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ORBITAL DATA CENTERS

The New Frontier of Global Computing and Satellite Data Utility

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Abstract

Orbital data centers are networks of satellites equipped with high-powered servers and AI chips designed to process data in low Earth orbit rather than on the ground. Satellite data utility transforms raw orbital imagery and remote sensing measurements into actionable intelligence. Existing Satellite Communication Systems provide traffic transmission for IoT Systems with Cloud Architecture. Fog and edge computing in space brings data processing and artificial intelligence directly onto spacecraft and satellites, transforming them from passive data relays into autonomous, intelligent nodes. Analysts suggest that orbital data centers could begin scaling in the first half of the 2030s. Moving data centers to space offers a way to bypass terrestrial energy crises, cooling limits, and grid bottlenecks driven by the artificial intelligence boom. What you get in space that you do not get on the ground is unlimited, continuous power. Major technology companies, aerospace leaders, and specialized startups are actively developing and filing plans for orbital data centers to handle intensive artificial intelligence workloads in space. Satellites in sun-synchronous orbit capture constant, uninterrupted solar energy without weather, atmospheric, or land constraints. Space also serves as a conduit for natural thermal management. Generative AI workloads require extreme compute power, transitioning legacy server racks from an average 7 kW to dense 50 kW–600 kW configurations. Orbital data centers could become a strategically important complement to Earth-based computing as AI drives unprecedented demand for power, cooling, and processing capacity.

Introduction

Valued at over \$514 billion in 2025 and surging toward nearly \$1 trillion by 2031, the global data center landscape is rapidly expanding and evolving. The recent surge has been driven by the artificial intelligence (AI) boom whose total operational capacity has reached approximately 67.7 GW globally, with projections aiming toward 200 GW by 2030. The United States commands the largest share of global data computing power and infrastructure by a wide margin, holding approximately 36% to 43% of total global computing capacity, and hosting over 4,700 to 5,400 data centers (roughly 45% of all operational facilities worldwide). This dominance is driven by hyperscale tech giants like Amazon, Microsoft, and Google. China is a close second in overall computing power, accounting for roughly 30% of the world's total capacity. While China operates fewer total hyperscale facilities than the United States, it produces incredible amounts of data and runs massive regional data hubs. Japan consistently ranks near the top for high-performance supercomputing capacity and total computational share. Germany and the United Kingdom have the largest infrastructure and computing hubs in Europe, each hosting over 500 major data center facilities. Italy, Finland, Switzerland, France, and Canada round out the top tier of global compute capacity.

Generative AI workloads require extreme compute power, transitioning legacy server racks from an average 7 kW to dense 50 kW–600 kW configurations. Traditional air cooling is being replaced by direct-to-chip liquid cooling and rear-door heat exchangers, with over 36% of operators actively deploying liquid thermal management. Strained regional grids and multi-year interconnection wait times are forcing a pivot toward behind-the-meter power generation, including natural gas microgrids, battery energy storage systems (BESS), and localized renewables. Hyperscale facilities can consume up to 5 million gallons of water daily and require massive baseline electricity, contributing to local grid congestion and water table depletion in drought-prone regions. Grassroots opposition and rising local utility

costs have triggered legislative pushback, temporary moratoriums, and project disruptions across multiple U.S. states and international markets.

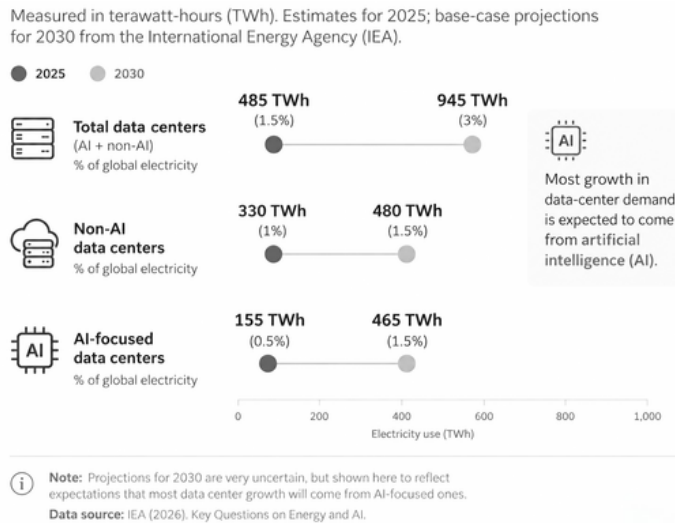
Alternatives to terrestrial data centers have proven to be scarce against current power grids and local zoning laws. Early space pioneers originally dreamed of space-based solar power by capturing solar energy in orbit and beaming it down to Earth. However, transmitting energy wirelessly back to Earth proved far too inefficient (losing up to 95% of the power in transmission). Innovators realized it was far more practical to send the data centers up to the power source rather than sending the power down to Earth. In space, solar arrays can operate in sun-synchronous orbits 24/7 without weather or nighttime interruptions, generating up to eight times more power per square meter than on Earth. The concept shifted from science fiction to business reality as reusable rockets dramatically slashed the cost of lifting equipment into low-Earth orbit (LEO), making heavy orbital computing economically viable.

