

SPACE-BASED DATA CENTERS ROADMAP: THE CASE FOR CAUTION

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CHAPTER 1.1:

Introduction to Space-Based Data Centers

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Innovation for Cool Earth Forum

WORKING PAPER

TABLE OF CONTENTS

CHAPTER 1.1: 1.1-1
INTRODUCTION TO SPACE-BASED DATA CENTERS – *Colin McCormick*

A. Orbits 1.1-4
B. Communications 1.1-7
C. Launch Costs 1.1-9
D. References 1.1-12

CHAPTER 1.1:

INTRODUCTION TO SPACE-BASED DATA CENTERS

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MAIN MESSAGES

- Operating AI data centers in space is technically feasible but would involve challenges across the full lifecycle of space systems. Space-based data centers (SBDCs) will likely be made up of large groups ("constellations") of individual satellites, each with a power consumption similar to that of the highest-powered satellite ever deployed (the International Space Station).
- SBDC operators are targeting "Sun-synchronous terminator" orbits because they maximize solar PV generation. These orbits will be in high demand, and the scale of proposed SBDC constellations could create highly problematic orbital congestion.
- SBDCs will seek to transfer data (satellite-to-satellite and satellite-to-ground) via growing “internet mega-constellations”. Companies controlling these constellations will have a large competitive advantage in developing scaled SBDCs.
- The cost of launching mass to low Earth orbit (LEO) has fallen dramatically over the past several decades. Forecasting future cost reductions is extremely difficult, but costs could fall to $300/kg by 2040. Reusable rocket boosters are the most important driver of falling launch costs, with some individual boosters already reaching more than 30 re-uses.

Operating computers on satellites in Earth orbit is not new. All current satellite systems host some level of on-board computing power to perform basic operations, such as data processing, communications and attitude control. Existing supply chains provide space-qualified computing, memory and networking equipment, as well as related software stacks, and the broader space industry has decades of experience in operating these systems in orbit. This computing capability is universally powered by on-board, space-qualified solar photovoltaic (PV) and battery systems, with associated supply chains and lengthy in-service experience by the space industry. (Radioisotope power systems have been used on a small number of spacecraft in Earth orbit. For example, see NASA’s site on radioisotope power systems[1] and World Nuclear News 2026.[2])

However, the concept of space-based data centers (SBDCs) would dramatically expand the scale of on-board computing power deployed in Earth orbit. This can be seen by comparing the power requirements with existing satellite power levels. The highest-powered satellite ever deployed is the



International Space Station. Source: Shutterstock

International Space Station (ISS), which has a peak power-generation capacity of 250 kW.[3] The Chinese Tiangong space station was originally designed to operate at roughly 27 kW,[4,5] although this may have increased to over 100 kW.[6] Commercial communications satellites typically operate in the range of 10 kW, and Earth-observation satellites, such as Sentinel-2A and -2B, operate at roughly 1 kW.[7] By contrast, meaningful terrestrial data center compute capability draws megawatts of power, with commercial artificial intelligence (AI) inference data centers in the range of 50 MW and AI training data centers approaching or exceeding 1000 MW (1 GW). Individual racks of AI accelerator chips (such as graphics processing units (GPUs)) consume more than 100 kW, with significant projected increases.[8] As a result, operating "data centers" for the purpose of AI computation (model training and/or inference) on a relevant scale in Earth orbit would involve an enormous increase in power generation and management on satellites, which naturally raises questions about the technical feasibility of this concept.

In addition to power-related issues, the technical feasibility of SBDCs involves challenges across the full life-cycle of space systems, including scaling the supply chain underpinning production and assembly of relevant components, scaling global launch capacity and the associated physical launch infrastructure, scaling and operating the required ground stations and communications infrastructure, scaling the implementation of collision avoidance for mega-constellations, and reliably planning for and implementing end-of-life satellite disposal strategies. Assessing feasibility across all these dimensions is crucial for delivering a comprehensive picture of how realistic it would be to pursue SBDCs at meaningful scale.

