

In-Situ Resource Utilisation Feedstocks for Photocurable Manufacturing: Separation, Variability, Qualification and Logistics

From raw extraterrestrial material to a controlled particulate or molecular feedstock for light-curable manufacturing

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Abstract

In-situ resource utilisation does not produce a manufacturing feedstock merely by excavating regolith. Photocurable processing requires controlled particle size, composition, volatile state, optical behaviour and binder compatibility. Separation and beneficiation introduce mass, energy and yield losses, while spatial variability creates lot-to-lot changes that terrestrial formulations rarely encounter. This review defines the feedstock qualification and logistics chain for photocurable ISRU manufacturing, from resource mapping and extraction through separation, conditioning, acceptance, storage and blending, without presuming that a particular lunar or Martian composite route is already selected.

Keywords: ISRU; feedstock; regolith; beneficiation; separation; variability; photopolymer; logistics; qualification; additive manufacturing

1. Significance and scope

ISRU is valuable because it can reduce launched mass, but the engineering benefit depends on how much local material reaches a controlled manufacturing state. Reviews of lunar-regolith AM consistently identify feedstock preparation and environmental adaptation as central gaps between laboratory demonstrations and autonomous construction [1-3].

ER-441 and ER-442 own lunar- and Mars-specific photocurable composites. This review owns the upstream feedstock system common to both: excavation or collection, separation, conditioning, acceptance, storage and delivery to the formulation step.

2. Resource, feedstock and beneficiation boundary

Raw regolith contains a distribution of particle sizes, mineral phases, agglutinates or glass, volatiles and contaminants. A printer requires a bounded subset of those states. The conversion from resource to feedstock therefore has yield and reject streams that must be included in the mass balance, consistent with an explicit SRU process framework [1].

Feedstock specifications should be written in manufacturing variables: particle-size distribution, optical absorption/scattering, moisture or volatile content, composition range, morphology and contaminant limits. Geological labels alone do not define printability.

Screening, grinding, magnetic or electrostatic separation, thermal treatment and chemical extraction can each improve one variable while worsening another. Finer grinding may improve resolution yet raise energy demand and surface area; drying may stabilize storage while changing agglomeration.

3. Separation and beneficiation define the process window

A qualification route should report separation efficiency, energy per accepted mass, wear/contamination from processing hardware and the fraction of mined material that enters the final formulation.

Spatial variability is expected. An autonomous plant should either tolerate that variability, blend lots to a target state or reject out-of-window feedstock. A formulation tuned to one simulant batch is not an ISRU control strategy.

4. Variability requires lot control and blending

Incoming acceptance can use rapid proxies only if those proxies are calibrated against print-relevant outputs. Colour or bulk chemistry may correlate with optical attenuation in one region and fail in another.

Photocurable routes commonly retain some Earth-supplied organic binder unless an in-situ source or recovery loop exists; regolith-based additive-manufacturing reviews identify binder/process choice as part of the infrastructure problem [2]. High local-solids fraction does not automatically mean high mission-level ISRU efficiency if binder, additives and cleanup consumables dominate launched mass.

Binder recovery and resin reuse should be treated as logistics variables with quality limits. Demonstrations of additive manufacturing with lunar regolith structures show why feedstock preparation and forming route must remain traceable to the manufactured state [3]. Cross-contamination between regolith lots or recovered resin can erase the traceability needed to diagnose failures.

Packaging and transport inside the habitat or processing plant matter because dry fine powders contaminate mechanisms while wet slurries demand sealed storage. Feedstock form should be selected with the entire handling chain in view.

5. Binder/logistics balance and device-level verification

The strongest ISRU architecture may use different feedstock states for different products: coarse material for large structures, finer fractions for precision VPP, and extracted constituents for functional materials. One universal feedstock is not required.

Device-level verification should run the complete chain from representative raw simulant through separation, conditioning, formulation and printing, with yields and rejected material measured at every boundary.

Robustness tests should introduce controlled variation in the raw input and verify whether feedstock acceptance and blending prevent downstream drift in cure or properties.

Axis	Measurement	Failure mode
Raw resource	location, simulant/resource identity	geological label used as process specification
Separation	yield, energy, contamination	accepted fraction reported without rejects
Acceptance	PSD, optical/compositional bounds	single batch used as universal feedstock
Binder balance	local vs Earth-supplied mass	solids loading equated with ISRU efficiency
Logistics	storage, blending, traceability	feedstock handling omitted from process

Table 1. Domain-specific qualification matrix for ISRU feedstocks used in photocurable manufacturing.

6. Transfer limits and minimum reporting dataset

Autonomous operation requires metrology that can be maintained and calibrated in mission conditions. A laboratory instrument that cannot be cleaned, referenced or repaired off-Earth is not a closed qualification solution.

Report resource/simulant identity, separation sequence, yields, energy, accepted PSD/composition/optical state, storage condition, blend rules, binder fraction and recovered-material policy.

Demonstrate traceability from raw lot to printed part and quantify how feedstock variability propagates into rheology, cure and final properties.

7. Minimum qualification framework

A minimum ISRU-feedstock programme should maintain a mass balance from collected resource to accepted manufacturing feedstock. For each beneficiation step, report feed, product and reject fractions, energy use, contamination introduced by hardware and the particle/composition variables that justified the separation.

Lot control should define sampling frequency, blending rules, acceptance limits and disposition of off-spec material. The feedstock specification should be written in variables that matter to photocurable processing, including optical attenuation, particle size/morphology, volatile state and binder compatibility, so geological variability can be translated into manufacturing risk.

8. Engineering conclusions

ISRU becomes a manufacturing supply chain only when resource variability is converted into a controlled feedstock with known yield and logistics. The engineering value of local material therefore depends not on excavation alone but on beneficiation, acceptance, storage and delivery losses that remain visible in the system mass and energy balance.

References

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Competing interest

Juan Seguro 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.