Pivoting to Orbital Data Centers

Data centers are dedicated physical facilities housing computer servers, data storage systems, and networking equipment used to store, process, and distribute digital information, cloud services, and artificial intelligence workloads. There are thousands of massive data center campuses and millions of smaller server rooms globally (with thousands of large commercial and hyperscale facilities in the U.S. and worldwide) powering the modern internet. In orbit, there are virtually zero full-scale commercial data centers. Only a tiny handful of experimental or proof-of-concept edge-computing payloads and pathfinder satellites (such as early tests by Starcloud and Google's Project Suncatcher) have been launched to test processing data in space. However, major tech companies and filings with the Federal Communications Commission (FCC) suggest future mega-constellations of thousands or even millions of orbital data-center satellites. Large-

scale systems are still in the experimental, regulatory, or developmental phases rather than active operation.

AI data centers on Earth currently consume roughly 415 to 485 terawatt-hours (TWh) of electricity annually (about 1.5% to 2% of global demand), a number projected to double or triple to nearly 950 TWh by 2030, according to the International Energy Agency. Non-AI data centers on Earth consume roughly 275 to 280 terawatt-hours (TWh) of electricity annually, accounting for about two-thirds of total global data center energy use. Traditional data centers currently use roughly twice the electricity of dedicated AI facilities, though AI demand is growing at a much faster rate.



On Earth, data centers can span multiple football fields in size and require immense amounts of electricity and water, leading communities to push back against construction in their area. Orbital data centers in space source their energy entirely from uninterrupted solar power, requiring roughly 1 megawatt (MW) of power for every small node, while grand-scale commercial proposals target 1 gigawatt (GW) to 1 terawatt (TW) of compute capacity. A single 1-megawatt space data center node requires up to 6,000 square meters (about 1.5 acres) of flexible solar panels. The benefit of switching from terrestrial to orbital is that unlike Earth-bound solar farms, orbital arrays receive near-constant sunlight without atmospheric interference or weather disruptions, maximizing energy generation efficiency. Moreover, a 1-MW power and computing module is estimated to weigh around 75 tons, heavily dominated by the solar arrays and thermal management systems.

Space eliminates the massive terrestrial electricity costs dedicated to active cooling systems (like chillers and massive water pumps), since computers can theoretically radiate waste heat directly into the cold void of space. To expel the immense heat generated by high-performance AI chips using thermal radiation alone, vast sprawling surfaces of structural radiators are required (calculating up to 2.15 million square feet for certain heavy configurations). Supplying gigawatt-scale power systems to orbit remains constrained by heavy-lift rocket economics, requiring launch costs to drop significantly from current prices to roughly \$50–\$100 per kilogram via reusable mega-rockets like SpaceX's Starship

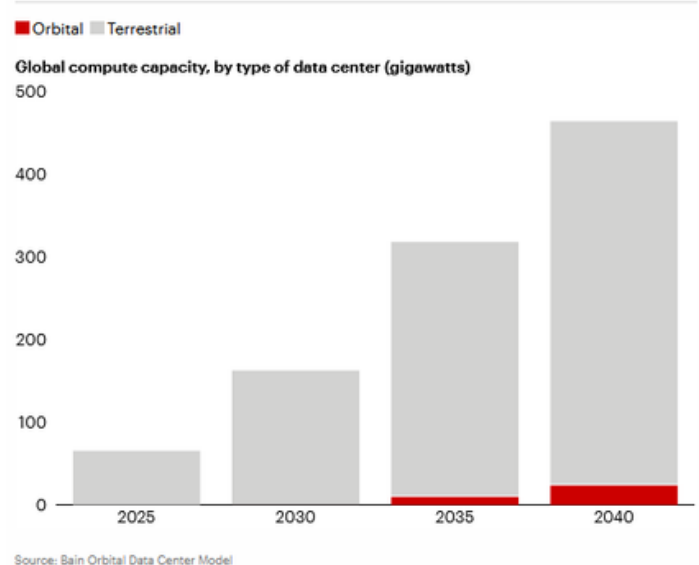
The Link Between Satellite Data Utility and Orbital Data Centers