To date, many concepts have been advanced that offer potential approaches to SBDCs in a commercial context, including some early pilot demonstrations. Multiple companies have applied to the US Federal Communications Commission (FCC) for licenses to operate SBDCs. This Roadmap will not attempt to assess all proposed SBDC variations but will instead concentrate on the most commercially relevant concepts with direct policy implications. These concepts are driven by three basic design choices:

1. Selecting which orbit(s) to use, including the altitude and inclination (ranging from equatorial to polar orbits). This choice determines the available sunlight and thus PV-generated power capacity, the thermal environment and thus radiator sizing and orientation, the ground-to-orbit communications requirements, the survivability/longevity of the satellite due to radiation and orbital debris impacts, the launch costs and feasible launch sites, and the end-of-life disposal options. Most commercially relevant concepts propose using nearly polar, sun-synchronous orbits (SSOs) that are calibrated to follow the dawn or dusk terminator because they remain almost entirely in sunlight. (Some proposals have also included other

orbital inclinations.)[9] They also propose using altitudes in the range of 500–800 km or higher. (The ISS orbits at 400-km altitude, roughly halfway between an equatorial and polar inclination.)

2. Designing the overall satellite constellation, including the number and arrangement of individual satellites. This choice determines the in-orbit communications needs among SBDC satellites, the number and type of launches needed, the survivability/longevity of the satellites and the end-of-life disposal options. Most commercially relevant concepts propose a large number (hundreds to hundreds of thousands) of individual satellites operating as a constellation, with each hosting roughly one rack equivalent of AI accelerator chips. By leveraging high-bandwidth optical communications, these individual satellites remain digitally connected and jointly form a full-scale SBDC.

3. Choosing individual satellite mission life. While traditional, government-funded science missions, such as Landsat and Sentinel, are designed for multi-decadal service, individual satellites forming an SBDC constellation may have far shorter planned lifetimes, particularly given the rapid obsolescence of AI accelerator chip technology. Most commercially relevant concepts propose individual satellite mission lifetimes in the range of roughly 3–5 years, with no provision for hardware upgrades or maintenance during service life. To maintain the overall constellation, replacement satellites would be launched continually, and end-of-life satellites would be de-orbited.

Within this range of design choices, several key factors drive the technical feasibility of building, launching and operating this form of SBDC.

1. Mass of individual satellites per unit of power consumed by the information technology (IT) equipment—essentially how heavy an individual satellite must be to host a fixed amount of AI compute power. This mass must be small enough per kW of power to enable economically viable launches and safe end-of-life disposal. The main contributions to the mass are the solar PV array, batteries, cooling equipment, AI chips and memory, communications systems and the satellite bus/spacecraft platform. In the later sections of this chapter, we examine the main subsystems and their likely masses, including a high-level assessment of whether technology innovation could meaningfully reduce the mass in the near to medium future.

2. Global launch capacity and per-kg costs for these individual satellites. While the number of objects launched into space each year has risen dramatically, it is still only thousands, not hundreds of thousands.[10] SBDC constellations that envision very large numbers of satellites would require correspondingly large numbers of launches. Due to relatively short mission lifetimes for each satellite, the cadence of launches would also need to continue at a high pace indefinitely. The current global launch infrastructure, including rockets and launch sites, would need to be expanded significantly to achieve this pace. Notably, not all launch sites are able to place satellites into SSOs given geographic constraints, so the siting of new launch sites and expansion of existing ones may be a significant constraint.

3. Supply chain for key satellite components. The solar PV arrays, batteries, cooling equipment and other components the space industry currently uses are typically supplied at small volumes by highly specialized manufacturers. As for AI accelerator chips, memory and networking equipment, there is essentially no validated manufacturing base and little clarity on how well conventional components could be used directly on satellites. This supply chain will need dramatic expansion to service SBDCs at full scale.

