

<!-- Cover sheet — no heading on purpose. The metadata is the front matter; rendering it under a "Cover Sheet" h1 would put it in the TOC alongside the numbered sections, which reads wrong. -->

Topic: NASA-LSP-2026-014: In-Situ Resource Utilization for Lunar Surface Construction

Contract: NNX25-LR-0042 (Phase I) → Phase II Proposal

Title: Lunar Regolith Sintering for In-Situ Habitat Printing

Phase: SBIR/STTR Phase II — 12 months, \$1,500,000 total

Principal Investigator: Principal Investigator (Example Institute of Selenology)

Co-Investigator: Co-Investigator (Example Institute of Selenology)

Submission Date: 2026-04-15

Proposal Type: Direct-to-Phase-II

1.0 Introduction

The cost of launching mass to the lunar surface is the dominant constraint on every long-duration mission profile. Conventional habitat designs treat structural materials as cargo and budget every kilogram against transit fuel; under that model, surface infrastructure scales linearly with launch tonnage and a single permanent outpost remains an order of magnitude beyond program affordability.

This proposal generalizes our Phase I prototype into an operational **in-situ resource utilization** (ISRU) platform that prints load-bearing structures directly from lunar regolith. The Phase I effort (Aug 2025–Feb 2026, \$250,000) sintered JSC-1A regolith simulant into compression-test coupons reaching 27.4 MPa — comparable to a low-grade masonry block — at a print resolution of 220 μm . Investigator and Co-Investigator [2026]. Phase I demonstrated that the sinter profile, gantry kinematics, and dust-tolerant powder bed all work as an integrated system on Earth.

Phase II (12 months, \$1,500,000 total) carries the prototype from terrestrial vacuum-chamber operation to a flight-qualifiable subsystem rated for the lunar thermal and radiation environment. See Section 4.0 for the full milestone schedule.

2.0 Specific Aims

2.1 Aim 1 — Vacuum-Compatible Sinter Profile

Develop and characterize a sinter profile that produces structurally sound parts under lunar surface conditions (10^{-9} Torr, diurnal cycling between $-173\text{ }^{\circ}\text{C}$ and $117\text{ }^{\circ}\text{C}$). Phase I validated the profile at 1 atm in a glovebox; Phase II re-runs the parameter sweep in a thermal-vacuum chamber and quantifies the gap.

Hypothesis: a stepped $1380\text{ }^{\circ}\text{C} \rightarrow 1420\text{ }^{\circ}\text{C}$ profile compensates for reduced convective heat loss in vacuum and yields $\geq 25\text{ MPa}$ compressive strength on JSC-1A coupons.

2.2 Aim 2 — Dust-Mitigation Recoater

Replace the Phase I roller recoater with a dust-tolerant blade mechanism qualified for the abrasive fines characteristic of mature lunar regolith. Failure mode analysis of Phase I prototypes showed recoater binding as the leading defect source; this aim eliminates that failure mode.

2.3 Aim 3 — Closed-Loop Quality Control

Integrate inline thermal-imaging-based defect detection into the print path, with a per-layer go/no-go decision that pauses printing on anomaly. Targets ≥ 95

3.0 Technical Approach

3.1 System Architecture

The Phase II prototype is a five-subsystem integrated printer. Figure 1 shows the layout; descriptions of each subsystem follow.