Satellite data utility transforms raw orbital imagery and remote sensing measurements into actionable intelligence for agriculture, disaster management, infrastructure, and environmental monitoring. AI companies rely on data centers to efficiently process user requests and are seeking more compute for the anticipated adoption of the technology. The past few decades have seen a marked acceleration in observation data derived using both in situ and remote sensing measurements. Making data available via interoperable portals will facilitate data sharing. Remote communities can benefit from the availability of satellite data on a local level. Due to the impartial nature of satellite data, it can be applied to other fields with impactful results. Meteorology, Agriculture, Insurance and Finance, Energy and

Infrastructure, Logistics and Supply Chain, Mining, and Urban Planning and Real Estate. The possibility of infusing satellite data with artificial intelligence has the potential of turning raw images from space into instant, actionable information.

Furthermore, existing Satellite Communication Systems provide traffic transmission for IoT Systems with Cloud Architecture. Fog and edge computing in space brings data processing and artificial intelligence directly onto spacecraft and satellites, transforming them from passive data relays into autonomous, intelligent nodes. Edge computing in space places computing power and AI directly on the satellite or payload, allowing raw data (such as Earth observation imagery) to be processed instantly at the source rather than waiting for transmission to Earth. Whereas fog computing in space extends edge principles across proliferated low-Earth orbit (LEO) constellations, utilizing inter-satellite optical links to create a distributed, multi-layer mesh network between spacecraft and ground stations. Satellites capture massive amounts of redundant or cloud-obscured imagery; onboard edge processing filters out useless data ("trash data") before sending only high-value insights down, saving precious bandwidth. This enables real-time analysis for critical applications like wildfire detection, methane leak tracking, disaster early warning, and autonomous debris avoidance.

Orbital data centers are networks of satellites equipped with high-powered servers and AI chips designed to process data in low Earth orbit rather than on the ground. Analysts suggest that orbital data centers could begin scaling in the first half of the 2030s.



Arguably, orbital computing hinges on three variables: launch, satellite infrastructure, and operating costs. To set up a constellation of orbital data centers amounting to 100 megawatts would cost roughly 50% more per kilowatt than a comparable terrestrial facility. Orbital compute will become more viable if three conditions converge; terrestrial infrastructure constraints worsen, satellite systems become lighter and more capable, and launch economics improve.

Space-based data centers could become technically feasible at scale within the next decade, but won't be competing with terrestrial infrastructure on cost because orbital data centers have a remarkably higher cost premium. When factoring in AI, satellites have the added advantage of processing sovereign data. At bare minimum, orbital data centers should be complementary to terrestrial infrastructures as opposed to being the replacement. According to Boston Consulting Group, orbit-advantaged use cases are substantial enough for satellites to capture 10% to 15% of the global AI data center market by 2040. If this is your field or industry, the complementary factor of orbital data centers is evident, even to investors and policymakers, for the Earth is not enough.

Orbital Data Center Race

Major technology companies, aerospace leaders, and specialized

startups are actively developing and filing plans for orbital data centers to handle intensive artificial intelligence workloads in space. For example, SpaceX filed plans with the FCC to launch up to 1 million AI-optimized satellites, partnering with Nvidia to test space-optimized computing racks as early as late 2027. Blue Origin plans to optically interconnect 5,408 satellites with symmetrical upload and download speeds reaching up to 6 Tbps globally, in what will become the TeraWave constellation. They will begin deployment in the fourth quarter of 2027 using Blue Origin's heavy-lift New Glenn rocket. Starcloud proposed an 88,000-satellite constellation designed for AI inference and data processing, to deliver approximately 20 gigawatts of total compute capacity. The constellation will integrate SpaceX's Starlink Mini Laser terminals for optical inter-satellite cross-links.

