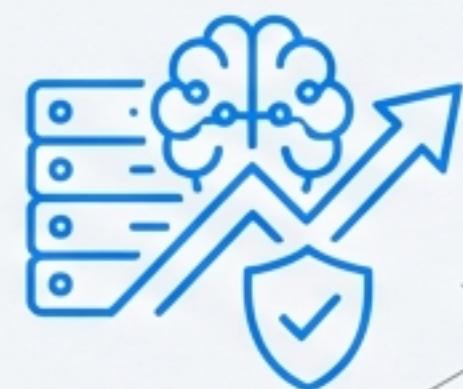
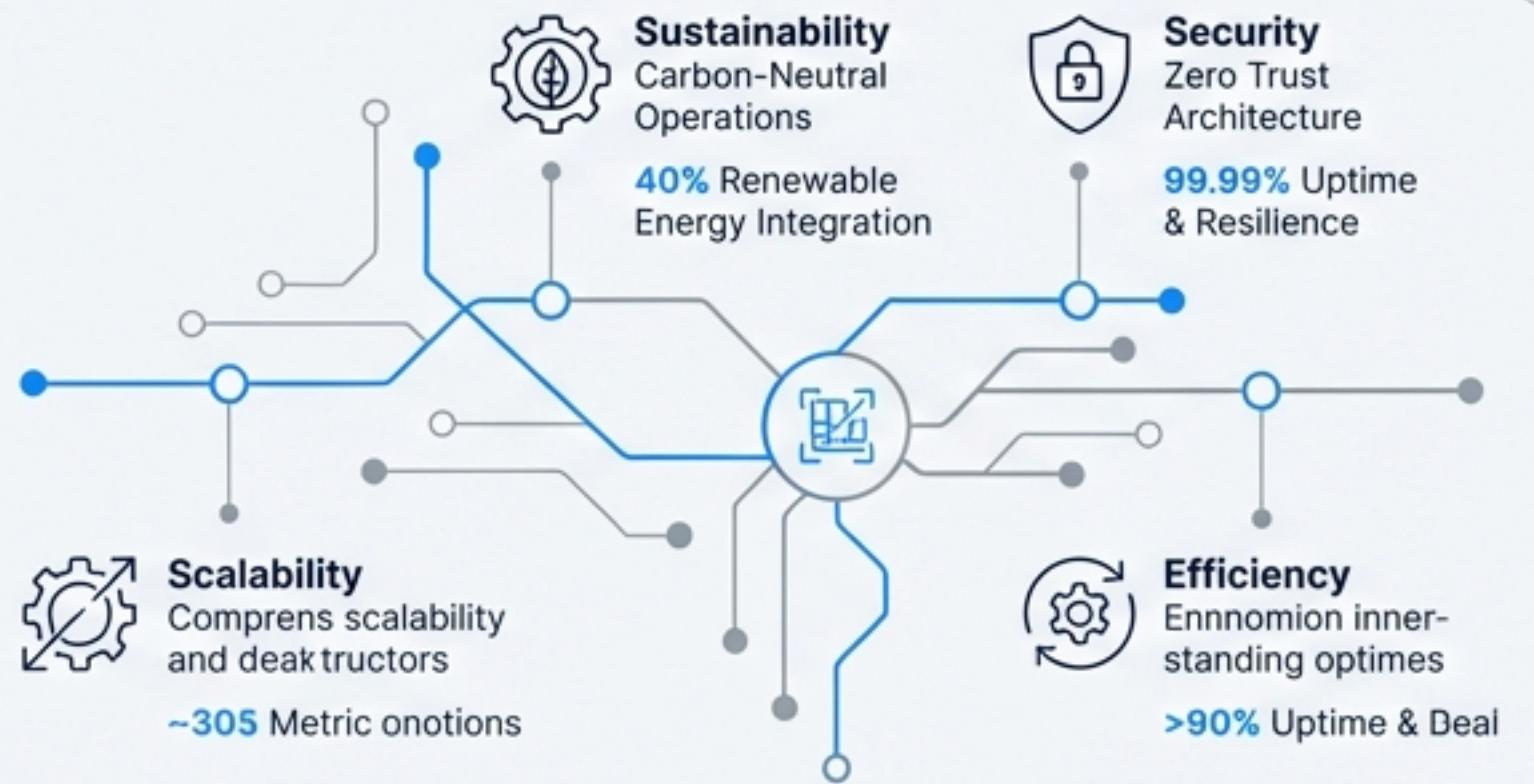


The Modern Data Center: From Blueprint to Benchmark

An Intelligence Briefing on the Core
Pillars of Critical Infrastructure



Source: Global Data Center Intelligence Report 2024.

