

SPACE-BASED DATA CENTERS ROADMAP: THE CASE FOR CAUTION

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CHAPTER 1.2:

Power Systems

Roger Aines, Colin McCormick and David Sandalow



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CHAPTER 1.2:

POWER SYSTEMS

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MAIN MESSAGES

- The power system is a significant contributor to the overall weight of a spaced-based data center (SBDC).
- Significant technology innovations and major expansions of supply chains would be needed to limit the weight of a 100-kW SBDC to one tonne (the weight suggested by SpaceX in US regulatory filings).
- Heavier satellites cost more to launch, have greater de-orbiting risks, emit more greenhouse gases (GHGs) and do more damage to the ozone layer.

Power systems for space-based data centers (SBDCs) must meet several requirements. First, these power systems must include solar photovoltaic (PV) arrays large enough to provide power for the satellite's information technology (IT) equipment and other systems. Second, these solar PV arrays must also have generation capacity to simultaneously charge batteries, which are needed to run the satellite during orbital eclipse periods (when the satellite moves through Earth's shadow and the PV arrays stop generating power). Third, if the SBDC will provide artificial intelligence (AI) compute services continuously, the power systems must carry batteries that are large enough to hold the electrical charge needed to run the full IT capabilities of the satellite during the orbital eclipse period, which is roughly 15–25 minutes for satellites orbiting at the altitude of the Reference SBDC (500–800 km, (see Text Box 1-1). Finally, SBDC power systems must include cabling and voltage transformers, known as power conditioning and distribution units (PCDUs), that effectively condition and route electric power among the PV array, batteries, IT equipment and other systems.



A satellite in orbit with solar photovoltaic (PV) panels. Source: Shutterstock

Designing a power system to meet these requirements would be easy if weight did not matter. But the weight of an SBDC satellite has a significant impact on its launch costs, de-orbiting risk, emissions and other characteristics. The power system will be a major contributor to the

overall weight (mass) of an SBDC, so understanding the feasible range of power system weight is important.

SBDC developers state they will be able to design power systems with high power but low weight, which means the total number of launches to build a targeted amount of compute (e.g., 1 GW) would be relatively small. SpaceX has made the most prominent claim, suggesting that a satellite with 100 kW of compute power would weigh only a single tonne (an overall power-to-weight ratio of 100 W/kg).[1-4]

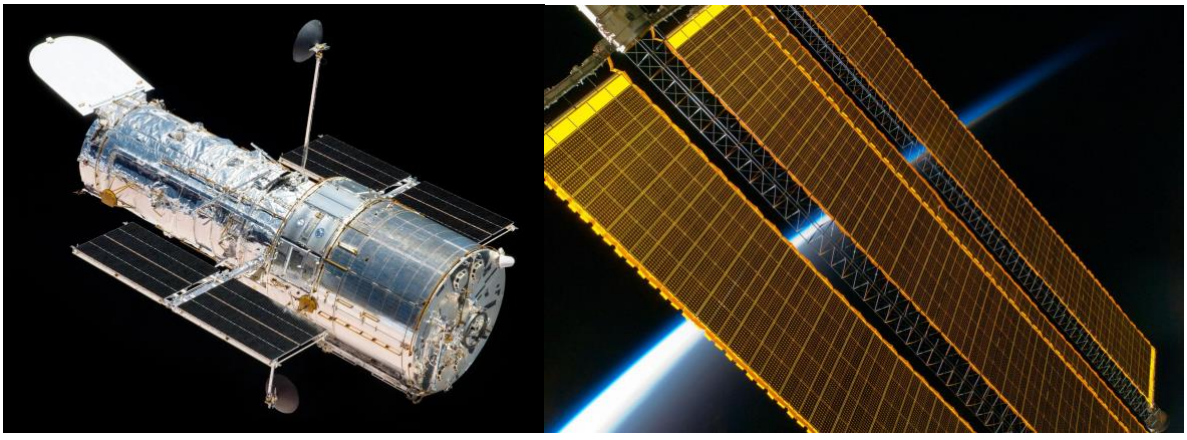
If SBDC developers cannot engineer power systems within their weight targets, more launches will be required to achieve any given level of compute. This would increase costs, de-orbiting risks, greenhouse gas (GHG) emissions and stratospheric ozone impacts. As a result, policymakers should assess SBDC developers' claims with respect to power system weight in assessing the risks and impacts of SBDCs. This chapter analyzes the power-to-weight ratios of SBDC power systems, highlighting the policy impacts of this figure.