Google is also jumping in on the action with the aptly named Project Suncatcher. The project uses Google's custom Tensor Processing Units (TPUs) to handle artificial intelligence calculations outside of energy-constrained terrestrial data centers and run scalable machine learning workloads in space. Google aims to link dozens or hundreds of satellites in close formation using high-bandwidth, short-distance laser communications (free-space optical links) to function like a unified data center. To meet that objective, the tech giant has been testing hardware resilience and plans further orbital validation with Planet Labs to launch prototype satellites to evaluate optical links and in-space compute viability. The initial mission will be part of SpaceX's upcoming Transporter-18 rideshare mission, which will carry 130 payloads to orbit. In addition to Google's Project Suncatcher, the mission's payload includes Star Catcher's "Protostar" orbital power demonstrator, Blackwing Space's "Baby Bird" nanosatellite, two Canadian methane-monitoring satellites, Nordspace's first pathfinder satellite, "Terra Nova," and Sateliot's five new 5G IoT/NTN satellites as part of its "Draconis" deployment.

Orbital Compute Inc. has also unveiled plans to deploy a constellation of up to 100,000 low Earth orbit (LEO) satellites designed to function as space-based data centers delivering 10 gigawatts of artificial intelligence computing power-satellite constellation. Orbital partnered with Reflex Aerospace to build modular AI data center platforms in space. Kepler Communications operates active multi-GPU compute and storage-carrying relay satellites utilizing optical mesh networks in low Earth Orbit. Kepler Communications operates the largest space-based edge computing cluster in low Earth orbit, featuring 40 NVIDIA Jetson Orin processors distributed across 10 interconnected optical data relay satellites. Axiom Space is another company venturing into space for its data center by developing custom orbital edge-computing and data nodes as part of its commercial space station program. The company is building the world's first commercial space station to serve as the successor to the International Space Station (ISS) that is scheduled to retire at the end of 2030. Lonestar Data Holdings is deploying StarVault, the world's first commercial space-based sovereign data storage and edge-computing service. The company focuses on off-world disaster recovery, sovereign data storage, and edge compute services stretching from LEO to the lunar surface.

Pixxel and Sarvam AI have partnered to build and launch India's first orbital data center satellite, named Pathfinder, scheduled for late 2026. The partnership will ensure the launch of a 200 kg-class satellite equipped with data-center-grade GPUs into low Earth orbit. Pixxel will spearhead the design, construction, launch, and operation of Pathfinder, while Sarvam AI will provide the sovereign AI backbone, running full-stack model training and real-time inference in space. The platform will aid in the processing of the hyper-spectral imagery on board in real time to spot issues like wildfires or crop diseases. Both companies are based in India. Sarvam AI builds large language models (LLMs) and multi-modal AI systems specifically tailored for Indian languages, culture, and context. They have developed indigenous foundational models like Sarvam 30B and Sarvam 105B, trained from scratch on Indic languages. Pixxel is an international space data company that builds high-resolution commercial hyper-spectral imaging satellites to monitor the health of the Earth by capturing hundreds of narrow light bands beyond normal human sight. The company is revered for its Firefly constellation, a commercial network of six (with plans of expanding to 24) high-resolution hyper-spectral Earth-imaging satellites. By utilizing the satellite data gathered, Pixxel can catch crop diseases, nutrient deficiencies, and water stress long

before they are visible to standard cameras. That information can also track deforestation, expose ecological changes, and identify industrial emissions.

Another Indian space-technology startup, TakeMe2Space (TM2S), is also exploring the idea of in-orbit data centers and orbital computing infrastructure with a mission to make edge AI processing accessible directly in space, allowing clients to analyze Earth observation data in orbit and transmit concise insights back to Earth instead of massive, raw data files. Scheduled to launch aboard a SpaceX Falcon 9 rocket (Transporter-18 rideshare mission), the 14 kg MOI-1A satellite serves as India's first dedicated orbital computing satellite. It carries Nvidia Jetson Orin NX processors delivering 117 TOPS of AI computing power alongside a 9-band multispectral imager. TM2S aims to have six MOI satellites forming a constellation to deliver complete daily global average by Q4 2027. The company secured 23 commercial and educational customers for the MOI-1A mission from various sectors like agriculture, mining, insurance, and space data analytics firms.