NotebookLM

Five Critical Questions Defining Today's Infrastructure Strategy



1. **Capacity:** How do we define scale from hyperscale to the edge?



2. **Redundancy:** What are the industry-standard trade-offs for ensuring uptime?



3. **UPS:** Which technologies guarantee instantaneous power continuity?



4. **Generators:** What is the consensus on long-term power endurance?



5. **Efficiency:** How is performance measured, and what does the data reveal?



Data Center Scale Is Defined by Orders of Magnitude

Capacity

Industry sources align that hyperscalers operate on a scale vastly larger than enterprise or edge facilities.

Edge



~50–500 kW

Enterprise /
Colocation
Inter Bold



1–20 MW

Hyperscale
Inter Bold



50–100+ MW

Hyperscale

Typical Range: 50–100+ MW

Expert Insight: “200 MW facilities are now becoming normal for new hyperscale builds.” (Source: McKinsey, 2025)

Enterprise / Colocation

Typical Range: Positioned between the two extremes, with real-world examples varying widely but generally in the single to low double-digit MW range.

Edge

Typical Range: ~50–500 kW

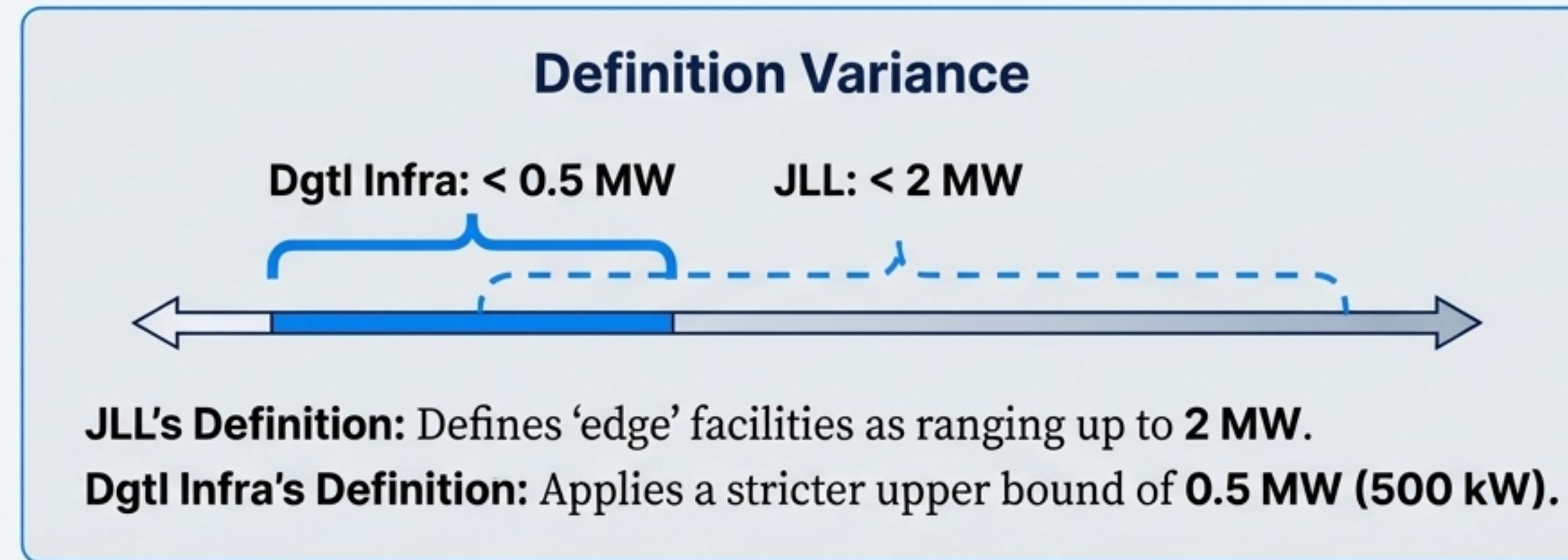
Context: Designed for low-latency applications closer to end-users.