A. Satellite Power System Components

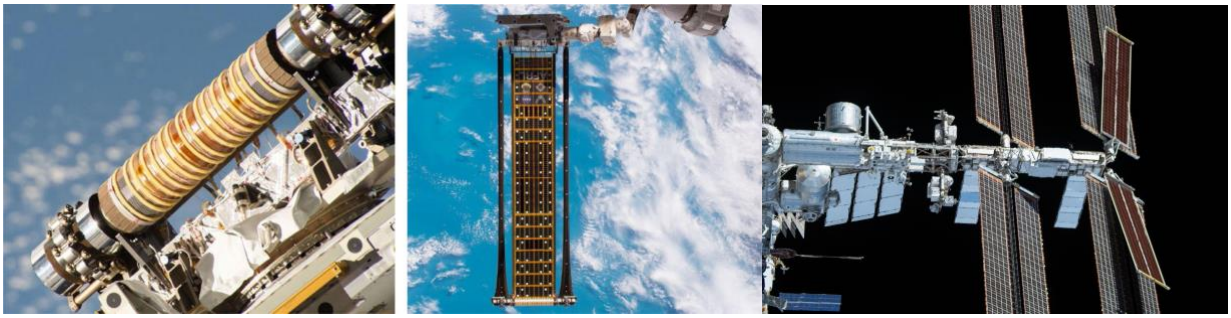
The main components of the power systems in today's satellites are photovoltaics (solar panels), batteries and power-distribution equipment (e.g., transformers).

i. Solar photovoltaic (PV) array

Satellites currently use either triple-junction gallium arsenide (GaAs) or silicon solar PV arrays (or both). GaAs PV arrays have several important advantages. They are relatively resistant to radiation damage, meaning that panels retain their generating capacity in space far longer than silicon PV panels. They also have a high conversion efficiency (roughly 30%, compared to 20% or lower for silicon) meaning that panels can be lighter and have a smaller area to generate the same amount of power.[5] But GaAs is substantially more expensive than conventional silicon PV, and the current global production base is roughly 2 MW per year, far too small to supply PV arrays at the GW scale proposed by SBDC developers.[6] Efforts to expand this production face serious material supply



The triple-junction gallium arsenide (GaAs) photovoltaic (PV) solar panels on the Hubble Space Telescope, 2009. Source: NASA. Silicon solar PV arrays on the International Space Station (ISS), 2008. Source: NASA



The ISS roll-out solar arrays (ROSAs) being deployed. Source: Yan et al., 2025.[15] Open Access. CC BY-NC-ND 4.0. The ISS with its new roll-out solar arrays, 2021. Source: NASA

challenges because global gallium supply is heavily concentrated in China, which has sharply restricted exports.[7] Operating SBDCs on triple-junction GaAs PV therefore faces significant cost and supply constraints.

To lower costs and enable high-volume production, many satellite developers use silicon PV, despite its disadvantages. Fortunately, recent innovations have helped mitigate some of silicon's shortcomings. Most notably, silicon PV arrays that are fitted with cover glass have partly improved radiation resistance, at the cost of increased weight and reduced conversion efficiency.[8,9] The use of polymer layers to radiation-harden silicon PV on flexible substrates for satellite applications is also emerging.[10] The disadvantages of operating SBDCs on silicon PV may therefore be somewhat reduced, and the advantages of being able to access a mature and widely scaled silicon PV supply chain may outweigh them.

Beyond silicon, other potential PV options for SBDCs under development include copper indium gallium selenide (CIGS),[11] perovskites and organic solar cells.[12] While these systems theoretically can achieve high power-to-weight ratios (enabling lightweight SBDCs), they have not yet been demonstrated at scale in space, and their respective production bases also remain relatively small compared to silicon PV.

