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The Cost-to-Orbit Collapse: Reusable Heavy Lift

How reusability is dragging launch from $54,500/kg to a sub-$1,000/kg world — and what that unlocks

Delta-V — Research Desk

Coverage: Delta-V

ABSTRACT

How far, how fast, and how durably is the marginal cost of reaching orbit falling — and what does a sub-$1,000/kg world unlock? This deep-dive reconstructs the $/kg trajectory from the Space Shuttle's ~$54,500/kg [1] to a reused Falcon 9 list price near $2,700–$3,250/kg [2][3] and an internal marginal cost reported around $629/kg [3], then projects the Starship and Neutron step-change against demonstrated cadence — 165 Falcon-family flights in 2025, ~85% of the U.S. total [6]. Building a transparent unit-cost model from reuse count, refurbishment fraction and cadence, Delta-V estimates a credible ~$150–$400/kg internal Starship floor by ~2030 in the central case — an order of magnitude below today's commercial price, but two orders above Musk's $10/kg aspiration. The collapse is real but asymmetric: it accrues first to the vehicle owner, not the customer. The strategic implication is that mass to orbit stops being the binding constraint, shifting scarcity to spectrum, manufacturing throughput, and on-orbit operations — re-rating the entire satellite, defense and in-space services stack rather than the launchers alone.

Keywords: cost to orbit, reusable launch, Falcon 9, Falcon Heavy, Starship, Neutron, launch cadence, constellations, $/kg, heavy lift, Golden Dome, space economy

Executive Summary

The price of reaching orbit has fallen further in fifteen years than in the previous fifty, and reusability is the reason. The Space Shuttle delivered payload to low Earth orbit (LEO) at roughly **$54,500/kg** on a total-program basis [1]. A reused Falcon 9 today lists at **$2,700–$3,250/kg** to LEO ($69.75M for ~22,800 kg) [2][3] — a ~16–20× reduction in nominal terms over a single generation. The decisive number, though, is not the price but the **internal marginal cost**, reported around **$629/kg** for a reflown Falcon 9 [3]. That gap — between what SpaceX charges and what it spends — is the entire economic story: the collapse has already happened on the cost side; the price side is lagging because there is no competitive pressure forcing it down.

The next step-change is **fully reusable super-heavy lift**. SpaceX's Starship targets 100–150 t to LEO with both stages recovered; credible near-term analyst estimates cluster at **$100–$500/kg**, with Musk's long-run $10/kg target treated as aspirational and unproven [4]. Rocket Lab's partially reusable **Neutron** (13 t to LEO with downrange booster recovery) extends the model to the medium-lift class, with a maiden flight slipped to Q4 2026 [5].

Cadence is the proof of concept. SpaceX flew **165 Falcon-family orbital missions in 2025** (170 including Starship test flights) — about **85% of the U.S. total** and nearly twice China's output — its sixth consecutive annual record, up from 25 in 2020 [6]. The FAA licensed a record **148 commercial operations in FY2024**, up >30% year-on-year, and forecasts that figure could more than double by FY2028 [7].

Demand is responding, not saturating. SpaceX operates **>9,000 Starlink satellites** [8]; AST SpaceMobile is deploying the largest commercial arrays ever flown to LEO for direct-to-device service [8]; and the U.S. **Golden Dome** missile-defense initiative — with cost estimates from $175B (White House) to $1.2T (CBO) [9] — assumes a proliferated, launch-hungry space architecture that only cheap lift makes affordable.

> **BOTTOM LINE:**
> The cost-to-orbit collapse is real, durable, and already an order of magnitude deep on a marginal-cost basis — a reused Falcon 9 costs SpaceX ~$629/kg [3] versus the Shuttle's ~$54,500/kg [1]. Delta-V estimates a credible **~$150–$400/kg internal Starship floor by ~2030** in the central case (Delta-V estimate). But the saving accrues first to the vehicle owner, not the customer: list prices have barely moved because no rival can yet compete. The binding constraint on the space economy is shifting away from mass-to-orbit toward spectrum, satellite manufacturing throughput, and on-orbit operations.

1. Context and Scope

This report quantifies the falling cost of reaching orbit and traces its consequences across two Delta-V coverage domains in particular — **launch vehicles, cadence and cost-to-orbit** (domain 1) and **space-economy financing, contracts and unit economics** (domain 7) — with spillover into constellations (domain 2), defense space (domain 4) and in-space services (domain 3).

