PART 15 · SECOND EDITION · SEPTEMBER 2026 (FIRST PUBLISHED JULY 2026)

Sustainability & Efficiency

Every efficiency number is a boundary choice, every carbon claim an accounting choice, every liter a basin choice. This is where sustainability stops being a report and starts deciding whether your campus gets built.

ONE SURVEY, TWO WEIGHTINGS

1.52

Uptime's 2026 respondent mean PUE

The respondent mean is 1.52; capacity weighting gives 1.36. Different weights answer different questions and do not rank cooling architectures.

UPTIME INTELLIGENCE UPDATE 518, THE GROWING PUE ADVANTAGE OF LARGER DATA CENTERS, 2026-08-06, ANALYSING THE UPTIME INSTITUTE GLOBAL DATA CENTER SURVEY 2026 · AS-OF 2026

THE REFRAME

Sustainability stopped being a report. It is now a permit condition, a design input, and a grid negotiation.

Six fronts decide whether your campus gets built and stays welcome: energy, water, carbon, heat, disclosure, and flexibility. Every one is settled at scoping time, not in the annual report.

ACT I

Measure what matters

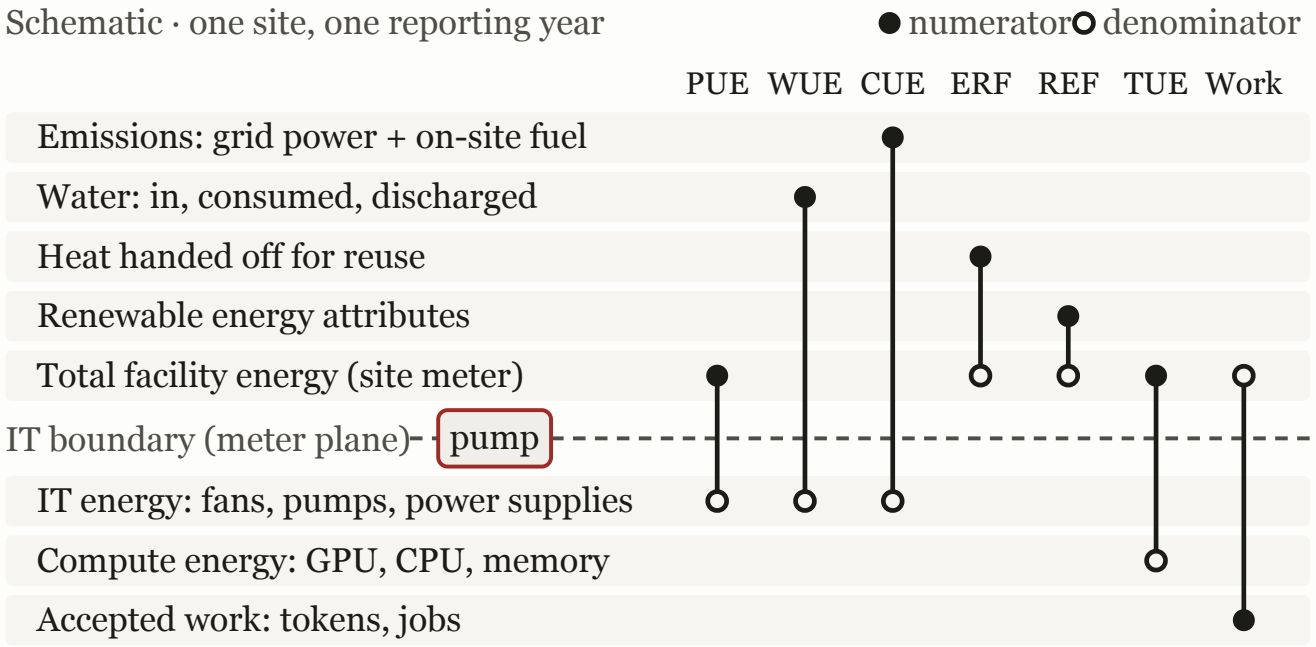
PUE was built to expose waste in air-cooled halls. In a liquid AI factory it rewards moving losses across the IT line — and says nothing about water, carbon, or useful work. The metric you pick is itself a decision.

THE POST-PUE STACK

Four questions one number can't answer

Each metric sees one boundary and hides the rest

Schematic · one site, one reporting year



Move pump energy into IT: PUE drops; total site energy doesn't.