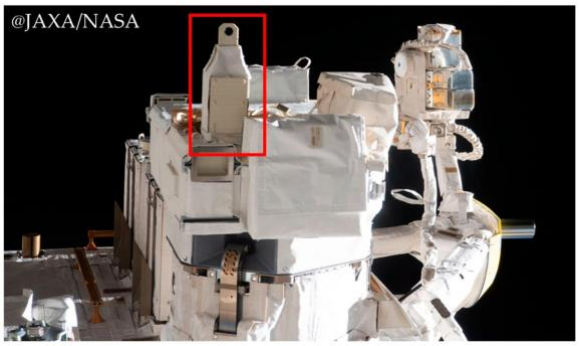
The International Space Station (ISS) carries the largest solar array of any spacecraft ever launched. Its original arrays use monocrystalline silicon PV, but radiation damage has reduced their generating capacity significantly.[13] Beginning in 2021, they were augmented with "roll-out solar arrays" (ROSAs) using GaAs PV.[14] The Chinese Tiangong space station is also equipped with GaAs solar PV.[15] State-of-the-art ROSA units use extremely light carbon composite lenticular tubes for deployment booms.



GaAs solar PV on the Chinese space station. Source: Yan et al., 2025.[15] Open Access. CC BY NC-ND 4.0

When considering the type of PV that could be used for SBDCs, it is important to note the highly competitive market for space-capable PV with favorable characteristics (lightweight, radiation-hard, high conversion efficiency). Demand from communications mega-constellations and space-based solar power for terrestrial consumption may grow rapidly in the near term, potentially making supply constraints even tighter.[9] SBDC developers targeting high-power (>100 kW) satellites with low weight may therefore need to adopt emerging and still largely unproven PV technologies, sourced from a still-nascent production base, or they may need to procure at higher prices to secure supply.

ii. Batteries and power conditioning and distribution units (PCDUs)



Inside the red box: a lithium-ion battery on the exposed section of the International Space Station (ISS). Source: Miyazawa et al., 2025.[19] Open Access. CC BY 4.0

Satellite power systems also incorporate batteries to power on-board systems during the eclipse period of the orbit. Lithium-ion batteries offer many advantages and have become standard for many satellite applications.[16] Advanced lithium-ion batteries can store up to roughly 250 Wh per kilogram (Wh/kg).[17] The size of the battery carried by an individual SBDC satellite would depend on its total power consumption (in kW) and the amount of time it would spend in eclipse, during which the battery would need to discharge power. Additionally, batteries cannot fully discharge their stored energy without dramatically shortening their lifetime, so the depth-of-discharge is typically limited to no more than 40% for satellites in low Earth orbit (LEO).[18]

PCDUs combine different power regulation and conversion equipment to optimize solar array generation, control power flow to loads and batteries, protect against electrical faults and provide other power system services.[20] They generate heat (for example, through voltage conversion), which must be dissipated by the thermal-management system. Because they are so central to the overall functioning of the satellite, they must be highly reliable, with redundant systems to avoid single-point failures. Satellite developers are increasingly looking to wide-bandgap semiconductors like gallium nitride (GaN) rather than silicon to reduce weight and improve PCDU performance.[21]

B. Power System Weight Estimate

The weight of solar panels, batteries and PCDUs is a significant percentage of the total weight of satellites. Reducing the weight of these components while maintaining (or improving) their performance is a key challenge in keeping the weight of an SBDC as low as possible. SBDC developers have not shared details of their potential power system designs, so to estimate the likely weight of the power system for our Reference 100-kW SBDC (see Text Box 1-1), we use approximate values and compare them with the design of other satellite systems.

i. Solar photovoltaic (PV) array

State-of-the-art ROSA units, such as those used on the ISS, if equipped with triple-junction GaAs PV panels, could potentially achieve a component-level power-to-weight ratio of 218 W/kg.[15,22] This suggests a 100-kW solar PV array could weigh as little as 0.46 tonnes. However, as noted above, GaAs PV panels are likely to be highly supply-constrained, and ROSA units have not yet demonstrated that high of a power-to-weight ratio in scaled deployment. ROSA units using silicon PV panels would have a lower power-to-weight ratio and would consequently have to be heavier to supply 100 kW.