The system boundary is **payload mass delivered to a reference orbit (LEO, ~28.5°/200–550 km unless noted) and the all-in cost of delivering it**. Three cost concepts must be kept distinct, because conflating them is the single most common error in launch-economics commentary:

1. **List/transaction price** — what a customer pays per kg (e.g., Falcon 9 ~$2,700–$3,250/kg [2][3]). This embeds margin and reflects market power, not cost.

2. **Internal marginal cost** — what the operator spends to fly one additional mission with an already-built, reusable vehicle (Falcon 9 reportedly ~$629/kg [3]). This is the number that governs how low prices *could* go under competition.
3. **Fully-burdened / amortized cost** — marginal cost plus an allocation of vehicle build, R&D, range, and fixed overhead across the flight life. This is the honest long-run figure and the basis of the Delta-V model below.

In scope: the $/kg trajectory and its drivers (reuse count, refurbishment, cadence, fairing recovery); demand response; scenarios to ~2030; and public-market equity implications. Out of scope: deep-space Δv and trans-lunar injection economics (touched only as demand), detailed propulsion thermodynamics, and any non-public/ITAR-restricted program detail.

2. Technology Landscape and State of the Art

2.1 The reusability mechanism

Cost-to-orbit is dominated not by propellant — which is a few percent of launch cost — but by **hardware amortization**. An expendable rocket discards its entire airframe, engines and avionics every flight; a reusable rocket spreads that capital across many flights and substitutes a (much smaller) refurbishment cost. The unit economics therefore hinge on three levers:

- **Reuse count (N)** — how many times a booster/airframe flies. Falcon 9 booster B1067 reached **33 flights by early 2026** [3]; SpaceX targets far higher for Starship.
- **Refurbishment fraction (f)** — refurb cost as a share of new-build. Falcon 9 booster refurbishment is reported at **~10% of a new rocket** [3]; fairing recovery and reuse remove a ~$6M-class component from the expendable column.
- **Cadence** — flights per year, which amortizes *fixed* costs (workforce, range, facilities) and is what makes a high N achievable in a reasonable calendar window.

The Falcon 9 second stage is still expended; **Starship's leap is upper-stage reuse**, which removes the last expended hardware block. That is also the hardest, least-proven part: orbital-class upper-stage recovery and rapid reflight has not yet been demonstrated at production cadence (as of mid-2026).

2.2 Competing Pathways

Pathway	Principle	Payload to LEO	Reuse status	$/kg basis	TRL / Status
Space Shuttle (retired)	Partially reusable winged orbiter + SRBs + expended tank	~27,500 kg [1]	Partial, high refurb	~$54,500/kg program [1]	Retired 2011
Falcon 9 (reused)	RTLS/droneship booster + expended 2nd stage + reused fairings	~22,800 kg [2]	Booster ≤33 flights [3]	~$2,700–$3,250/kg price; ~$629/kg internal [3]	Operational, mature
Falcon Heavy (reused)	3 reusable cores + expended 2nd stage	~63,800 kg [10]	Side cores reused	~$1,500/kg ($97M list) [10]	Operational, low cadence
Neutron (Rocket Lab)	Reusable 1st stage, expended 2nd stage, integrated fairing	13,000 kg (downrange) [5]	Booster reuse (planned)	~$3,850/kg projected [5]	In development, maiden Q4 2026 [5]

Starship (SpaceX)	Fully reusable booster + ship; on-orbit refueling	100–150 t target [4]	Both stages (unproven)	$100–$500/kg analyst range [4]	Test flights; orbital reuse unproven

The pattern is clear: each generation removes more expended hardware and pushes N higher. Falcon Heavy already undercuts Falcon 9 on $/kg list price (~$1,500/kg vs ~$2,700/kg) precisely because it amortizes more recovered mass per launch [2][10] — but its low cadence limits the benefit. Starship is the only architecture that attacks the upper stage, which is why its projected $/kg is an order of magnitude below Falcon 9 — and why so much rides on capabilities not yet demonstrated.

3. Techno-Economic Analysis

3.1 Cost Model and Assumptions

The Delta-V model computes fully-burdened internal $/kg as:

$/kg = [C_build/N + C_refurb + C_2nd-stage + C_ops/cadence-share] ÷ payload_kg

where C_build is amortized over N flights, C_refurb is the per-flight refurbishment, C_2nd-stage captures any expended upper stage, and C_ops is fixed cost allocated by cadence. All inputs below are either cited or labelled Delta-V estimate.

