FIREFLY AEROSPACE

# Logistics and the Design of a Lunar Harbor

Prepared for Lunar Surface Innovation Consortium
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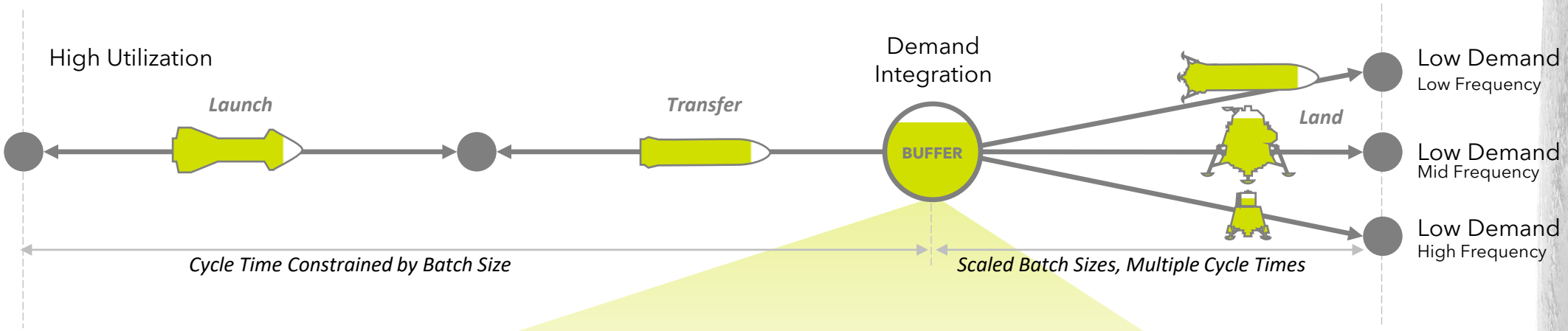
# **CONCEPT** AGGREGATION HUBS

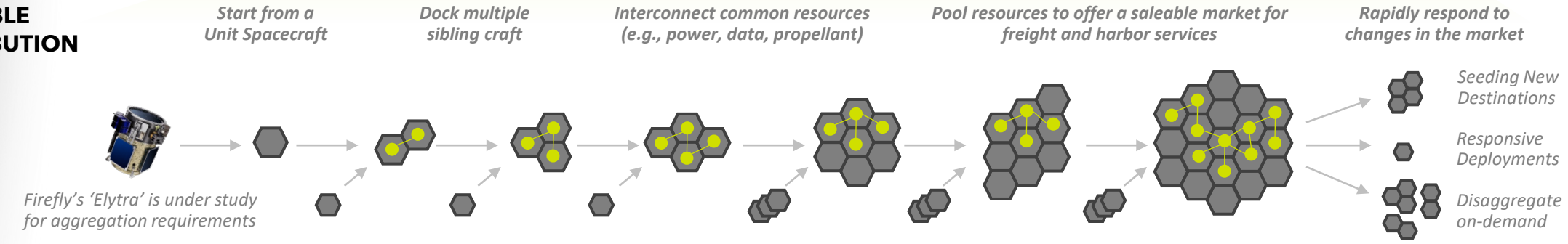
## DECOUPLE SURFACE DEMAND FROM LAUNCH UTILIZATION

**DEMAND INTEGRATION**




*Given a fixed system throughput, a buffer improves both utilization for upstream deliveries and frequency for downstream deliveries.*

**SCALABLE DISTRIBUTION**




*With lower per-unit commitment costs than a station, aggregations offer an incremental growth solution to meet traffic demand as it develops.*