ii. Batteries and power conditioning and distribution units (PCDUs)

A 100-kW SBDC with 30 minutes of eclipse time and a 40% depth of discharge limit would need a minimum of 125 kWh of battery energy capacity to fully power the satellite for the duration of each eclipse. For comparison, the ISS has approximately 360 kWh of battery capacity, meaning each SBDC would need roughly one-third of the ISS battery capacity.[23-25] Space-qualified lithium-ion batteries have been demonstrated with up to roughly 250 Wh/kg of energy capacity at the pack level.[26,27] This suggests that a 125-kWh battery would weigh roughly 500 kg (0.5 tonne). The SpaceX Starlink V2 mini satellites use approximately 11 kWh of nickel manganese cobalt (NMC) lithium-ion batteries[28] to serve a total power demand that may be 28 kW (third-party-validated figures are not available).[29]

No systematic scaling information is available for the weight of PCDUs relative to satellite power. Proven systems have a weight-to-power ratio of roughly 12 kg/kW for larger (kW-scale) satellites.[30,31] This suggests that a PCDU serving a 100-kW satellite would weigh 1.2 tonnes.

Using these rough estimates, the total power system of a 100-kW SBDC is likely to be no lighter than 2.2 tonnes (see Table 1.2-1). This alone—without any cooling systems, IT equipment or communications—is over twice the stated estimates of the entire satellite weight projected by SpaceX as noted above. Reducing this value would require major innovations across multiple systems, drawing on nascent supply chains that are many orders of magnitude smaller than what would be required for GW-scale SBDC constellations.

Table 1.2-1: *Estimated weight of the power system components for a 100-kW space-based data center (SBDC).*

Component	Rough scaling value	Weight for a 100-kW space-based data center (SBDC)
Solar photovoltaic (PV) arrays	218 W/kg	0.46 tonnes
Batteries	250 Wh/kg	0.50 tonnes
Power conditioning and distribution unit (PCDU)	12 kg/kW	1.2 tonnes
Total	N/A	2.16 tonnes



Launch and separation of the HOTBIRD 13F satellite in October 2022. Source: ESA

C. Comparison with Current Satellites

The above estimate of power system weight can be put into context with current satellite weights. As noted, the ISS is the largest satellite ever launched, with a total weight of roughly 420 tonnes[32] and a total power generation capacity of 215 kW.[33] This suggests the overall satellite power-to-weight ratio is 0.5 W/kg, or 200 times lower than stated SBDC targets of 100 W/kg.

Another important comparison can be made to the HOTBIRD 13F and 13G satellites, which use the Airbus Eurostar Neo satellite platform. These satellites have 22 kW of electrical power (supplied by triple-junction GaAs PV arrays[34]) and weigh 4500 kg at launch, for a power-to-weight ratio of 4.9 W/kg, 20 times lower than SBDC design targets.[35]

The most relevant comparison may be with the SpaceX Starlink V2 satellite, which has many similarities to an SBDC satellite (although the Starlink V2 is significantly smaller). The V2 mini may have approximately 28 kW of electrical power[29] (as noted, third-party validated figures are not available) and weighs 575 kg at launch, for a presumed power-to-weight ratio of 49 W/kg, half the SBDC design target.

D. Conclusions

This analysis suggests that the power system required for a 100-kW SBDC satellite would weigh over 2 tonnes by itself. Significant technology innovations and major expansion of supply chains for specific space-qualified equipment would be needed to reduce this figure. While the power system is likely to make up a large fraction of the overall satellite's weight, the weight of the cooling system, IT equipment, communications equipment and other systems will make the total weight significantly higher. SpaceX's stated weight target (1 tonne for a 100-kW SBDC) is far more optimistic than this estimate would suggest. It is also far more optimistic than any previously demonstrated satellite.

If SBDC developers cannot engineer satellites within proposed weight targets, the overall impacts of a SBDC constellation for any given level of compute would be much higher, including higher costs, ground damage and casualty risks, GHG emissions and stratospheric ozone damage. Policymakers should be aware of the connection between estimated satellite weight and these impacts.

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