Parameter	Value	Unit	Basis / Source
Shuttle program $/kg	~54,500	$/kg	Total program ÷ payload [1]
Falcon 9 list price	69.75M / ~22,800	$ / kg	SpaceX list, ~$2,700–$3,250/kg [2][3]
Falcon 9 internal marginal cost	~629	$/kg	Reported ~$15M reflight ÷ payload [3]
Falcon 9 booster reuses (max)	33	flights	B1067, early 2026 [3]
Booster refurb fraction	~10%	% of new-build	[3]
Falcon Heavy list $/kg	~1,500	$/kg	$97M ÷ 63,800 kg [10]
Neutron payload (downrange recovery)	13,000	kg	[5]
Neutron projected $/kg	~3,850	$/kg	Analyst estimate [5]
Starship payload to LEO (target)	100–150	t	[4]
Starship near-term $/kg (analyst range)	100–500	$/kg	[4]
Starship marginal cost target	~$2M / flight	$	High-reuse case [4]
2025 Falcon-family orbital flights	165	flights/yr	[6]

> **THE TAKE:**
> The most decision-relevant figure in launch economics is the **price-to-cost ratio**, not the headline $/kg. At a ~$2,720/kg list price and a ~$629/kg internal cost, a reused Falcon 9 carries an implied **gross margin near 75–77%** (Delta-V estimate, from [2][3]). That margin is not a SpaceX quirk — it is *stored deflation*. It is the buffer the incumbent can release the moment a credible competitor (Neutron, New Glenn, a Chinese reusable) reaches reliable cadence. The cost collapse has therefore *already occurred*; the **price** collapse is a future event that competition, not physics, will trigger.

3.2 Levelized Cost / Unit Economics — the $/kg trajectory

The historical and projected trajectory (LEO, internal-cost basis where available, otherwise list price; vintages noted):

Era / Vehicle	Year	$/kg to LEO	Cost concept	Source

Space Shuttle	1981–2011	~54,500	Program total	[1]
Falcon 9 (expendable, early)	~2010	~10,000+	List	[1][2]
Falcon 9 (reused, list)	2024–26	~2,700–3,250	List price	[2][3]
Falcon Heavy (reused, list)	2024–26	~1,500	List price	[10]
Falcon 9 (reused, internal)	2024–26	~629	Marginal cost	[3]
Neutron (projected)	2027+	~3,850	Projected price	[5]
Starship (analyst near-term)	2027–30	~100–500	Projected	[4]
Starship (Musk long-run target)	2030s+	~10	Aspiration	[4]

The shape is a **classic learning curve punctuated by an architectural step** — a smooth Falcon-era decline, then a discontinuity at full reuse. The internal-cost line (~$629/kg today) already sits ~86× below the Shuttle. The open question is not whether Starship lowers cost but *by how much, and how much of it reaches the customer*.

Delta-V central-case Starship floor (Delta-V estimate). Take a ~$2M marginal cost per flight at high reuse [4], a conservative steady-state payload of ~100 t (below the 100–150 t target to allow for performance reserve and full reusability penalties), and add an amortized allocation of vehicle build and fixed ops. Marginal alone implies ~$20/kg; loading realistic build amortization (lower N than advertised in early operations), upper-stage refurbishment that is *not* yet near 10%, and range/ops gives a **fully-burdened ~$150–$400/kg by ~2030** in the central case. This is ~7–18× below today's Falcon 9 list price but **15–40× above** the $10/kg aspiration. The gap between marginal (~$20/kg) and burdened (~$150–$400/kg) is the early-operations tax: low N and immature upper-stage reuse dominate until cadence and reflight life mature.

3.3 Sensitivity

The fully-burdened $/kg is most sensitive, in order, to: **reuse count N**, **upper-stage refurbishment fraction**, **realized payload mass**, and **cadence** (which sets fixed-cost amortization). One-way sensitivity around the Delta-V central case:

Driver	Downside	Central	Upside	Effect on $/kg
Reuse count N (ship)	5	20	100+	High — build amortization dominates at low N
Upper-stage refurb fraction	40%	20%	<10%	High — the unproven lever
Realized payload	50 t	100 t	150 t	Medium — linear denominator
Cadence (flights/yr)	20	50	100+	Medium — fixed-cost spread
Catastrophic loss rate	high	nominal	nil	Tail risk — a loss resets N

The two **left-tail** drivers (low N and high upper-stage refurb) are exactly the ones not yet demonstrated. A world where Starship's ship flies 5 times and needs 40% refurb lands closer to **$1,000–$2,000/kg burdened** (Delta-V estimate) — better than Falcon 9 but not transformative. The transformative outcome ($/kg in the low hundreds) requires the upper stage to behave like the booster already does.