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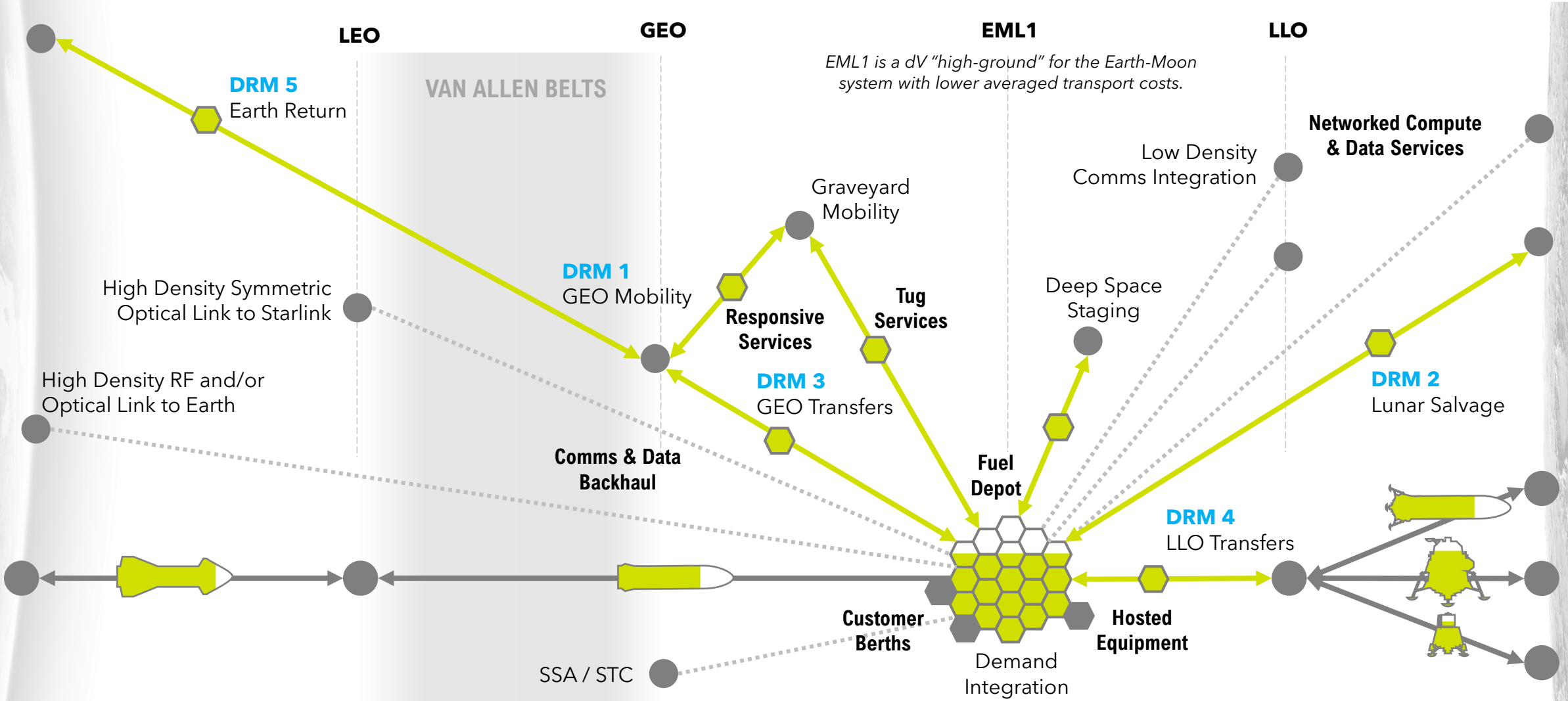
# **CONCEPT** CORE SERVICES

## CARGO FORMS THE ANCHOR MARKET FOR ANY HARBOR




*As an EML1 aggregation grows it can offer increasingly more valuable services in cargo logistics, tugs, refueling, SSA, power, comms, data, and salvage.*

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# **LOGISTICS** DEMAND MODELING

## SCALING THE ADDRESSABLE MARKET FOR THE LUNAR SURFACE

*What should a model lunar population look like for a deeper exploration of supply chain assumptions?*

**CORE ASSUMPTION:** The key demand metric is down-mass, (e.g., descent propellant, surface equipment, and maintenance/resupply cargo).

| General Surface Equipment | Mass (kg) | LRUs (QTY) | Scrap Rate (LRU/year) |
|---|---|---|---|
| Small Ground Equip. (QTY) | 50 | 10 | 0.1 |
| Med Ground Equip. (QTY) | 500 | 100 | 0.1 |
| Large Ground Equip. (QTY) | 5000 | 1000 | 0.1 |

Cargo is normalized and sampled as small, medium, or large demand signals.

| General Lander Definitions | Propellant (kg) | Payload (kg) | Dry Mass (kg) |
|---|---|---|---|
| Small Class Lander | 1000 | 150 | 500 |
| Medium Class Lander | 10000 | 1500 | 5000 |
| Large Class Lander | 100000 | 15000 | 50000 |

Landing is normalized and sampled as small, medium, or large delivery signals as well as propellant demand signals.

| Years Elapsed | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cargo Received (MT) *at the Moon* | 6.3 | 13 | 21 | 30 | 53 | 84 | 125 | 202 | 319 | 500 | 796 |
| Cargo Launched (MT) *from the Earth* | 221 | 321 | 438 | 603 | 951 | 1362 | 1894 | 2900 | 4370 | 6615 | 10274 |

