

# Grand-Challenge Portfolio for Photopolymer Engineering: Research Questions, Dependency Graphs and Decision Value

*Strategic convergence and foresight*

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## Abstract

This Engineering Review converts explicit evidence gaps in the frozen late-corpus strategic reviews into a bounded research portfolio. Entry is deliberately strict: a challenge is admitted only when an upstream controlled object states the gap, the question is researchable, and resolving it could change an engineering decision, qualification boundary or evidence requirement. Six challenges meet that rule in the controlled material available to this review. They concern regulatory evidence maintenance, material/package excursion disposition, transferability of a biofabrication interface map, direct evidence for semiconductor-oriented cleanliness and metrology, repeated-wash qualification of photopolymer wearables, and auditable evidence-system traceability. No formal value-of-information calculation, expected utility or objectively optimal ranking is attempted; those methods remain outside this article. No directed dependency edge is asserted where the controlled upstream material does not establish one. The resulting graph therefore contains six nodes and zero evidence-supported inter-challenge edges. That absence is itself a controlled result: the current gaps are a portfolio, not a demonstrated hierarchy. Proposed study stopping conditions and update rules connect each challenge to a bounded decision and prevent obsolete gaps from persisting by identifier alone.

**Keywords:** grand challenge; photopolymer engineering; research portfolio; evidence gap; dependency graph; decision value; qualification; traceability

## 1. Significance, scope and ownership

ER-499 owns the conversion of explicit open questions into a dependency-aware research portfolio. It does not summarise every Engineering Review, duplicate ER-399 formal value-of-information methods, or perform the ER-500 synthesis across ER-401 to ER-499. The final portfolio is populated only from controlled upstream passages available to this review.

A challenge enters only when the upstream gap is explicit, the question is researchable, resolving it could change an engineering decision or evidence requirement, and a closure criterion can be stated. A challenge is not admitted merely because a topic sounds important.

## 2. Challenge record and graph semantics

Each challenge record contains: identifier, exact upstream owner, open question, decision potentially affected, evidence needed, closure criterion and dependency status. A directed edge A → B would mean that answering A supplies evidence, a method or a boundary needed before B can be interpreted or acted upon. It would not mean that A is more important.

The controlled upstream material used here does not establish a directed prerequisite relation among the six admitted challenges. The graph therefore has six nodes and zero edges. No edge is invented to make the graph visually denser.

## 3. GC-499-01 - Regulatory evidence maintenance

Owner: ER-492.

**Open question.** Which existing evidence remains valid after a relevant regulatory change, which evidence must be revisited, and which downstream records, labels, technical files or customer declarations require controlled revision?

**Decision potentially affected.** Whether a previously qualified evidence package remains usable without uncontrolled reconstruction of regulatory history.

**Evidence needed.** The changed official instrument, role/object analysis and a controlled mapping from the change to affected evidence and downstream records.

**Closure criterion.** The evidence set that remains valid and the records that require revision are identified explicitly and reproducibly.

## 4. GC-499-02 - Material/package excursion disposition

Owner: ER-493.

**Open question.** When water or thermal sensitivity matters, which measured material and package states are sufficient to decide whether an exposure excursion remains inside the qualified envelope, given that chamber RH, weather records and transport logs cannot substitute for material-state measurement?

**Decision potentially affected.** Release, hold, requalification or rejection after storage or transport excursions.

**Evidence needed.** Exposure history linked to material-state and package-state measurements under the relevant formulation and package configuration.

**Closure criterion.** Excursion disposition can be based on measured state rather than ambient logs alone, without turning one package/material history into a universal limit.

## 5. GC-499-03 - Independent test of the biofabrication interface map

Owner: ER-494.

**Open question.** Does the bounded interface map established for methacrylated-starch systems reproduce, narrow or fail in a second independent photocurable material/platform family?

**Decision potentially affected.** Whether the identified shared interfaces can be treated as a broader qualification architecture or must remain family-specific.