4. Market and Demand Outlook

Falling cost has not produced slack capacity; it has produced **induced demand** — Jevons-paradox dynamics, where cheaper access expands the set of economically viable missions faster than supply grows. Three demand engines:

- **Constellations.** Starlink alone is >9,000 satellites on orbit [8] and remains the dominant single payload class. Direct-to-device entrants (AST SpaceMobile flying the largest commercial LEO arrays ever deployed [8]) and Earth-observation/PNT fleets extend the curve. Each generation of satellite is heavier and more numerous, absorbing the new lift.

- **Defense.** The **Golden Dome** architecture and SDA's Proliferated Warfighter Space Architecture assume thousands of sensor and interceptor satellites; cost estimates span $175B–$1.2T [9]. Defense is the demand source least sensitive to price and most sensitive to *assured, sovereign, high-cadence* access — a structural tailwind for U.S. launchers.
- **In-space.** Stations, servicing, logistics and manufacturing only close their business cases below a cost-to-orbit threshold; sub-$1,000/kg is roughly where many of these models move from speculative to marginal.

4.1 Scenarios to ~2030 ($/kg and U.S./allied launch capacity)

Three scenarios (Delta-V estimates, built on cited cadence and cost inputs):

Scenario	Starship reuse maturity	Central $/kg (LEO, burdened)	Annual U.S.+allied orbital flights ~2030	Customer price realized
Bull	Upper-stage reuse proven, high N, ~100+ flights/yr	~$100–200	~400–600	Falls toward ~$500–1,000/kg as New Glenn/Neutron compete
**Central **	Partial upper-stage reuse, moderate N	~$150–400	~300–450	Falcon-class price sticky ~$2,000–2,700/kg; Starship priced opportunistically
Bear	Upper-stage reuse delayed, low N, a loss event	~$1,000–2,000	~200–300	Little change; Falcon 9 remains workhorse

Across all three, **cadence keeps rising** — the FAA's forecast of licensed operations more than doubling by FY2028 [7] holds even in the bear case, because Falcon 9 and emerging competitors carry the load if Starship slips. The variable is *cost per kg*, not *whether* access expands.

> **WHAT THIS UNLOCKS.**
> A durable **sub-$1,000/kg** world makes mass a non-binding constraint for most commercial constellations: satellite *manufacturing throughput* and *spectrum/orbital-slot rights* become the bottleneck. A **sub-$500/kg** world (bull case) brings in-space manufacturing, large-aperture defense sensors, and propellant depots into the money, and makes "launch it again rather than service it" the default — pressuring the very on-orbit-servicing thesis that cheap launch was supposed to enable.

5. Feasibility, Scale-Up, and Risk

The cost collapse to ~$629/kg internal is **demonstrated and durable** for Falcon-class lift — this is not a forecast. The Starship step-change is **plausible but unproven**, gated on upper-stage reuse and cadence. The honest read: Falcon-era economics are a floor the industry already stands on; Starship economics are an option, not a given.

5.1 Risk Register

Risk	Likelihood	Impact	Mitigation / Tell
Starship upper-stage reuse never reaches low refurb	Medium	High — caps the step-change at ~$1,000/kg	Watch reflight interval & refurb disclosures
Single-provider concentration (SpaceX ~85% U.S. flights [6])	High	High — pricing power, supply-chain single point	New Glenn/Neutron reaching cadence

Catastrophic loss resets reuse count / grounds fleet	Medium	High — N is the dominant cost lever	Anomaly response time, return-to-flight
Demand disappoints (constellation overbuild, defense budget cut)	Medium	Medium — cadence amortization weakens	Golden Dome appropriations, Starlink capex
Regulatory throughput (range, FAA, environmental)	Medium	Medium — caps cadence regardless of cost	Part 450 reform pace [7]
Price stays sticky; cost saving not passed through	High	Low for operators, High for customers	Competitor list prices

6. Market and Equity Implications

The cost-to-orbit collapse is **owned by a private company** — SpaceX is not publicly traded — so the listed-equity exposure is *indirect*: the names that win are those whose business models are **enabled by cheap lift** (constellation operators, defense-space, in-space services) and the one credible listed **competitor** to the launch monopoly. This is exposure commentary, not investment advice; see Disclosures.

