and analytical uncertainty.

Report solid/filler condition, liquid and gas composition, emission controls, energy inputs, solvent or carrier use, and the acceptance criteria for the intended valorisation route.

8. Engineering conclusions

Pyrolysis can divert photopolymer waste from disposal, but circular value depends on what each output stream becomes. Product identity, filler quality, emissions and energy must be reported together before thermochemical recovery can be compared with alternative routes.

References

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Competing interest

Juan Segurola is founder, CEO and CTO of 3Dresyns by Resyner Technologies S.L., which develops and commercialises photopolymer materials and related additive-manufacturing technologies. This review is an engineering analysis and does not constitute a product-performance claim or a device qualification.