**Evidence needed.** Direct evidence from an independent family covering material identity, optical exposure, network formation, state change and biological attribution without importing conclusions by analogy.

**Closure criterion.** The second family either reproduces specified interfaces, identifies bounded exceptions, or falsifies proposed transferability.

## 6. GC-499-04 - Direct cleanliness and metrology evidence for semiconductor-oriented use

Owner: ER-495.

**Open question.** What direct evidence is required before a photopolymer patterning result can support any bounded claim about cleanroom compatibility, contamination control, overlay, inspection or downstream transfer?

**Decision potentially affected.** Whether a material/process may move from pattern-replication demonstration into a semiconductor-oriented qualification path.

**Evidence needed.** Direct measurements in the excluded domain being claimed; pattern fidelity alone is not a substitute.

**Closure criterion.** At least one excluded domain is supported directly enough to move from explicit exclusion to a bounded qualification claim, with the remaining excluded domains still separated.

## 7. GC-499-05 - Repeated-wash qualification of photopolymer wearables

Owner: ER-497.

**Open question.** What photopolymer-specific repeated-wash evidence is sufficient to distinguish retained device function from retained wearability?

**Decision potentially affected.** Whether a wearable remains qualified after repeated laundering rather than merely continuing to perform one function.

**Evidence needed.** Repeated-wash testing on the photopolymer-containing system with separate measures for functional retention and wearability-relevant degradation. Non-photopolymer wash evidence can motivate the test but cannot supply a transferable survival value.

**Closure criterion.** A repeatable protocol distinguishes function retention from wearability retention and does not infer photopolymer durability from a different material system.

## 8. GC-499-06 - Audit metric for evidence-system traceability

Owner: ER-498.

**Open question.** Which explicit audit metric can distinguish a genuine increase in versioned, machine-readable, traceable decision evidence from a mere increase in data volume?

**Decision potentially affected.** Whether evidence-system investment is improving traceability, representativeness and decision calibration rather than only increasing stored information.

**Evidence needed.** An owner-defined audit metric with numerator, denominator, versioning rule, decision linkage and failure interpretation.

**Closure criterion.** The metric can detect the case in which data volume rises without improved traceability, representativeness or decision calibration.

## 9. Dependency graph result

The six admitted challenges are currently parallel in the controlled evidence. No upstream passage establishes that closing one is a prerequisite for interpreting or acting on another. Accordingly, the dependency graph is an edgeless directed graph with nodes GC-499-01 through GC-499-06.

This is not a claim that the research programmes are physically independent. It is a narrower claim: no dependency edge is supported by the controlled evidence used for this article. New frozen evidence may add an edge in a later version only if the prerequisite relation is explicit and traceable.

## 10. Decision value without formal ranking

Each challenge has decision value because its closure could change a release, qualification, evidence-maintenance, transferability or strategic-evidence decision. That qualitative decision link is sufficient for portfolio admission. ER-499 does not calculate expected utility, value of information or a universal priority score.

The portfolio is therefore intentionally unranked. Absence of ranking prevents a large or visible topic from being labelled more important merely because it contains more gaps or more citations.

## 11. Portfolio maintenance and retirement

A challenge remains open only while its owning gap remains open. It is narrowed when new evidence reduces but does not close the question; closed when the recorded closure criterion is met; and superseded when a later frozen ER replaces the decision boundary.

The challenge identifier is stable within this version. New evidence changes status or evidence linkage, not the historical record of why the challenge entered the portfolio.

## 12. Translate a challenge into a study with a stopping condition

The proposed development of each challenge distinguishes the decision, the unknown and the observation that would resolve enough of the unknown to change the decision. A broad request for more data does not provide a stopping condition. A challenge record should therefore specify the receiving claim and the boundary within which its closure would apply. Closing a study does not necessarily close the entire research topic.

For the repeated-wash challenge, a possible study object is a declared photopolymer-textile architecture under one defined exposure sequence. The endpoints would distinguish retained function from retained wearability and interface condition. A successful study could support that bounded architecture while leaving other materials and protocols unresolved. For the package-excursion challenge, the study would instead connect measured exposure with material and package state and the corresponding disposition. The two studies should not share a generic success score merely because both concern durability.

