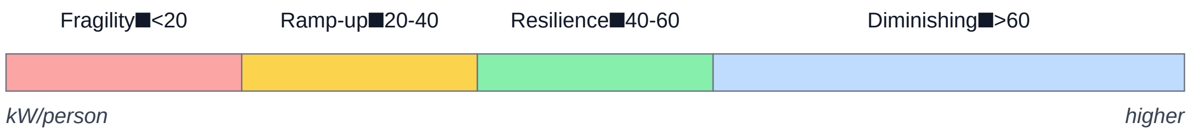
Energy Gate (Layer Zero):
A Phase-Stability Metric and Architecture Study for Early Mars Settlements

Concept Note (5-8 pages) — proposal-ready language

Project type	Architecture study + quantitative modeling + validation plan
Core hypothesis	Continuous power per person (kW/person) acts as a phase gate for resilient scaling.
Heuristic thresholds	Fragility: <20 kW/person • Gate: ~40 kW/person (sustained) • Resilience band: 40-60 • Diminishing returns: >60
Phases (aligned to v9 atlas)	Outpost → Settlement → City → Civilization (phase-toggleable Sankey and panels)
Primary outputs	Energy Gate Score, scenario library, validated guidance for architecture decisions, and an audit-friendly visual atlas interface.
Requested support	Recognition + access; then scoped funding for Phase-1 work package.



Interpretation: treat the ~40 kW/person threshold as a scale gate; do not increase population or cadence until the gate is met continuously.

1. Executive Summary

This concept note proposes a compact, testable “Energy Gate” framework to reduce catastrophic risk in early Mars settlement scaling. The key idea is to treat **continuous power per person** (kW/person) as a **phase gate**. Below the fragility zone, settlement growth is brittle: life support margins shrink, ISRU becomes intermittently starved, maintenance backlogs grow, and governance/operations lag behind complexity. The Energy Gate converts this intuition into a quantitative metric, linked to a phase-toggleable architecture atlas (Outpost → Settlement → City → Civilization), so stakeholders can audit assumptions and see consequences of changing power, ISRU intensity, automation, and logistics cadence.

Proposed Phase-1 outcomes

- A formal **Energy Gate Score** with explicit definitions for “sustained power”, reserve margin, and critical-load fraction.
- A scenario library that identifies **failure thresholds** and **safe ramp schedules** across the four phases.
- A validation report: what the gate predicts, where it fails, and how it should be updated (falsifiable science).
- A review-ready demonstration interface integrated into the existing v9 atlas (JS-free, offline, print-vector).

This document is written to be attachable to a funding inquiry as a concise architecture study proposal. The full settlement atlas remains the integration target, but the Energy Gate is the spear-tip: small enough to fund, strong enough to scale.

2. Problem Statement and Motivation

Mars settlement concepts often emphasize transport, landing, and habitat hardware. However, early settlements fail not only by lack of hardware, but by **system brittleness under scaling**: intermittent power, maintenance debt, supply-chain delays, and delayed institutional adaptation. A compact gating metric is needed to prevent premature increases in population or cadence that outstrip energy and operations capacity.

Why power per person?

Continuous power is the enabling substrate for nearly every survival-critical function: atmospheric processing, thermal control, water recovery, food production, ISRU, robotics/automation, communications, medical care, and manufacturing. Per-capita normalization makes cross-phase comparison possible and provides a single variable that can be monitored and optimized.

Energy Gate heuristic (as currently specified)

Fragility: <20 kW/person • **Gate:** ~40 kW/person sustained before ramping • **Resilience band:** 40-60 kW/person • **Diminishing returns:** >60 kW/person. The heuristic is explicitly stated as a **design lens** that requires validation using mission-specific load models.

Phase framing and integration target

The proposal uses a four-phase framing consistent with the existing atlas controls: **Outpost**, **Settlement**, **City**, and **Civilization**. The atlas already implements phase toggles (e.g., Sankey per phase) to visualize how mass and power flows change with phase. This proposal turns that interface into a test harness: each phase becomes a scenario class with explicit assumptions.

3. Objectives, Research Questions, and Success Criteria

- **O1 — Define the Energy Gate Score:** formalize kW/person gate definitions, including sustained power, reserves, and critical-load fraction.
- **O2 — Quantify phase transition constraints:** determine when growth (population, cadence, industrial load) becomes brittle vs resilient under plausible assumptions.
- **O3 — Validate or falsify:** test the heuristic against mission-style load models and analog data (where available) and publish error modes.
- **O4 — Deliver a review-ready interface:** integrate metrics into the phase-toggleable atlas so stakeholders can audit assumptions and outputs.

Key research questions

- RQ1: What definition of “sustained kW/person” best predicts operational brittleness (downtime, maintenance backlog, life-support margin)?
- RQ2: How sensitive is the gate to ISRU intensity, automation fraction, and dust-storm duty cycles?
- RQ3: Under what conditions does the 40-60 kW/person band fail (counterexamples)?
- RQ4: How should the gate be modified for different architectures (nuclear-dominant vs solar-dominant, centralized vs distributed)?

Success criteria (Phase-1)

Criterion	Definition (measurable)
C1	Energy Gate Score computed for each phase scenario with confidence interval and clear pass/fail rule.
C2	At least 12 scenarios (3 per phase) executed with sensitivity sweeps across power availability and ISRU/robotics loads.
C3	Validation report includes at least 3 falsification tests (where heuristic fails or needs adjustment).
C4	Atlas integration demonstrates phase toggles and clear visualization of gate margin and dominant drivers.

4. Method and Technical Approach

The Energy Gate is treated as a compact systems metric built from first-principles load accounting and operational stability. The method is deliberately modular: funders can review definitions, assumptions, and validation steps independently.