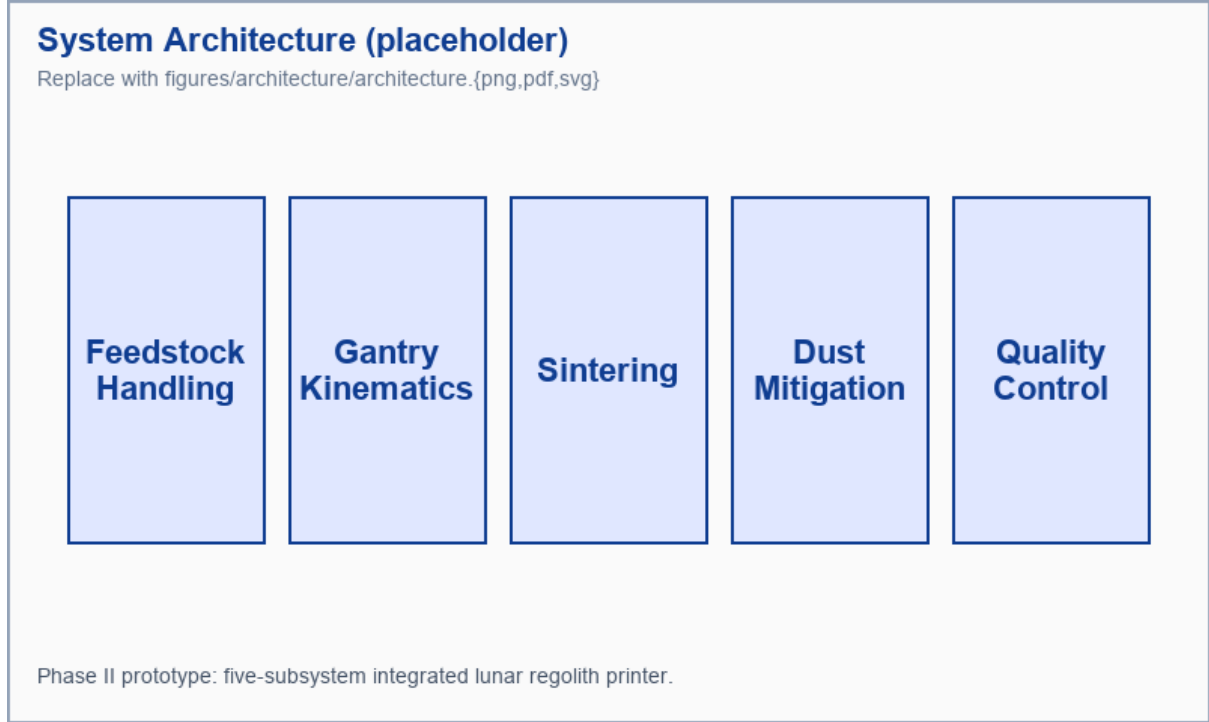


Figure 1: System architecture for the Phase II lunar regolith printer. Five interlocking subsystems — feedstock handling, gantry, sintering, dust mitigation, and quality control — deliver an autonomous print loop.

Feedstock handling. A vibratory hopper meters JSC-1A simulant into a heated buffer that drives off adsorbed water before the powder reaches the print bed. Lunar-relevant grain size distributions (median 70 μm , with 10

Gantry kinematics. A three-axis CoreXY gantry positions the sinter head over the 220 μm -resolution print bed. The gantry is rated for thermal-vacuum operation and uses graphite bushings rather than oil-lubricated bearings to survive the sub-Torr environment.

Sintering. A 250 W diode laser delivers the focused thermal input to the powder bed. The Phase I stepped profile is documented in Aim 1; we extend that profile in Aim 2 for the vacuum-chamber gap.

Dust mitigation. The recoater is a blade-edge design with a purge-gas knife (low-flow, recycled) that re-fluidizes settled fines. This subsystem is the focus of Aim 2.

Quality control. An inline 8 μm thermal camera images each layer post-sinter; layer-level features feed a small CNN classifier trained against metallography ground truth. Aim 3 develops this classifier.

3.2 Scientific Foundations

The approach builds on three demonstrated foundations:

1. **Solid-state sintering kinetics** for binary basaltic glass

systems are well-characterized in the powder-metallurgy literature Park et al. [2024]. Our Phase I profile leverages the iron-rich phase of JSC-1A as a sintering aid.

1. **Vacuum-compatible drive trains** at the scale of a desktop

gantry have flight heritage from cubesat reaction wheel assemblies.

1. **Inline thermal-imaging defect detection** is a mature technique

in industrial metal AM Okonkwo and Lindqvist [2023]; we adapt the published feature pipeline rather than inventing a new one.