4. Data transfer networks for SBDC constellations requiring extremely high-bandwidth communications. To perform fast AI compute operations (both training and inference), SBDCs will require scaled communication networks both in-orbit (between/among satellites) and ground-to-orbit. A small handful of incumbent companies—most notably Space-X (Starlink), Amazon (Leo) and Blue Origin (TeraWave)—are rapidly building large mega-constellations of communications satellites (providing "internet from space") and are clearly positioning themselves to provide this networking service. Other companies are also intending to develop these constellations, including Eutelsat OneWeb, Rivada Space Networks, Telesat, GuoWang and Qianfan. From the viewpoint of market competition, early movers may create impenetrable barriers to other entrants by controlling space-based data communications. Access to these high-speed networks in orbit, as well as access to radio frequency spectrum to support ground-to-orbit communications, will be essential to operating SBDCs. (Mega-constellations also create considerable orbital crowding and satellite disposal risks.[11])

5. Regulatory environment for satellite launches, operations and disposal. While not a technical challenge per se, regulatory guidance will shape design choices and engineering approaches in important ways.

The following sections address these major topics, although not in exhaustive detail. Other SBDC concepts that have been proposed but will not be addressed in this roadmap include systems in orbit around or on the surface of the Moon[12] and systems in highly eccentric (Molniya or Tundra) Earth orbits.

A. Orbits

There are three basic parameters that describe how objects orbit the Earth. The altitude is the height of the orbit above the Earth's surface, the inclination is the angle the orbit makes with the equator, and the eccentricity is how "stretched" or oval-like the orbit is compared to a perfect circle (see Fig. 1.1-1).[13,14]

Orbits with a high altitude (roughly 36,000 km), zero inclination (i.e., orbiting over the equator) and zero eccentricity (i.e., circular) are known as geostationary ("GEO"). They complete one full revolution around the Earth in 24 hours, making them always appear "stationary" in the sky above a ground observer. GEO orbits have historically been the most commercially valuable, and positions ("slots") in GEO are coordinated by the International Telecommunication Union (ITU) because a small number of high-powered telecommunications satellites placed in these orbits can provide high-bandwidth communications services over large geographic areas.

Low Earth orbits ("LEO," up to roughly 2000 km) have historically been used for many other purposes, including Earth observation (e.g., National Aeronautics and Space Administration (NASA) Landsat missions) and commercial satellite imagery. Satellites in these orbits complete one rotation much more quickly than GEO. For example, the International Space Station (ISS) (400-km altitude) completes one orbit in roughly 90 minutes.[15] Satellites in LEO are therefore constantly moving across the sky to an observer on the ground, spending much of their time over the horizon and therefore out of sight. Communication with satellites in LEO has typically required a network of ground stations around the Earth or a mission that tolerates waiting long periods of time (up to hours) to transfer data to/from the satellite. The geographic placement of these ground stations depends on orbital inclination because the inclination of the orbit (from equatorial to polar) affects the ground locations that the satellite passes over.

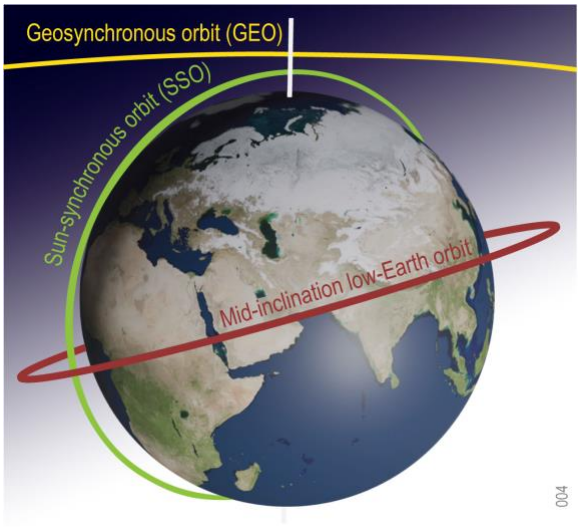


Figure 1.1-1. *Illustrative Earth orbits. Green: a sun-synchronous orbit (SSO) at roughly 640-km altitude and 98° inclination (nearly polar). Red: roughly 2000-km altitude and 30° inclination. Yellow: geosynchronous orbit (GEO) at roughly 36,000-km altitude and 0° inclination (equatorial). The Earth's pole is indicated for reference only. Source: Colin McCormick*