The proposed stopping rule would state what evidence is adequate for the local decision and what residual uncertainty remains. Its justification belongs to the intended use, not to a desire to mark the portfolio complete.

### **13. Update the portfolio when its evidence base changes**

An expanded upstream review may locate direct evidence where the earlier controlled version identified a gap. The portfolio must then re-examine the owning passage. A gap should not remain open solely because it has a stable identifier, nor should one new source be treated as closing a broader question than it actually addresses. The update can retain the challenge, narrow it, close a bounded component or supersede the record, with the reason and source version preserved.

Dependency edges require the same discipline. Sharing an instrument or dataset may create an efficiency opportunity without establishing a scientific prerequisite. The proposed graph should distinguish a required evidential dependency from a convenient resource relationship. If the evidence establishes neither, the absence of an edge remains the appropriate representation.

A useful portfolio review would report the decisions affected by newly acquired evidence, including cases where the preferred action did not change. That is more informative than counting completed studies alone. The method remains qualitative here: it introduces no expected-utility calculation, probability-weighted ranking or claim of an optimal research budget.

### **Evidence appraisal and qualification framework**

#### **From challenge label to testable protocol**

The portfolio is scientifically valuable only if each named challenge can be converted into a falsifiable question. A protocol record should contain the proposed mechanism or failure mode, the observation that would count against it, the controls, the measurement endpoint, the applicable population of processes or materials and the evidence needed for a decision. In a repeated-wash study for a wearable interface, for instance, the primary outcome must be chosen before cycling: feature retention, stiffness, conductivity or another function cannot be substituted retrospectively because it produced a favourable result. In evidence traceability, the primary outcome could be whether an independent reviewer can reconstruct a release decision from version-controlled data without consulting unstated assumptions. Those examples specify methods, not verified results.

#### **Dependencies must be measured rather than inferred from adjacency**

The corpus contains related questions, but thematic overlap is not a causal dependency. To add an arrow between challenges, the author would need a documented reason that progress on one is necessary for evaluating another. A shared reference, material class or chapter heading is insufficient. A useful ledger therefore separates an ownership link, an evidence link and a prerequisite link, with the latter requiring a source-backed rationale and an explicit effect on study order. If no such basis exists, the graph must remain without edges. This preserves the previously approved zero-edge result and avoids creating a prioritisation hierarchy from editorial grouping.

#### **Outcome-based portfolio maintenance**

At each update, a challenge should be classified as unresolved, under test, answered, superseded or retired, with links to the decisive evidence. The choice to retire a question must name whether its uncertainty was reduced, its decision ceased to matter, or its definition was replaced. Simply adding publications does not establish progress if none measure the relevant endpoint. Portfolio quality should be assessed by the proportion of questions with actionable study designs, traceable sources and decision relevance, not by the number of challenges listed. Formal economic ranking would require validated costs and uncertainty models that are not available in the present corpus record.

### **Supplementary critical review: evidentiary and qualification boundaries**

#### **Challenge admission and evidence provenance**

A portfolio entry should be admitted on a documented gap, a consequential decision it affects, and a test that could reduce that uncertainty. A theme with commercial appeal but no bounded hypothesis remains an idea rather than an evidenced grand challenge. For each existing record, the source passage, its limitation, the unanswered question and the potential decision effect should remain linked. This prevents repeated editorial restatements from being counted as independent evidence. The six retained challenges have different experimental objects and should not be merged into a generic transformation programme. Critically, a challenge inventory does not demonstrate dependency among its entries. A directed edge requires a documented prerequisite, and a zero-edge graph must remain zero until such evidence is introduced.