Last month, China launched the PEGA-SUS1 satellite from the Dongfeng Commercial Space Innovation Experimental Zone on the Kinetica-1 Y18 (Lijian-1 Y18) carrier rocket. It was the first satellite of the planned nine-satellite PCL-Pegasus Constellation jointly built by Pengcheng Laboratory, GalaxySpace, and the Southern University of Science and Technology. The launch carried an on-board AI computing payload to process data directly in space rather than sending raw information back to Earth, a 5G non-terrestrial network (NTN) payload based on 3GPP standards and microwave communications, a high-speed space-to-ground laser communication instrument, and equipment to serve as a catapult for 6G frontier technologies and integrated space-air-ground networks.

There are many other firms across the world considering deployment due to the increasing demand for compute capacity and related energy costs. One can deduce that if terrestrial infrastructure constraints continue tightening, even a small share of global compute capacity could become strategically important.

Why Move Data Centers to Space?

Moving data centers to space offers a way to bypass terrestrial energy crises, cooling limits, and grid bottlenecks driven by the artificial intelligence boom. What you get in space that you do not get on the ground is unlimited, continuous power. Satellites in sun-synchronous orbit capture constant, uninterrupted solar energy without weather, atmospheric, or land constraints. Space also serves as a conduit for natural thermal management. Earth-bound data centers consume massive amounts of water and electricity for chillers and air conditioning. Space relies on the freezing vacuum to cast off heat using specialized radiators, removing terrestrial water constraints. In space, one can bypass terrestrial permitting and grid structures, saving time and cutting through related bureaucratic red tapes. Saturation of downlink bandwidth makes sending raw Earth-observation or climate-monitoring data down to Earth slow and costly. Processing this information directly in orbit acts as an efficient edge-computing solution. However, challenges still exist.

The vacuum of space lacks air or water, meaning heat cannot be transferred via convection or conduction. Heat dissipation must rely entirely on thermal radiation, which is extremely slow and requires massive radiator surface areas (potentially millions of square feet for a single facility). Powering high-density artificial intelligence server racks requires massive amounts of continuous energy, necessitating giant, heavy deployable solar panels that drive up launch weights and costs. Unfiltered solar ultraviolet rays degrade exterior infrastructure and radiators over time, reducing their lifespan and performance.

Maintenance and hardware obsolescence is also a challenge. Technicians cannot manually service or swap out broken components in orbit, meaning a single hardware failure requires replacing entire satellites. High-performance GPUs and AI chips advance and become obsolete every 1 to 2 years, whereas orbital satellites have much longer lifecycles of 5 to 7 years. The elements in space like unshielded cosmic rays and high-energy particles cause frequent data bit-flips and corrupt computations, requiring heavy shielding or redundant error-correcting systems. Congested low-Earth orbits pose collision risks with space

junk, threatening total destruction of expensive computing nodes.

Recycling materials from terrestrial data centers relies on established circular supply chains, whereas recycling orbital data centers presents a major logistical hurdle because hardware often burns up during atmospheric re-entry. Terrestrial facilities handle retired hardware in predictable, bulk cycles through professional IT Asset Disposition (ITAD) networks. Proposed space-based computing constellations face a completely different end-of-life dynamic. AI satellite clusters feature short GPU lifespans, meaning thousands of units require regular decommissioning. Most retired orbital hardware is directed to burn up in the atmosphere or pushed into distant disposal orbits, permanently removing critical raw materials—like copper, gold, and palladium—from Earth's active supply chain. Large-scale re-entry creates upper-atmosphere pollution and ozone risks, leading regulators to scrutinize traditional satellite disposal methods. Large-scale re-entry creates upper-atmosphere pollution and ozone risks, leading regulators to scrutinize traditional satellite disposal methods. Scientists and engineers are exploring closed-loop recovery methods for orbital hardware. Research investigates capturing defunct orbital assets using robotic arms or special cranes, then melting down metal alloys to 3D-print new satellite components directly in space. Technologies are being tested to convert solid rocket fuel residues and melted aluminum into electrical fuel or propellants for ongoing missions.

It shouldn't come as a surprise that the leading countries in terrestrial data centers are also leading the orbital data center race. They have realized earlier that continued use of the computing capacity of current data centers will not be sufficient to meet the ambitions of the next industrial revolution and they must oblige the inherent inclination to build more rather than recoil in the face of prevailing challenges. The race continues.

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