The advent of "mega-constellations" with hundreds or thousands of satellites in LEO is changing this situation. These large groups of satellites are launched and deployed so that they spread out along one or more orbital paths, with at least one satellite always in view of a ground station.[16] Satellites in the constellation "relay" data among themselves to transfer it to/from the ground without significant delay. Mega-constellations have made LEO orbits of great interest to operators building satellite communication networks, potentially shifting economic value away from GEO.[17] A further advantage of LEO is lower launch costs because less powerful rockets are needed to reach these lower altitudes.

For several reasons, LEO orbits are also the primary focus of companies pursuing space-based data centers (SBDCs). First, SBDCs in LEO could use the communications backbone of LEO-based "internet mega-constellations" to provide fast data transfer (see Chapter 1.1(B)-Communications). Second, launch costs to LEO are relatively low and likely falling as global launch capacity grows (see Chapter 1.1(C)-Launch Costs). And third, LEO orbits with inclinations close to polar orbits are known as "sun-synchronous" (SSOs), meaning they always fly over points on the ground at the same local time. When this time is calibrated to be either dawn or dusk, the resulting "terminator" orbit places the satellite in near-continual sunshine (almost never entering the Earth's shadow), allowing solar photovoltaic (PV) arrays to continually provide power and reducing the need for batteries and excess solar panel capacity to charge them (see Chapter 1.2-Power Systems). Terminator orbits also stabilize the satellite's thermal environment: because the Sun's direction relative to the orbit stays nearly constant year-round, a radiator can hold a favorable, near-constant orientation to deep space (see

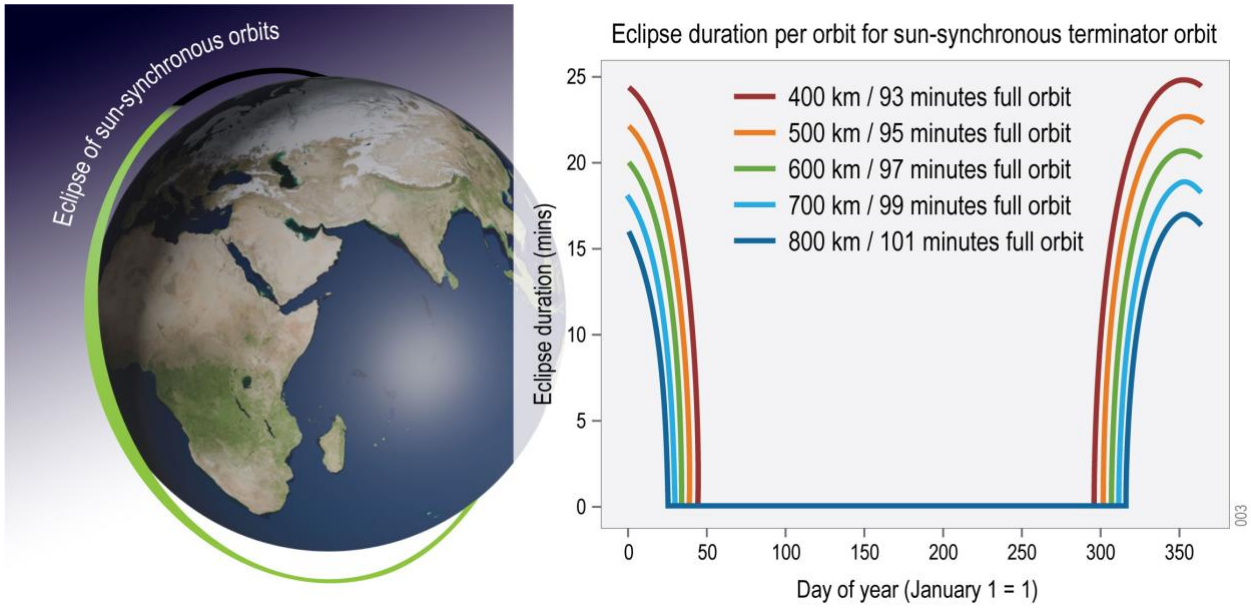


Figure 1.1-2. *Left: Illustration of 640-km-altitude terminator orbit in maximum eclipse, which occurs at solstice when the Earth's axis is tilted farthest from the sun. Each orbit lasts 98 minutes. Right: Eclipse duration per orbit by day of the (calendar) year. Source: Colin McCormick*