Capacity

The Term 'Edge' Lacks a Standardized MW Definition

While the concept of edge is consistent (small, distributed), its technical definition varies significantly between industry analysts.



This variance matters for investors and operators, as the term 'edge' can describe projects with a 4x difference in potential scale and investment. The underlying message remains consistent: edge is orders of magnitude smaller than hyperscale.



Redundancy Models Offer a Direct Trade-Off Between Cost and Uptime

The industry uses a clear ‘N’ framework to define levels of resilience, with each tier offering progressively higher availability.

Model N



Baseline requirement; no redundancy.

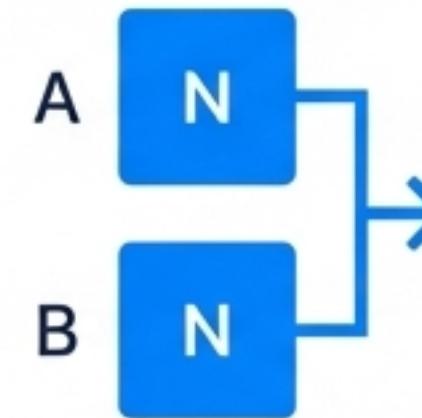
Associated Uptime (Tier I):
~99.671%

Model N+1



One additional component for backup. Provides fault tolerance for a single component failure.
Associated Uptime (Tier II/III).

Model 2N



Fully redundant, mirrored system.

Associated Uptime (Tier IV):
~99.995%

Model 2(N+1)



A fully redundant system with an additional backup for each side. The highest level of fault tolerance.

Source: Definitions and uptime data corroborated by CoreSite, 123NET, and Uptime Institute.

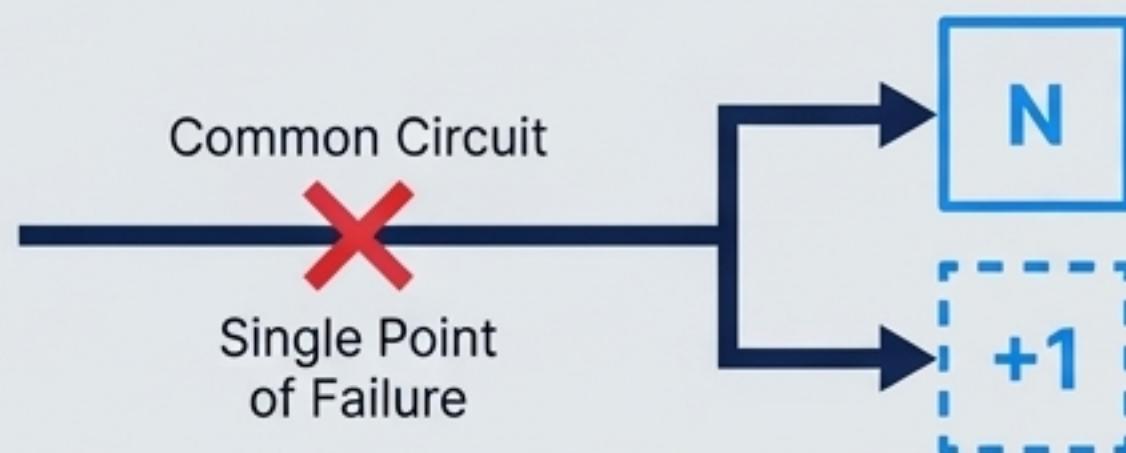


N+1 Is the Industry Workhorse, But It Is Not Fully Fault-Tolerant

While N+1 protects against component failure, it does not protect against the failure of the entire system circuit.