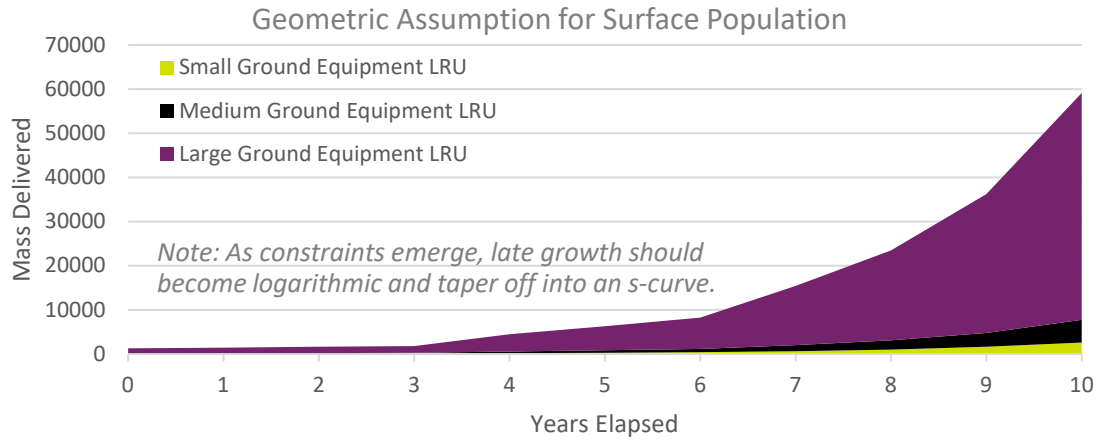
This summation focuses exclusively on lunar down-mass demand and does not account for a lunar up-mass market in this specific context.

**CORE ASSUMPTION:** A proven market invites additional investments which compound, resulting in geometric growth during the early market phases.

**Generalized Surface Population**

| Years Elapsed | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Small Ground Equip. (QTY) | 5 | 8 | 13 | 20 | 32 | 51 | 80 | 127 | 202 | 320 | 508 |
| Med Ground Equip. (QTY) | 1 | 2 | 3 | 4 | 7 | 11 | 16 | 26 | 41 | 64 | 102 |
| Large Ground Equip. (QTY) | 1 | 2 | 3 | 4 | 7 | 11 | 16 | 26 | 41 | 64 | 102 |

| Years Elapsed | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Equip. Demand (MT) | 6.3 | 7.1 | 8.0 | 9.0 | 22 | 31 | 41 | 77 | 117 | 181 | 295 |
| Prop. Demand (MT) | 44 | 50 | 57 | 65 | 154 | 215 | 282 | 520 | 790 | 1220 | 1980 |