#### **Experiment design and retirement criteria**

The next step after admitting a challenge is to specify the smallest discriminating study, its measurements, controls, credible alternative explanations, stopping criteria and possible outcomes. For example, repeated-wash qualification is not addressed by merely measuring initial adhesion; it requires a declared textile construction and a defined functional endpoint after controlled service simulation. A traceability challenge similarly needs a comparison between records and a verified physical object, not only confirmation that digital identifiers are internally consistent. A challenge may be retired when it is answered, absorbed into a better-defined question, or no longer influences a decision. The portfolio should preserve the evidence and reason for retirement. This governance proposal creates no unsupported ranking or mathematical value-of-information estimate.

### **Critical synthesis: Research-portfolio evidence and dependency testing**

A challenge portfolio is an analytical map, not a set of demonstrated scientific dependencies. A putative link between conversion measurement, durability and application approval should be validated by experiments that show whether improved measurement actually reduces uncertainty in the downstream decision. Correlation between research topics is not proof that one work package is a prerequisite for another. Every dependency should therefore specify a measurable input, expected information gain and a criterion for refutation.

Portfolio ranking should distinguish scientific uncertainty, engineering impact and feasibility of generating discriminating evidence. A high-impact unresolved problem can be low priority when the proposed experiment cannot resolve the relevant mechanism. Conversely, a modest, well-designed interlaboratory comparison may unblock several qualification decisions. Records should preserve negative findings and retired hypotheses so future reviews do not repeatedly present the same untested question as a new challenge.

### **Research-program prioritization and discriminating experiments**

A useful scientific roadmap ranks uncertainties by decision relevance, not by whether a theme is fashionable. For each unresolved question, specify the property or mechanism, the competing hypotheses and an experiment capable of distinguishing them. Repeating a mechanical coupon measurement under nominally identical settings offers limited value if conversion, extraction and post-cure histories remain uncontrolled.

A minimum cross-study comparison set should capture resin composition at an appropriate disclosure level, equipment and spectral conditions, geometry, orientation, environmental exposure, washing, post-curing and the tested specimen state. Uncertainty should include between-batch and between-machine components when claims are intended to transfer. Data omissions should be recorded explicitly rather than filled by typical values or assumptions.

Evidence integration also demands negative results and failed qualification attempts. A roadmap that considers only successful demonstrations systematically overestimates readiness. The proposed output is a decision matrix of uncertainty, experiment, acceptance authority and subsequent verification, rather than a claim that the reviewed literature already closes these gaps.

## **14. Limitations**

This portfolio is bounded to explicit gaps in the controlled upstream material available to this review. It does not claim that these are the only important research questions in photopolymer engineering. It does not infer missing challenges from roadmap symmetry, market expectations or general technical knowledge.

No challenge is admitted from ER-496 in this version because the controlled material used here does not supply an explicit evidence-gap passage suitable for the challenge schema. This is an omission by evidence rule, not a statement that ER-496 has no open research questions.

## **15. Conclusions**

A grand-challenge portfolio is useful only if it preserves the evidence boundary that generated each question. Six challenges meet the architecture rule in the controlled late-corpus material: regulatory evidence maintenance, material/package excursion disposition, independent testing of biofabrication-interface transferability, direct cleanliness/metrology evidence for semiconductor-oriented qualification, repeated-wash qualification of photopolymer wearables, and an audit metric for evidence-system traceability.

The controlled evidence establishes no directed prerequisite among them, so the current dependency graph has six nodes and zero edges. That result avoids inventing hierarchy. ER-499 therefore supplies an auditable portfolio and maintenance rule, while formal ranking remains outside scope and ER-500 remains the terminal corpus synthesis.

## **References**

No external public reference is introduced by this terminal portfolio. Challenge admission is based on frozen upstream Engineering Review passages identified by article in the challenge records above; these internal corpus sources are not represented here as numbered public references.

## **Competing interests**

The author is Founder, CEO and CTO of 3Dresyns by Resyner Technologies S.L. The company develops and supplies photoresins and related process materials. No proprietary formulation, manufacturing sequence, process window or comparative product recommendation is disclosed.

## **Data availability**

No new experimental dataset was generated. The challenge records above identify the internal Engineering Review sources used to define the portfolio.

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