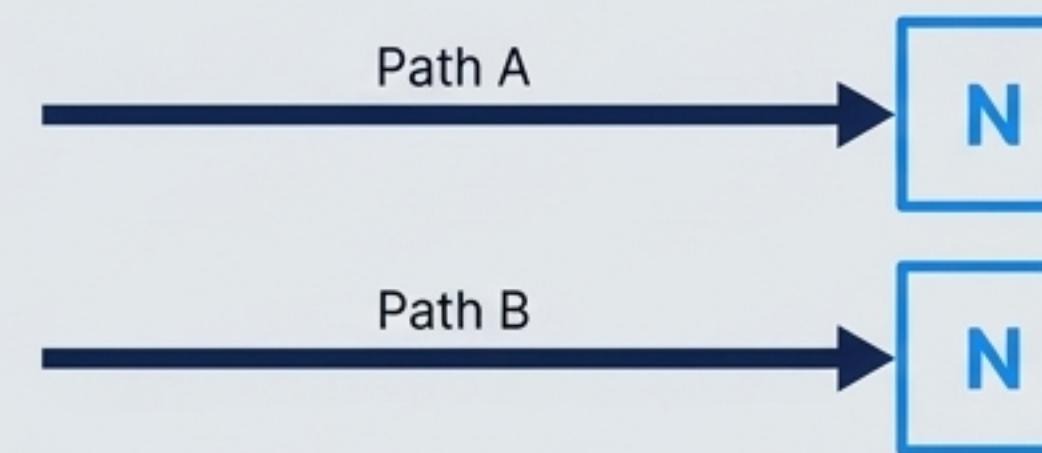
Operational Nuance

The N+1 Limitation



Sources like 123NET note that an N+1 design still has a single point of failure if a common power or cooling circuit is compromised.

The 2N Advantage



In contrast, a true 2N architecture is fully fault-tolerant, with two independent, mirrored distribution paths. It is designed to sustain at least one worst-case failure without impacting the critical load.

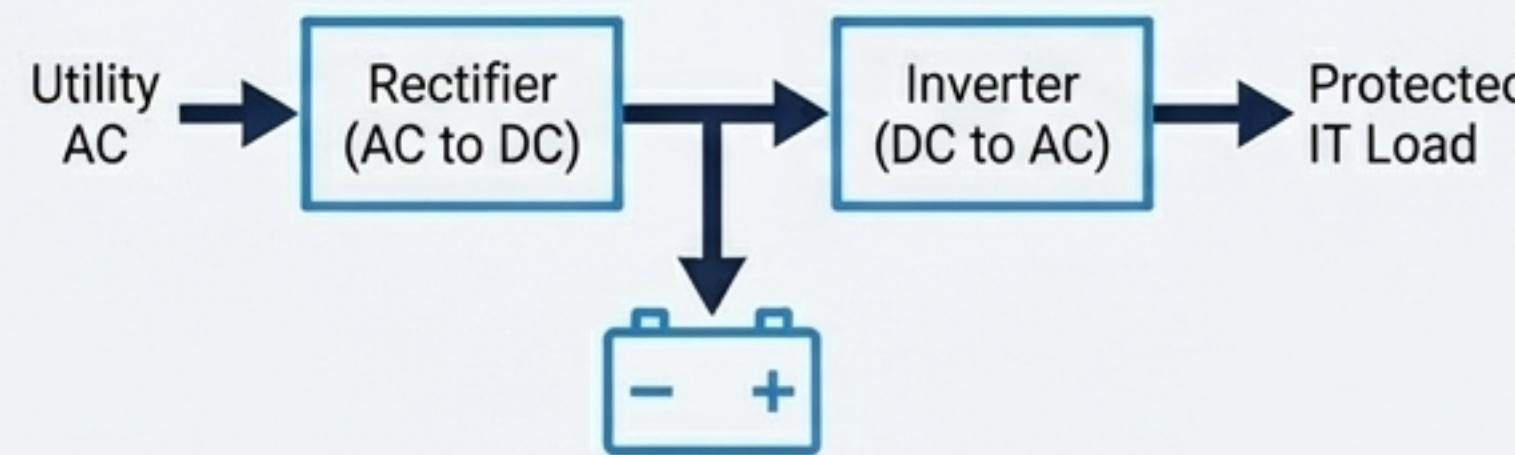
The choice between N+1 and 2N is a fundamental decision balancing cost against the risk of a site-wide outage.