4.1 Metric definition (Energy Gate Score)

Define a per-phase Energy Gate Score EG as a function of: (i) continuous delivered power per person (kW/person), (ii) reserve margin (fraction of capacity above critical loads), (iii) stability of supply (variance, storm duty cycle, outage rates), (iv) critical-load fraction (life support + thermal + comm + medical), and (v) maintainability (crew-hours and spares required to sustain supply). EG outputs (a) pass/fail and (b) margin-to-gate.

4.2 Phase scenarios (aligned to atlas toggles)

Each phase (Outpost, Settlement, City, Civilization) becomes a scenario class with explicit assumptions: population range, infrastructure scope, ISRU intensity, automation share, and logistics cadence. The atlas already uses phase toggles (e.g., Sankey per phase) as a visualization shell; this project binds quantitative scenario parameters to those toggles for transparent review.

4.3 Sensitivity and failure-mode analysis

We perform parameter sweeps over: dust-storm duty cycles, reactor downtime, storage sizing, ISRU ramp rate, robotics utilization, and resupply delays. Outputs include: (1) threshold surfaces (where the gate fails), (2) dominant-driver decomposition, and (3) safe-ramp schedules (population/cadence increases only when the gate margin is maintained).

4.4 Integration into the atlas (audit-ready delivery)

The demonstration interface is delivered in the same style as the v9 atlas: single-file, JS-free, offline, print-vector. Phase toggles already exist (radio controls for Outpost/Settlement/City/Civilization); we add gate margin indicators, scenario metadata, and a results appendix inside the file, enabling review without external software.

5. Validation Strategy

The current heuristic is explicitly labeled “design lens only; validate with mission-specific load models.” Validation is therefore central, not optional. The goal is not to “prove” the heuristic, but to refine it into a falsifiable, reviewable metric.

5.1 Mission-specific load models

Construct load models for each phase that include: life support (ECLSS), thermal control, comms, medical operations, ISRU (water/oxygen/fuel), robotics, manufacturing, and habitat growth. Power supply options are modeled as nuclear-dominant, solar-dominant, and hybrid cases, with explicit storm-mode behavior.

5.2 Falsification tests

- Counterexample search: identify plausible architectures where settlements remain stable below the proposed fragility threshold.
- Stress tests: outage storms, resupply delays, and maintenance spikes; measure whether EG predicts brittleness before failure.
- Parameter drift: test sensitivity to assumed crew-hours for maintenance and automation productivity.

5.3 Validation outputs

Deliverables include a validation report with: calibration curves, confidence bands, failure cases, and recommended updates to the thresholds. The report explicitly states what the metric can and cannot claim at Phase-1 maturity.

6. Work Plan, Timeline, and Deliverables

6.1 Work packages (Phase-1, 20 weeks)

WP	Name	Schedule	Outputs
WP1	Metric formalization	Weeks 1-4	Define EG, sustained-power definition, reserves, critical-load taxonomy; draft technical note.
WP2	Phase scenarios + load models	Weeks 5-10	Build per-phase load models; encode supply options; implement storm-mode behaviors.
WP3	Sensitivity + failure modes	Weeks 11-16	Run sweeps; map threshold surfaces; produce safe-ramp schedules and dominant drivers.
WP4	Atlas integration + dissemination	Weeks 17-20	Integrate results into phase toggles; finalize report, scenario library, and demonstration package.

6.2 Deliverables

- **D1:** Energy Gate Score specification (definitions, thresholds, confidence bands).
- **D2:** Scenario library (minimum 12 scenarios) with inputs, outputs, and failure narratives.
- **D3:** Validation report (including falsification cases and recommended threshold updates).
- **D4:** Demonstration interface integrated into the phase-toggleable atlas (Outpost/Settlement/City/Civilization).
- **D5:** Executive brief (1-2 pages) for non-technical stakeholders.

6.3 Initial risk register (Phase-1)

Risk	Likelihood	Impact	Mitigation
R1: Over-simplification	Med	High	Explicitly publish failure cases; use confidence bands; keep metric modular.
R2: Missing data	High	Med	Use scenario ranges; identify which parameters drive uncertainty most; prioritize those for validation.
R3: Reviewer mismatch (too broad)	Med	High	Keep proposal anchored to Energy Gate; present atlas as interface, not as primary deliverable.
R4: Funding pathway constraints	High	High	Pursue recognition/access first; partner with eligible host organizations for funding transfer.

7. Resources, Team, and References

This concept can be executed by a small team (or a solo lead with part-time collaborators): systems modeler (lead), power systems engineer (review), ECLSS/ISRU reviewer, and an architecture reviewer. The atlas interface is already implemented as a single-file, JS-free, print-vector artifact; Phase-1 focuses on formalization and validation.

Budget (illustrative, to be tailored to call)

Cost element	Estimate	Notes
Labor (modeling + integration)	—	Primary driver; depends on duration and team size.
Reviewers/consultants	—	Targeted domain reviews (power, ECLSS, ISRU).
Compute + tools	Low	Primarily desktop compute; optional cloud runs for sweeps.
Dissemination	Low	Technical note, figures, and demonstration package.

References (internal artifacts)

- UNIVERSAL ATLAS — “Mars Civilization” (v9 — 2025-09-22). Energy Gate (Layer Zero) callout and phase-toggle panels.
- UNIVERSAL ATLAS (v9). Mass & Power Sankey — per phase (Outpost/Settlement/City/Civilization) interface used as the scenario visualization shell.

Appendix A: Suggested submission venues (to be customized)

This concept note is formatted to fit early-stage architecture study calls and advanced concepts programs. For any specific call, adjust: required page limit, budget format, and eligibility statements.