Chapter 1.3-Cooling). Satellites in these orbits experience a maximum of roughly 30 minutes of eclipse" (passage through the Earth's shadow) during one part of the year and continual solar illumination at other times (See Fig 1.1-2). Some commercial SBDC proposals have also included other orbital inclinations, which could reduce potential overcrowding in terminator orbits (see Chapter 2.2-Orbital Congestion and Debris) at the cost of increased solar PV array and battery requirements.[9]

Another implication of the choice to use terminator orbits (or any SSO) is the impact on launch site suitability. Rocket launches are typically conducted in locations where the initial stage of the launch is over open ocean or sparsely populated land. This reduces the chance of damage or injuries from falling debris in case of a launch failure. When launching into equatorial or low-inclination orbits, rockets launch to the east to match the rotation of the Earth, motivating the selection of launch sites on east-facing coastlines, such as the Kennedy Space Center (USA), the Tanegashima Space Center (Japan), the Guiana Space Centre (French Guiana) and the Wenchang Space Launch Site (China). However, when launching into polar orbits, rockets typically launch in a north or south direction. Existing launch sites may be near more populated areas in these directions, reducing their suitability for polar launches and potentially requiring development of new launch sites (see Chapter 1.5-Launch Capacity); this issue can lead to international disputes around damage from rocket launch failures (for example, see Lingle, 2026[18]).

While LEO technically extends to roughly 2000 km, many SBDC operators are considering orbits with altitudes of roughly 500 to 800 km. This is determined by several factors. Below roughly 400 km, drag from the upper reaches of the atmosphere can continually reduce a satellite's speed, eventually

causing it to re-enter the atmosphere and be destroyed unless the satellite periodically uses its engines to "boost" it back up.[19] Because SBDCs would likely carry very large-area solar PV arrays and radiator panels, this drag effect would be even more pronounced than for most current satellites. Above roughly 800 km, the impact of ionizing radiation increases substantially, potentially damaging satellite electronics and/or solar PV arrays and causing malfunctions.[20] (Significant radiation exposure also occurs below this altitude; see Chapter 1.4-Radiation Hardening.) A final consideration is the risk of collision with micrometeoroids and orbital debris (known collectively as MMOD). Satellites typically can carry shielding to protect sensitive components from impact, but this adds mass, cost and design complexity.[21] While satellites can perform maneuvers to avoid some of this material, orbits that avoid high MMOD concentrations reduce the risk of damaging or catastrophic collisions. Orbits with altitudes ranging from 500 to 800 km are appealing because they avoid some high-MMOD concentrations. However, significant risk would remain and would be exacerbated by the launch of large mega-constellations (see Section 2.2-Orbital Congestion and Debris).[22]

Finally, the choice of orbit influences the options for end-of-life disposal of individual SBDC satellites. Typically, higher orbits require extra propellant to actively bring them down into the atmosphere to burn up during re-entry, which adds mass and cost. "Disposal" or "graveyard" orbits are another option, but active propulsion is also required to maneuver satellites into these orbits.

Desirable orbits as described may be in extremely high demand by SBDC developers, raising questions about a range of impacts if satellites are placed into these orbits in large numbers. Safe avoidance of MMOD and other satellites will be increasingly critical, and without a formal process in place for sharing orbital "slots" (unlike GEO), this issue may be particularly challenging and will limit the total amount of compute in orbit.