Company (Ticker)	Exposure	Reasoning (tied to the thesis)	Horizon
Rocket Lab (RKLB, Nasdaq)	Positive	Only listed pure-play building a reusable medium-lift vehicle (Neutron, 13 t, maiden Q4 2026 [5]); FY2025 revenue ~$602M, +38% y/y, ~$1.85B backlog [11]. The one public way to own the reusability thesis directly — but valuation rich and Neutron unproven.	12–36 mo
AST SpaceMobile (ASTS, Nasdaq)	Positive	Direct-to-device constellation; heavy next-gen arrays only deployable affordably because lift is cheap [8]. Pure demand-side beneficiary; pre-scale, capital-intensive.	24–48 mo
Redwire (RDW, NYSE)	Positive	In-space infrastructure/manufacturing; FY2025 revenue ~$335M, +10% [11]. Cheaper lift is a prerequisite for the in-space-services TAM.	24–48 mo
Intuitive Machines (LUNR, Nasdaq)	Neutral-Positive	Cislunar logistics; cheap heavy lift expands lunar cadence but cadence/funding lumpy (FY2025 rev ~$210M, −8% [11]). Thesis-aligned, execution-dependent.	24–48 mo
Planet Labs (PL, NYSE)	Neutral	EO operator; cheap launch lowers a cost it has largely already absorbed — a second-order, not first-order, beneficiary. FY2026 rev ~$308M, +26% [11].	12–24 mo
Boeing (BA, NYSE)	Negative	Legacy expendable/ULA-era cost structure (SLS, Starliner) is exactly what reusability disrupts; launch is a small share of a diversified business, so impact is dilutive not existential.	Structural
Lockheed Martin (LMT, NYSE)	Neutral	Defense-space demand (Golden Dome, SDA) is a tailwind, partly offset by pressure on legacy launch-adjacent lines. Net wash; primes win on payloads, not lift.	Structural

THE TAKE:
The non-obvious read is that **cheap launch is bearish for the on-orbit-servicing premium and bullish for "constellation churn."** When replacing a satellite costs less than servicing it, the rational operator deorbits and reflies. That re-rates *manufacturers and operators of cheap, mass-produced satellites* above *servicers and life-extension specialists* — a within-sector rotation the market has not fully priced. And because SpaceX captures the launch margin privately, **the listed way to play the collapse is to own the demand it unleashes, not the launchers** — with RKLB the lone exception, as the only public vehicle-builder with a reusability story of its own.

7. Outlook and Strategic Implications

Mass-to-orbit is ceasing to be the binding constraint on the space economy. The Falcon-era cost collapse (~$629/kg internal [3]) is locked in; the Starship step-change is the swing factor, and Delta-V's central case puts a credible **~$150–$400/kg burdened floor by ~2030** (Delta-V estimate) — transformative versus the Shuttle, but well short of the $10/kg aspiration. The scarce resources of the next decade are **spectrum and orbital slots, satellite-manufacturing throughput, and on-orbit operating capability** — not kilograms.

The strategic asymmetry is that the cost saving sits as **margin inside a private incumbent** until competition forces a price collapse. For listed investors, that means the launch deflation is best captured **downstream** (constellations, defense-enabled payloads, in-space services) and through the **one credible listed challenger** (RKLB), rather than by waiting for a launch-price war that the market structure does not yet require.

WHAT TO WATCH:
1. **Starship orbital upper-stage recovery + reflight interval** — the single tell on whether $/kg breaks below ~$500. Watch refurbishment-fraction disclosures through 2026–2027. 2. **Neutron maiden flight (Q4 2026 [5]) and first reuse** — proof a *listed* company can field reusable lift; the credibility gate for RKLB's thesis. 3. **Golden Dome appropriations cadence** — the size and timing of SDA/SBI launch demand [9]; the largest single price-insensitive buyer of cheap lift. 4. **First sustained Falcon-class list-price cut** — the signal that competition (New Glenn/Neutron) has finally begun to release the stored deflation to customers.

Disclosures & Disclaimer

Methodology and Assumptions

This analysis separates three cost concepts — list price, internal marginal cost, and fully-burdened amortized cost — and labels which is used at each point. Historical and current $/kg figures are drawn from cited primary or reputable secondary sources; all forward figures are **Delta-V estimates** built from cited inputs (reuse count, refurbishment fraction, realized payload, cadence) using the cost model stated in §Techno-Economic Analysis. The Starship floor is derived by loading a cited ~$2M marginal-cost-per-flight assumption [4] with conservative build amortization and upper-stage refurbishment that is explicitly *not* assumed to match the booster's demonstrated ~10% [3], because orbital upper-stage reuse is unproven as of mid-2026. Scenario ranges bracket the two left-tail drivers (low reuse count, high upper-stage refurbishment). The conclusion would change materially if: (a) Starship demonstrates low-refurb, high-count upper-stage reuse (pushes toward the bull case); or (b) a loss event or regulatory throughput ceiling caps cadence (pushes toward the bear case). No non-public, classified, or ITAR-restricted information is used. Equity figures are from public sources [11] and are not adjusted; nothing here is investment advice.

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