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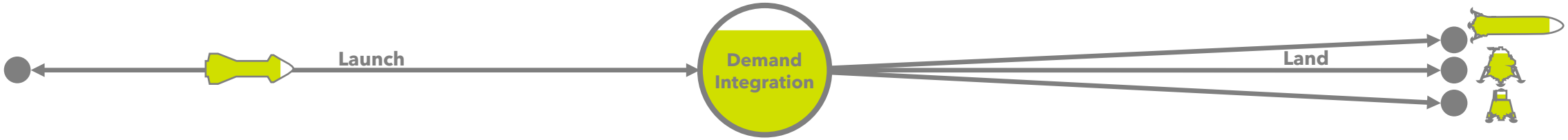
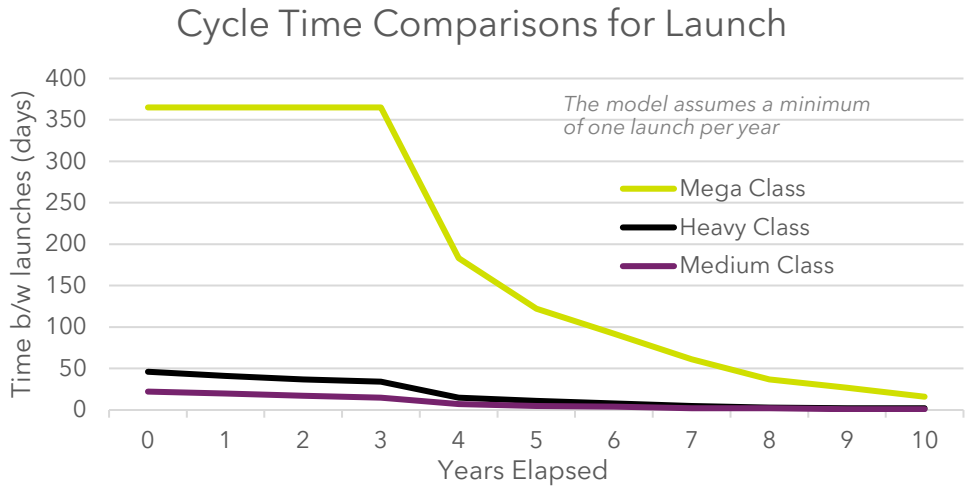
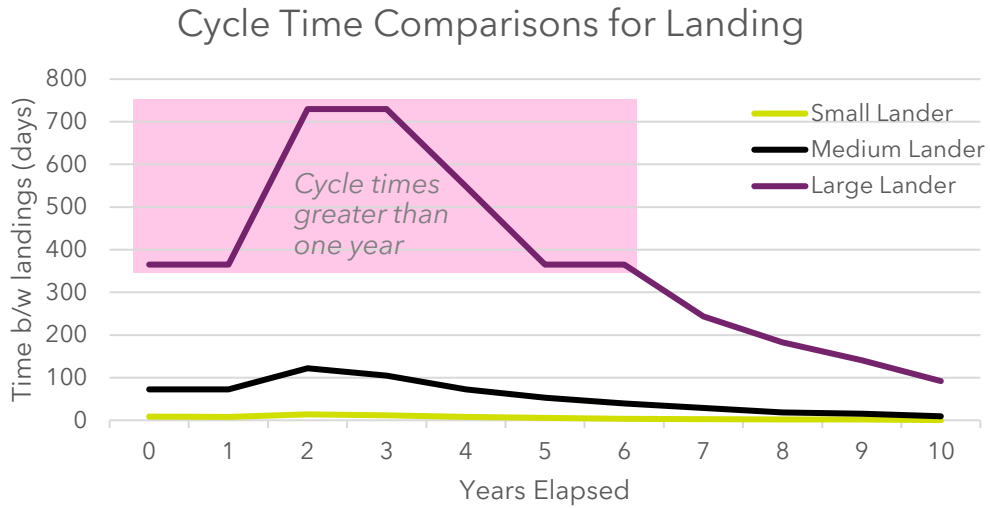
# **LOGISTICS** INPUT/OUTPUT SCALING

## UNDERSTANDNG BATCH SIZE WITHIN THE ADDRESSABLE MARKET




**Launches Required to Meet Throughput (per launch class)**

| Years Elapsed | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Mega Lift Class | <1 | <1 | <1 | <1 | 2 | 3 | 4 | 6 | 10 | 14 | 23 |
| Heavy Lift Class | 8 | 9 | 10 | 11 | 26 | 36 | 47 | 86 | 130 | 200 | 326 |
| Medium Lift Class | 17 | 19 | 22 | 25 | 59 | 82 | 108 | 200 | 303 | 466 | 759 |

Early market activity lacks the demand to fully manifest larger launch vehicles but will overwhelm medium and heavy launch vehicles as activity grows.

**Landings Required to Meet Throughput (per Lander Class)**

| Years Elapsed | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Small Lander | 43 | 48 | 54 | 61 | 149 | 209 | 276 | 513 | 782 | 1207 | 1970 |
| Medium Lander | 5 | 5 | 6 | 7 | 15 | 21 | 28 | 52 | 79 | 121 | 197 |
| Large Lander | 1 | 1 | 1 | 1 | 2 | 3 | 3 | 6 | 8 | 13 | 20 |

Early market activity lacks the demand to provide responsive shipping with large landers alone but too much demand for smaller landers to realistically support alone.

| Years Elapsed | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Landing Sites | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 4 | 4 | 5 | 5 |