B. Communications

Satellite communications have historically used the radio spectrum, with a dedicated band of reserved frequencies (see Figure 1.2-3).[23] The US government has recently sought to expand the amount of spectrum dedicated to satellite communications, particularly for "emergent space activities," including large constellations in low Earth orbit (LEO) providing high-speed broadband.[24] There is also reason to believe that some technical reforms can expand the ability of limited available spectrum to serve a growing number of satellites, such as dynamic spectrum sharing.[25,26] However, even with these changes, the use of spectrum will clearly be a point of competitive tension as demand grows dramatically with planned LEO mega-constellations.[27] This will impact space-based data centers (SBDCs) primarily through their ability to access high-bandwidth, low-latency ground-satellite data transfer, and how this bandwidth is allocated commercially will strongly influence the rate of mega-constellation deployment.[28] International rules governing the use of key radio frequency spectrum will be negotiated by national governments in 2027, with significant implications for countries engaged in or considering scaling up LEO mega-constellations.[29]

SBDCs will also have a major need for high-bandwidth, low-latency satellite-to-satellite data transfer to perform artificial intelligence (AI) compute tasks (training and inference). There are two reasons for this: (1) to enable data relay across a large constellation for the purpose of reaching a satellite

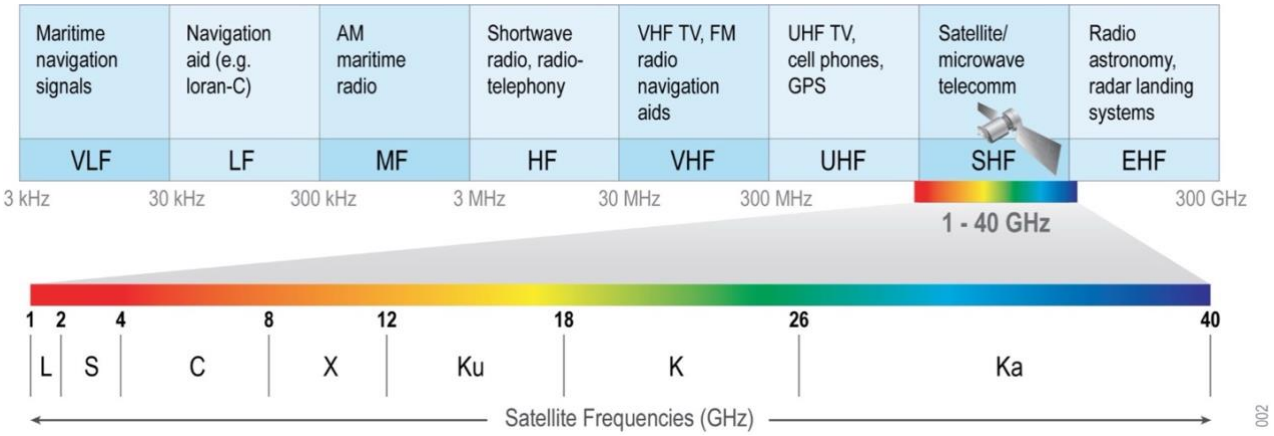


Figure 1.1-3. *Radio frequency spectrum with bands reserved for satellite communications. Source: Colin McCormick*

currently positioned over a ground station, which allows for low latency, and (2) to enable large AI models to be run in parallel across AI accelerator chips on multiple SBDC satellites.

For comparison, the rack-to-rack ("scale out") bandwidth in typical terrestrial AI data centers is 400 gigabits per second (Gbps) or higher, allowing large models to efficiently use multiple racks of AI accelerator chips simultaneously.[30] Because individual SBDC satellites will likely have levels of power consumption and compute that are roughly comparable to individual racks in terrestrial data centers, similar satellite-to-satellite bandwidth will likely be required. This data rate is far above what current satellite radio-frequency communication links (operating in the Ku- and Ka-bands) can achieve, which is typically only a few Gbps at best.