Double-Conversion UPS with VRLA Batteries Is the Established Industry Standard

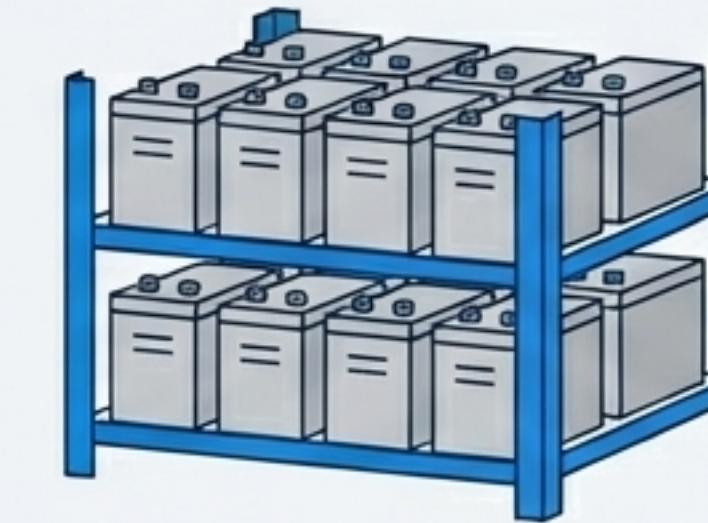
Most modern data centers rely on static, double-conversion Uninterruptible Power Supplies for instantaneous power, with Valve-Regulated Lead-Acid (VRLA) batteries as the primary energy storage medium.

UPS Topology: Double-Conversion



Provides the highest level of protection by continuously converting AC to DC and back to AC, isolating the IT load from power disturbances. This is the predominant choice for critical facilities.

Battery Chemistry: VRLA



The incumbent technology for decades due to its proven reliability and lower upfront cost.

Niche Solution: Rotary UPS (DRUPS), which use flywheels, are a niche solution found mostly in the European market. (Source: DCD)



Lithium-Ion Is Rapidly Displacing VRLA with a Compelling Lifecycle Advantage

While VRLA is the incumbent, Li-ion adoption is rising quickly due to its superior lifespan and performance characteristics.

	VRLA (Lead-Acid)	Lithium-Ion (Li-ion)
Lifespan	~5 years	~15 years (3x longer)
Recharge Speed	Slower	Faster
Upfront Cost	Lower	Higher

Area to Watch

The total cost of ownership (TCO) for Li-ion is becoming more attractive due to its longer life and reduced maintenance.

More vendor-neutral data on the long-term operational performance of Li-ion at scale is needed to fully validate vendor claims.

(Source: a noted gap in the research)



Diesel Gensets in N+1 or 2N Configurations Remain the Bedrock of Power Endurance

Across the industry, diesel generators are the default solution for providing backup power during extended utility outages.

Dominant Technology

Diesel is the proven, primary choice. Common unit sizes are 2–3 MW.

(Source: Rolls-Royce mtu via DCD, DCF on Generac)