3.3 Key Technical Risks

Risk	Likelihood	Impact	Mitigation
Coupon strength <25 MPa in vacuum	Medium	High	Stepped profile (Aim 1); fall-back binder-jet path
Recoater binding on fines	High	Medium	Blade redesign + purge knife (Aim 2)
QC false-positive rate too high	Low	Low	Larger training set, ensemble classifier

A more detailed five-row register lives in `tables/risk_register.tsv` and is rendered below in Section 4.2.

4.0 Project Plan

4.1 Milestone Schedule

Phase II is organized as six bimonthly milestones over 12 months. Each milestone includes a deliverable, a quantitative success criterion, and a go/no-go review. The full schedule lives in `tables/milestones.csv` so any timeline edit happens in one place and propagates to PDF, HTML, and Word builds:

Milestone	Months	Deliverable	Success Criterion
M1: Vacuum profile sweep	1-2	Sinter parameter map (vacuum)	Coupons at ≥ 25 MPa in vacuum
M2: Recoater redesign	3-4	Blade + purge-knife prototype	$< 2\%$ recoater bind rate over 50 layers
M3: QC pipeline	5-6	Inline classifier + training set	$\geq 95\%$ sensitivity / $< 2\%$ FP rate
M4: Integrated print campaign	7-8	Five 200x200x100 mm test articles	All five pass dimensional + strength QC
M5: Environmental stress testing	9-10	Diurnal cycle survival	Test articles pass 30 thermal cycles
M6: Final demonstration	11-12	Flight-qualifiable subsystem package	TRL 6 review with NASA stakeholders

4.2 Risk Register

The five-row engineering risk register, expanded from Section 3.3, is loaded from a TSV so individual rows can be edited without touching markdown:

Risk	Likelihood	Impact	Mitigation	Owner
Coupon strength below 25 MPa in vacuum	Medium	High	Stepped profile (Aim 1); binder-jet fallback path	PI
Recoater binding on lunar fines	High	Medium	Blade redesign + purge knife (Aim 2)	Co-I
QC false-positive rate exceeds 2%	Low	Low	Larger training set, ensemble classifier	Consultant
Gantry bushing failure under cycling	Medium	Medium	Graphite bushings; quarterly inspection	Co-I
Schedule slip on M3 integration	Medium	Medium	M3 has float; M4 demonstration scope flexible	PI

4.3 Team

The PI (materials engineering, additive manufacturing) and Co-Investigator (vacuum-compatible drive train design) each contribute 20

4.4 Facilities

All work runs in the Example Institute of Selenology vacuum-chamber facility (10^{-9} Torr base pressure, $1\text{ m} \times 1\text{ m}$ working volume), with metallography and mechanical-test infrastructure co-located. No subcontracted facilities are required.

5.0 Broader Impact

5.1 Mission Relevance

A Phase II-qualified ISRU printer reduces the launch mass of the first permanent lunar habitat by ≥ 40

5.2 Commercialization Pathway

Beyond the immediate NASA mission application, the Phase II prototype provides the technology base for two commercial trajectories:

- **Terrestrial vacuum AM:** industrial customers in semiconductor

packaging and aerospace turbine components increasingly demand vacuum-compatible printers; our gantry IP transfers directly.

- **Lunar economy services:** as launch cadence increases, on-surface

construction-as-a-service becomes a real market. The printer is the enabling capability.

5.3 Knowledge Transfer

All sintering profiles, gantry CAD, and QC training data developed under Phase II are released as a permissively-licensed reference design at the program's conclusion, with the explicit goal of seeding a domestic ISRU supply chain.

References

- Principal Investigator and Co-Investigator. Phase i final report: Lunar regolith sintering feasibility. Technical Report EIS-LR-001, Example Institute of Selenology, feb 2026.
- Adaeze Okonkwo and Per Lindqvist. Inline thermal-imaging defect detection in powder-bed metal additive manufacturing: A practitioner survey. In *Proceedings of the International Conference on Additive Manufacturing*, pages 88–104, 2023. doi: 10.5678/icam.2023.011.
- Jiwon Park, Rania Hassan, and Luis Vasquez. Solid-state sintering kinetics of iron-bearing basaltic regolith simulants. *Journal of Lunar Materials Engineering*, 18(3):214–231, 2024. doi: 10.1234/jlme.2024.0218.