However, recent major technical advances in the use of free-space optical (laser) communications for satellite-to-satellite communications have enabled far higher data rates.[31,32] Driven in part by technical standards and procurement actions by the US Space Development Agency (SDA),[33] optical communication terminals (OCTs) for satellite-to-satellite communications are entering the market and are being demonstrated in orbit.[34] These devices use laser beams to transmit data to optical receivers mounted on other satellites, forming mesh networks that achieve very high data rates and entirely avoid using radio spectrum. One challenging aspect of operating OCTs is maintaining precise pointing accuracy because terminals must align and hold a relatively small laser beam spot on a satellite-mounted receiver terminal tens to hundreds of kilometers away. However, OCTs have achieved bandwidths well over 1 Gbps and are targeting 100 Gbps or higher for constellations of satellites in LEO. These demonstrations suggest that this technology could provide the necessary bandwidth for individual SBDC satellites to transfer data at the rate required for large-model AI inference tasks. Efforts in Japan,[35] China,[36] Europe[37] and elsewhere are also rapidly advancing this technology. (While OCTs can be used for ground-to-orbit communication, the laser beams do not pass through clouds, meaning that communications can be disrupted by weather, which is not an issue for radio.)

OCTs are lightweight and draw relatively little power, meaning they are largely immaterial for mass and power budgets on individual satellites.[38] However, the supply chain for OCTs has a major bottleneck. Because demand for satellite-to-satellite laser communication has risen so dramatically, the production base has not been able to keep pace, and commercial availability of OCTs is highly limited. This subsector is likely to play a strategic role in determining the pace of SBDC deployment.[39,40]

In-orbit communication networks will also play an enormously important market role in the development of SBDCs. Companies that own these networks (particularly those based on mega-constellations) will have a major competitive advantage in operating SBDCs due to their ability to rapidly transfer data to anywhere in LEO—essentially a form of vertical integration across the full AI stack. Other companies seeking to develop SBDCs will need to either replicate this communications network (at enormous expense) or seek to secure data-transfer services over networks owned by third parties. Because nearly all the owners of data-transfer mega-constellations are themselves proposing to build SBDCs, they may be unlikely to provide these services to rival SBDC operators absent some form of open-access mandate. Such a mandate would be analogous to open-access frameworks for railroad networks,[41] electricity transmission[42] and terrestrial broadband provision.[43] The competitive development of SBDCs beyond a small handful of early-mover companies may therefore require policymakers to carefully examine whether some form of similar open-access requirements should apply to LEO mega-constellations. (See the discussion in Chapter 3.1-Key Governance Issues and Recommendations.)

C. Launch Costs

The cost of launching mass into low Earth orbit (LEO) has dropped significantly over the last several decades. NASA's Space Shuttle (operational 1981–2011) had a launch cost to LEO of approximately $55,000–65,000/kg.[44,45] Launch cost to LEO for the Falcon 9 is now approximately $2600/kg, and the Falcon Heavy cost is approximately $1500/kg.[44,46] Speculation on the future trajectory of launch costs is extensive, and specific claims by Elon Musk about SpaceX launch costs falling to below $100/kg in the near future have received enormous attention.[47] Realizing these costs would have dramatic impacts on the overall economics of satellite deployments, shifting constraints from cost to other parameters, such as orbital slot availability, launch capacity or radio frequency spectrum allocation.[48,49]



Space Shuttle blasting off. Source: Shutterstock

However, launch costs are complex to evaluate and are highly variable across platforms.[50] This makes it difficult to identify a single value for historic observed launch costs. Recent efforts to compile comprehensive historic launch cost data

using a harmonized methodology suggest that average actual costs have fallen from roughly $87,000/kg in 1960 to roughly $3900/kg in 2025.[51] It is important to note that these average cost reductions are not necessarily the result of technology improvement within a specific rocket family; much of the early cost reductions were due to reallocating payloads to other less expensive rocket systems.

Nevertheless, average launch costs have historically correlated with an increase in the total (cumulative) payload mass launched to LEO, according to an "experience curve" mathematical relationship (also known as Wright's Law). The observed correlation is that a doubling of the total (cumulative) payload mass launched to LEO has resulted in a 21.2% cost reduction on average across this time period.[51] Notably, this cost-reduction figure has been significantly higher since the end of the Cold War (1989): 44% cost reduction per doubling, suggesting that cost reductions have followed a structurally different and faster trend over the last three decades.