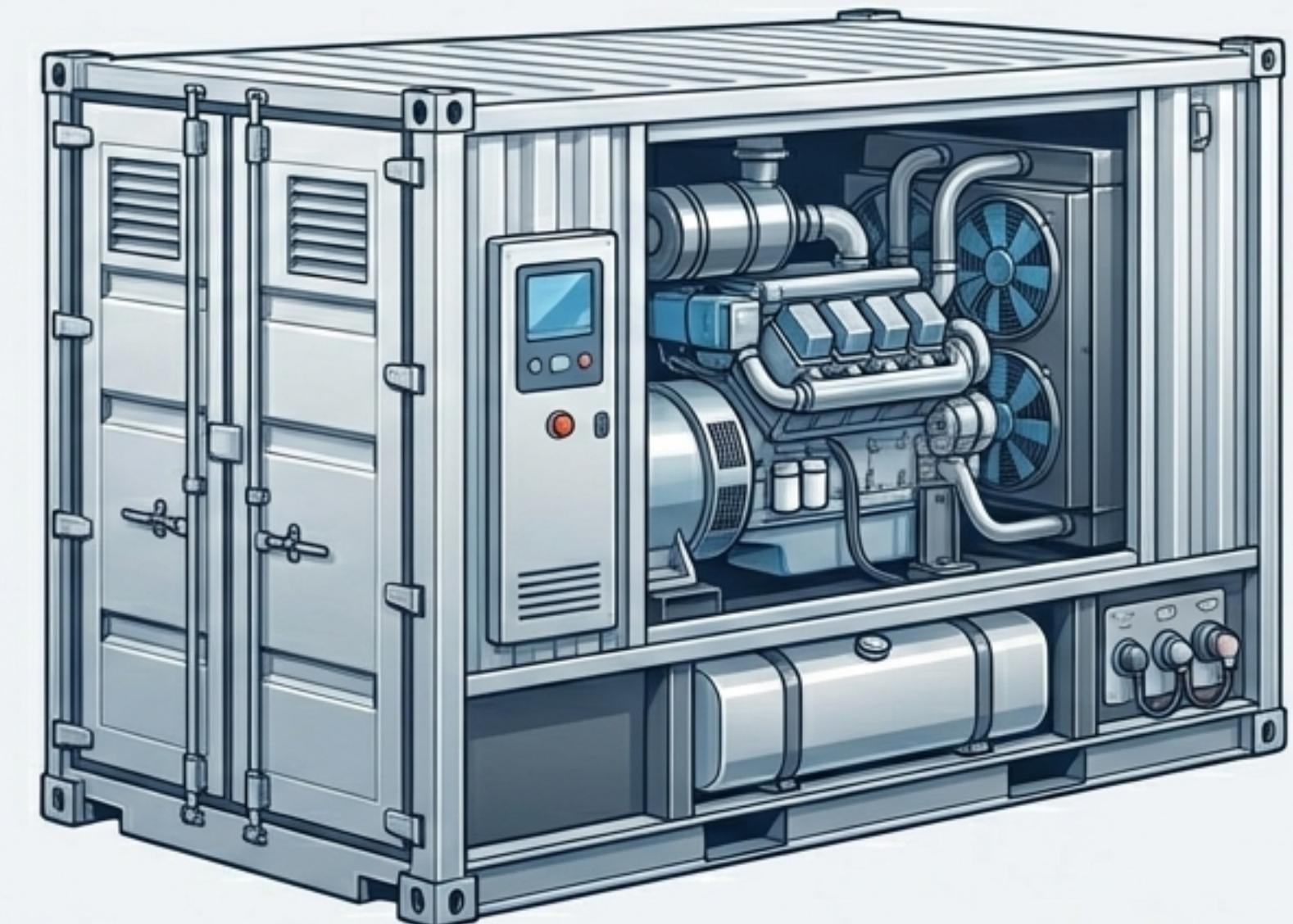
Standard Configurations

Generator farms are typically deployed in N+1 or 2N configurations to ensure reliability, mirroring the logic of the facility's overall redundancy model.

Utility Requirement

The most resilient designs (e.g., Tier IV) require redundant utility feeds from two separate substations, making the generator system a true last line of defense.

(Source: EPI/Uptime)





Natural Gas and Hydrogen Emerge as Alternatives, But Field Data Remains Limited

While diesel is standard, sustainability pressures and technological advances are driving interest in alternative fuel sources.

In Transition: Natural Gas

- **Status:** Emerging as a viable option, often touted by vendors.
- **Nuance:** Some experts note a potential drawback in slower ramp-up times compared to diesel.
- **Gap:** Lack of independent, large-scale field data on reliability in data center applications.

Future Outlook: Hydrogen Fuel Cells

- **Status:** Nascent, with high-profile pilot programs.
- **Example:** Microsoft's successful test of a 3 MW hydrogen fuel cell system.

Area to Watch

Hydrogen is praised for zero-emission operation, but industry reports caution it is not yet widely adopted. The gap between future hope and current reality is significant, with no neutral statistics on cost or reliability at scale.



