

Infrastructure-Scale Considerations for Electromagnetic Surface Launch in Lunar Export Architectures

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Executive Summary

Sustained lunar construction and industrial development require export architectures capable of moving material from the surface to orbit at throughput levels beyond demonstration scale. Propellant-dependent ascent models impose structural scaling limits due to recurring mass and plume-related surface disruption. Electromagnetic surface launch represents one of the few candidate approaches capable of enabling high-throughput export without recurring propellant expenditure. This note presents a first-order infrastructure-level assessment of energetic bounds, rail geometry constraints, terrain coupling, and surface-orbit interface requirements for multi-tonne-per-day export regimes. Results indicate that export scalability is governed principally by surface power generation, energy buffering capacity, and civil infrastructure footprint rather than launcher physics alone. The analysis demonstrates that export capability must inform early lunar construction planning decisions, including site selection, power architecture, and logistics layout.

1. Export as an Infrastructure Scaling Problem

The feasibility of lunar resource utilization at industrial scale depends not only on extraction and processing but on the ability to transport material to orbit efficiently and repeatedly. While chemical ascent systems remain indispensable for early missions, their reliance on consumable propellant introduces recurring logistical penalties and plume-induced regolith disturbance near surface infrastructure.

Electromagnetic surface launch reframes ascent as an energy-conversion problem rather than a propellant expenditure problem. Instead of launching propellant to lift additional propellant, steady-state surface power generation is accumulated and released in short-duration acceleration pulses. Under this paradigm, export scaling is fundamentally governed by power plant capacity, energy buffering systems, and rail corridor civil infrastructure.

2. Energetic and Throughput Bounds

Injection into low lunar orbit at altitudes of approximately 50–100 km requires exit velocities on the order of 1.6–1.7 km/s. The ideal kinetic energy per unit mass is given by:

$$E_k = \frac{1}{2} v^2$$

Where E_k is the ideal kinetic energy per unit mass (J/kg) and v is the rail exit (injection) velocity (m/s). For this velocity range, the ideal kinetic energy is approximately 1.3–1.5 MJ/kg. Accounting for aggregate system efficiency in the range of 40–60 percent, the electrical energy requirement becomes:

$$\frac{E_{elec,specific}}{kg} = \frac{1}{2} \frac{v^2}{\eta}$$

Where $\frac{E_{elec,specific}}{kg}$ is the electrical energy required per unit payload mass (J/kg), v is rail exit velocity (m/s), and η is the aggregate system efficiency (0-1), including conversion and loss mechanisms between stored electrical energy and delivered payload kinetic energy. This yields approximately 2.3–3.4 MJ/kg of electrical input energy. Scaling to export volumes expressed in metric tonnes (1 tonne = 1,000 kg):

- 1 tonne/day requires approximately 2.3–3.4 GJ/day
- 10 tonnes/day requires approximately 23–34 GJ/day
- 100 tonnes/day requires approximately 230–340 GJ/day

Average recharge power is determined by:

$$P_{avg} = \frac{E_{day}}{T_{day}}$$

Where E_{day} = total electrical energy required per day (J) and T_{day} = 86,400 seconds. At 10 tonnes/day, this corresponds to approximately 263–394 kW of average power. At 100 tonnes/day, required average power enters the multi-megawatt range.

Electromagnetic export is pulse-dominated in peak power but infrastructure-dominated in average power. Total energy per launch determines storage capacity. Average recharge power determines generation capacity. Peak pulse power, defined by payload mass, acceleration, and exit velocity, governs switching stress, conductor loading, and thermal rejection requirements.

Representative modeling indicates that a photovoltaic deployment on the order of 2,000 square meters, strategically placed in polar regions offering approximately 80 percent effective illumination exposure, is consistent with multi-tonne-per-day export under high-illumination polar deployment when coupled with buffered storage.

3. Rail Geometry and Terrain Coupling

Rail length is governed by the kinematic relationship:

$$L = \frac{v^2}{2a}$$

where L is rail length, v is exit velocity, and a is allowable inertial acceleration. Acceleration tolerance is expressed as multiples of Earth standard gravity ($g_0 = 9.81 \text{ m/s}^2$), consistent with conventional payload

structural qualification practice. Lunar gravity (1.62 m/s^2) is applied where physically relevant, including orbital mechanics and surface foundation loading.

Parametric first-order modeling has explored acceleration envelopes of 20–40 g-load for payload masses between 50 and 150 kg. A representative configuration consists of approximately 6 km of rail with a 2-degree terminal incline and a modest trim impulse at rail exit to refine injection targeting. This configuration supports injection to approximately 80–100 km altitude, producing orbital lifetimes in the range of 12–24 hours. This model is supported by an approximate 2000 m² photovoltaic solar farm.

This duration provides an operationally practical retrieval window, including a 2–3 hour capture opportunity for an autonomous grappler vehicle tasked with rendezvous and transfer to higher staging orbits.

The representative configuration is illustrative rather than prescriptive. The integration insight is that acceleration tolerance directly determines civil infrastructure footprint. Rail corridor length influences terrain selection, regolith stabilization requirements, radiator placement, and proximity to power generation assets. Export infrastructure therefore materially shapes early lunar construction planning decisions.

4. Surface–Orbit Interface and Operational Envelope

Injection conditions must ensure gravitational binding and sufficient orbital lifetime to enable recovery operations. At approximately 60 km altitude, one orbital period is on the order of two hours. A minimum of one full orbital period is required to ensure stable capture opportunity, while a 12–24 hour availability window increases operational robustness.

Exit velocity must therefore be bounded above the ideal circular solution to accommodate gravitational losses and targeting tolerances. Injection accuracy influences the size of the orbital corridor and the retrieval Δv requirements for the grappler system.

While detailed modeling of electromagnetic field behavior, rail structural dynamics, and orbital capture energetics lies beyond the scope of this overview, the first-order analysis demonstrates that export capability can be integrated within realistic power and civil infrastructure bounds.

5. Infrastructure Maturity Pathway

Progression toward infrastructure-grade deployment would plausibly proceed through terrestrial vacuum pulsed-power validation, followed by sub-tonne-per-day lunar demonstration, and ultimately multi-tonne-per-day export capability integrated with surface construction systems.

The principal conclusion is that export capability should not be treated as a downstream addition to lunar construction. Once throughput requirements are quantified, export becomes a power-generation and civil-infrastructure problem that must inform site selection, energy architecture, and logistics layout from the outset. Electromagnetic surface launch does not eliminate engineering constraints; it shifts them from propellant supply to power density, energy buffering, and infrastructure integration.