Historic technology "learning rates" such as these are not always good predictors of future cost reductions, but they can be helpful in evaluating potential future scenarios.[52] If the space industry continues to realize these rates, average costs would reach $1600/kg by 2030 and $300/kg by 2040 under a central scenario of future launches. Higher annual launch rates would accelerate this cost reduction but would require launching enormous amounts of mass. The cumulative mass launched to LEO through 2025 is approximately 43 million kilograms, which is set to double in approximately 8 years under current launch trends. (The five-year rolling average of the annual rate of increase of cumulative mass launched to LEO was 1.09 in 2025, using data from Terzi et al., 2026.[51] This rate of increase would lead to a doubling of cumulative mass launched in about 8 years.) This increase in cumulative mass launched, if the historic (post-1989) learning rate of 44% holds, is the basis for the 2030 cost forecast noted above. Under similar assumptions about sustained learning rates, reaching a launch cost of $200/kg would require roughly 5 doublings in the cumulative payload launched to LEO (post-2025). Current launch trends suggest this would take four decades, implying that reaching this cost before then is unlikely.

However, this projection is extremely sensitive to assumptions about the growth in future launch rates, and the acceleration in launches over the past five years adds enormous uncertainty to this forecast. For this and other reasons, efforts to forecast launch-cost reductions have led to a wide range of predictions. For example, earlier academic analysis of cost-reduction trends based on launch costs between 2000 and 2020 found that costs would not fall below $1000/kg before 2045.[53] Separate analysis released by financial analysts in 2022 found that launch costs could reach as low as $100/kg by 2040 or even lower in a "bullish" scenario.[54]

Projecting future launch trends (both in number and in total mass) is particularly challenging today because of the extraordinary concentration of launches in just one company (SpaceX), which is responsible for far over half of all mass in LEO. This concentration is a nearly unprecedented situation in any major economic sector.[55,56] While other competitors are seeking to enter the heavy-launch market, they remain limited.[57,58] One important implication of this concentration is that there would be no incentive or market pressure to pass reduced launch costs on to third parties in the form of

reduced launch prices. This issue is particularly pertinent if a company has other, company-internal uses for this launch capacity, such as extending its own communication and data-center mega-constellations.[59] As a result, even if average launch costs to LEO were to fall dramatically for a single firm in the near term, those reductions could remain essentially unavailable to the market at large.



Falcon 9 First Stage launch. Source: Shutterstock

It is helpful to analyze these launch trends in the context of the total mass of a SBDC. The reference 1-GW SBDC analyzed in this Roadmap (see XYZ) would require ten thousand 2.5-ton satellites, each with a100-kW power level, weighing a total of 25,000 metric tonnes (25 million kg). This is equivalent to roughly half of all mass launched to LEO cumulatively; if it were launched, it would significantly contribute to a doubling of this value. (Ongoing launches to maintain the constellation would increase this figure.) It would take roughly 50 of these 1-GW SBDCs to equal the additional cumulative mass launched to LEO to provide 5 doublings and to reduce the associated launch costs to $200/kg.

Beyond industry-wide averages, several major new launch vehicles are potentially driving down specific launch costs. The most prominent of these is SpaceX's Starship, with external analysts suggesting that it could deliver launch costs to LEO "into the low hundreds of dollars [per kg]."[60] However, there has been no independent cost assessment. Further, while repeated demonstrations of launch capability have been achieved, the high-cadence re-launch scenarios underpinning cost estimates have not yet been realized. The Blue Origin New Glenn rocket is also under development with some successful initial flight demonstrations, although third-party cost analyses are similarly unavailable. Multiple Chinese companies are developing heavy-lift rockets and have demonstrated some initial flight success, although no cost information is available. A key dimension of these efforts is the crucial role of re-usability of booster stages, which dominates cost estimates by amortizing costs over some number of re-uses.[61] SpaceX has demonstrated re-use of individual boosters over 30 times in individual cases, suggesting that achieving high booster re-use count may be feasible for other rocket systems, and costs may consequently fall faster than previously predicted.[62]

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