The Industry's Average PUE Has Plateaued Around 1.55

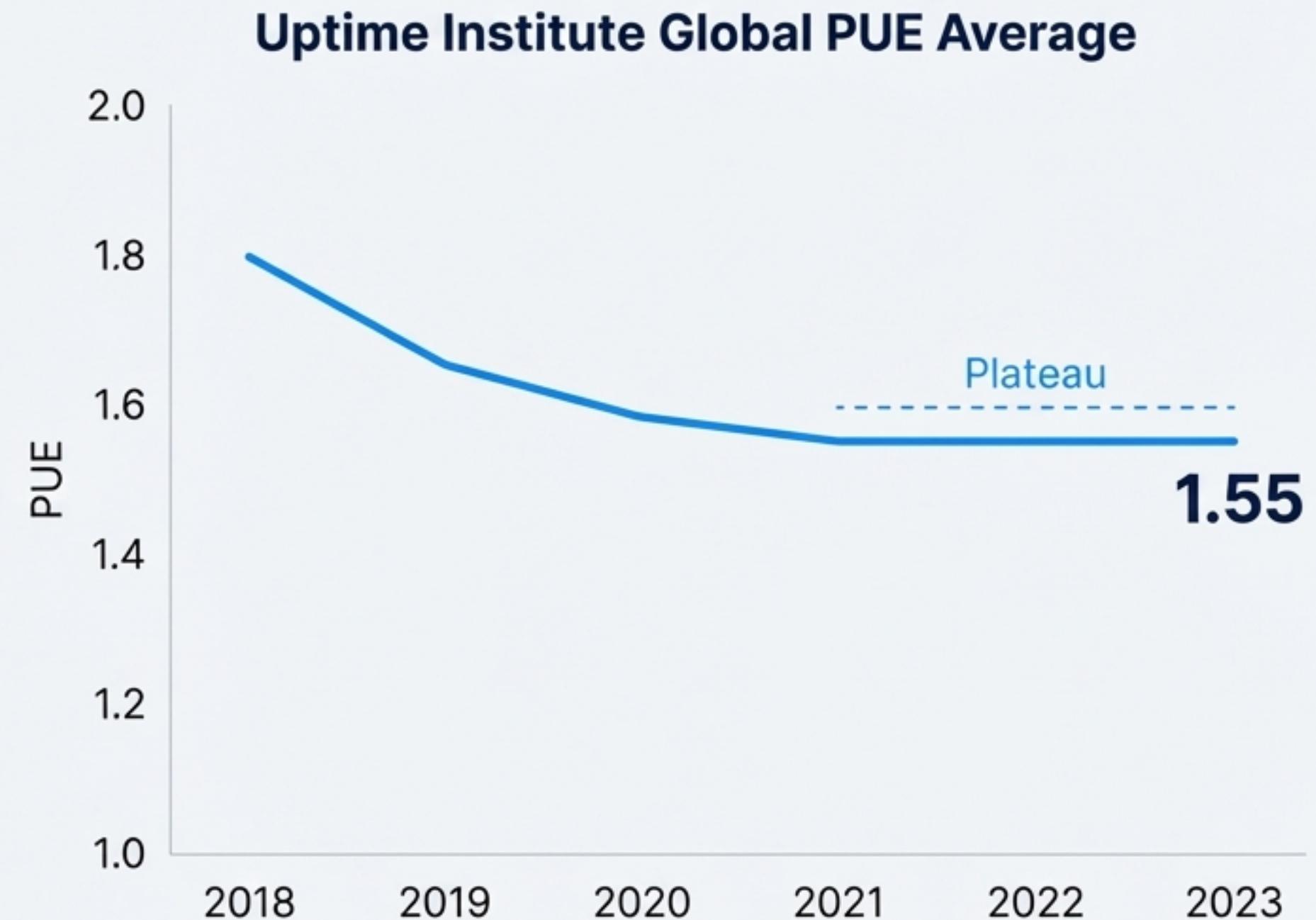
Power Usage Effectiveness (PUE) is the universal benchmark for data center efficiency, and recent broad-based surveys show improvements have leveled off.