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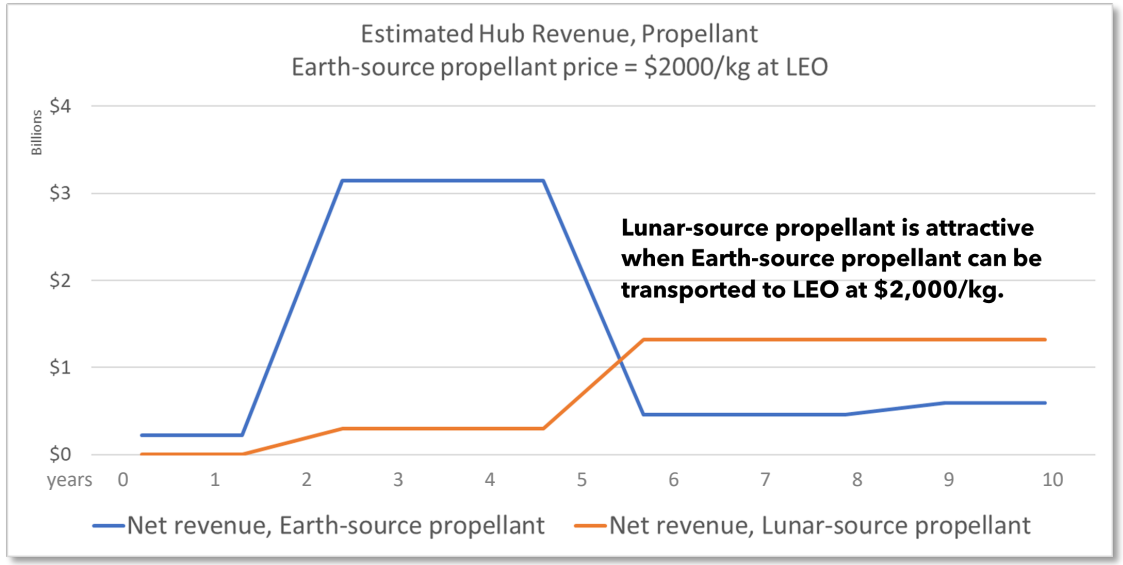
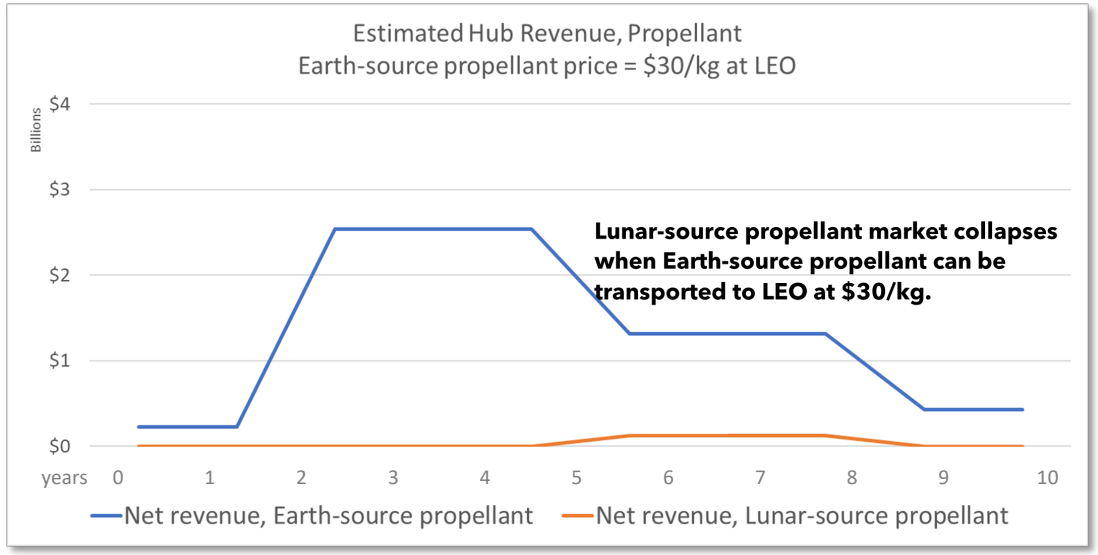
# **LOGISTICS** PRELIMINARY INSIGHTS

## REFUELING AND COUNTERINTUITIVE MARKET BEHAVIORS

*As launch vehicles compete to lower the cost-to-orbit, how might that affect lunar industry?*




Unsurprisingly, the cost of acquiring Earth-sourced propellant will outcompete lunar-sourced propellant initially, especially with reductions in the cost-to-orbit from Earth. With sufficient lunar cargo traffic, a market can however favor lunar-sourced propellant.




The further Earth cost-to-orbit is reduced, the harder it becomes for lunar-sourced propellant to compete. If reduced far enough, the same low launch costs that could accelerate industry on the Moon may also severely limit its development.

***NOTE:*** *Due to the layering of assumptions, no values here should be treated as a specific forecast, the relative relationships are more significant. The provided tranches here assume the same time frame as the ten-year logistics model.*

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