What is PUE?

A simple ratio: Total Facility Energy / IT Equipment Energy. A lower score is better, with 1.0 being perfectly efficient.

The Implication

This plateau suggests that efficiency gains from simple operational changes have been realized, and further improvements are becoming harder for the average facility to achieve.

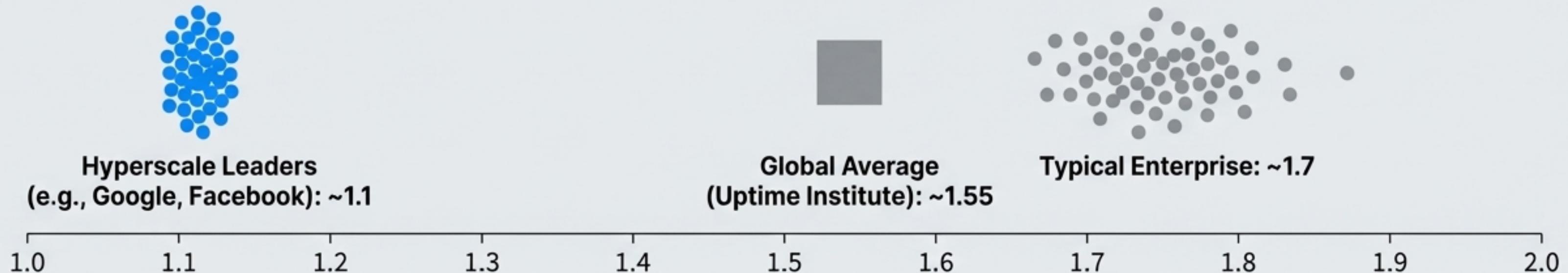




A Major Gap Exists Between Hyperscale Claims and Broader Industry Reality

The PUE figures advertised by elite hyperscalers are not representative of the wider industry, creating a significant performance divide.

Claim vs. Reality



Hyperscale Leaders: Google and Facebook consistently claim PUEs around **~1.1**.

Global Average: This is contrasted with the Uptime Institute's industry-wide average of **~1.55**.

Typical Enterprise: The average for enterprise data centers is estimated to be much higher, around **~1.7**.

Stakeholders should be skeptical of marketing claims. While some colocation providers may advertise PUEs of ~1.2, broad survey data suggests most facilities operate at a significantly lower level of efficiency.

A Strategic Framework for Data Center Infrastructure

Standard Practice Today

Mature, widely deployed



Capacity: Hyperscale (100+ MW) & Enterprise/Colo



Redundancy: N+1 and 2N Models



UPS: Double-Conversion Topology with VRLA Batteries



Generators: Diesel Gensets



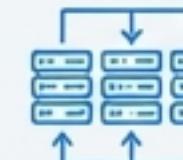
Efficiency: PUE as the primary metric

In Transition / Gaining Adoption

Proven but not yet dominant



Capacity: Edge deployments (<2 MW)



Redundancy: Distributed Redundancy Models (e.g., 3N/2)



UPS: Lithium-Ion Batteries



Generators: Natural Gas Gensets



Efficiency: Hyperscale efficiency levels (~1.1 PUE)

Future Outlook / On the Horizon

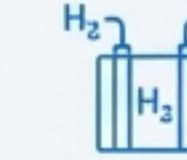
Emerging, limited field data



Capacity: Highly distributed, near-zero latency edge



UPS: Alternative energy storage



Generators: Hydrogen Fuel Cells



Efficiency: Advanced metrics beyond PUE (e.g., WUE, CUE)

About This Intelligence Briefing

The analysis presented in this document is synthesized from a comprehensive review of over 30 authoritative sources, including industry surveys, technical whitepapers, and operator disclosures.

Key data and frameworks are drawn from leading organizations such as:



Uptime
Institute®



JLL

Dgtl Infra



Data Center
Dynamics



Data Center
Frontier

Infrastructure is Strategy

Understanding these foundational pillars—from their consensus definitions to their emerging nuances—is essential for making sound investment and operational decisions in the digital age.