Accept each objective on its own: a good PUE cannot offset a failed water gate.

ERF: energy reuse factor · REF: renewable energy factor · TUE: total-power usage effectiveness

Schematic · Source: Guide derivation · as of September 2026

Pin PUE, WUE, ERF, and REF together — the EU now files them side by side — so no single number can be gamed by a boundary trick.

THE LIQUID-COOLING TRAP

TUE = ITUE x PUE

TUE keeps the computational-component boundary explicit

Moving fan/pump loads between facility and IT meters changes PUE without saving energy. Compare a fixed chip boundary with TUE, or energy at the same useful service.

SPRINGER, PATTERSON ET AL., TUE, A NEW ENERGY-EFFICIENCY METRIC APPLIED AT ORNL'S JAGUAR, ISC 2013, PP. 372–382 · AS-OF 2013 (ISC PROCEEDINGS)

WHERE THE LEVERAGE IS

Overhead, in three numbers

~55–70% (reference breakdowns)

In air halls cooling dominates overhead: the first lever, held to the measured budget

EPRI 1024624 · AS-OF LBNL 22-SITE STUDY VIA EPRI (2011); DC ATLAS ILLUSTRATIVE MODEL (2026-02)

94-97% → 98-99%

UPS efficiency, double-conversion vs eco mode — points that compound at GW scale

VERTIV LIEBERT EXL S1 UPS DATASHEET SL-26095 · AS-OF 2013-01 / 2020-01

1.09

Google's fleet-wide trailing-twelve-month PUE — what a mature fleet achieves

GOOGLE DATA CENTERS, 2026 PUE YEARLY REPORT, QUARTER 02 FLEET ROW · AS-OF Q2 2026 TRAILING TWELVE MONTHS

COMPARE THE SAME SERVICE AND CLIMATE

Cooling choice needs annual energy and water bins

COOLING ARCHITECTURE	QUALIFICATION GATE	ANNUAL ENERGY TEST	WATER AND SERVICE CONSEQUENCE
Legacy air + chiller	Named rack air duty and inlet limits	Compressor lift, fans and pumps across the annual bins	Cooling makeup, refrigerant and maintenance duties
Optimized air + economizer	Ambient air quality and permitted inlet band	Containment and economizer hours cut compressor runtime; include fan and humidification energy	Water, filtration and transient margin remain
Rear-door HX / air-assisted liquid	Rack air path and water interface	Door water removes air heat; count loop pumping and residual room cooling	Service access and leak response
Direct-to-chip liquid	Named TCS/FWS temperature, flow and chemistry	Warm water enables dry rejection when ambient/approach close; count CDU, fans and residual-air energy	Loop closure alone does not remove tower consumption
Immersion	Qualified server, fluid and	Pump and rejection curves at useful service	PFAS where the fluid meets the

ACCEPTANCE LIMITS ARE NOT A SETPOINT

QCT reference maxima: 45 °C inlet; 65 °C return

QCT GB200 NVL72 QoolRack has separate liquid-temperature maxima — declare the operating point

QCT lists 45 °C maximum liquid inlet and 65 °C maximum liquid return. These are separate limits, not a prescribed 20 K pair. Declare setpoint, design ΔT, fluid, flow, and margin.

QCT, QOOLRACK STAND-ALONE ADVANCED LIQUID COOLING FOR NVIDIA GB200 NVL72 SYSTEMS · AS-OF 2025-04

ACT II

The two licenses: carbon and water

Carbon is the global claim; water is the county hearing. One is settled by an accounting decision made before you contract power, the other by an evaporation decision poured into the plant.

100% ON PAPER, FOSSIL AT 2 A.M.

65% (2025 data centers)

Google's 2025 global 24/7 carbon-free-energy score

Google's June 2026 report: 65% globally, 90% Latin America, 83% Europe and 13% Asia-Pacific in 2025. Hourly matching locates gaps; it does not itself measure avoided grid emissions.

GOOGLE, 2026 ENVIRONMENTAL REPORT, JUNE 2026 · AS-OF 2026-06 REPORT; 2025 DATA

CLOSING THE LAST HOURS

Clean-firm is no longer exotic

835 MW (targeting 2027)

Microsoft's 20-year offtake from the restarted Three Mile Island Unit 1

CONSTELLATION · AS-OF 2026-08

~45 GW

The data-center SMR offtake pipeline — conditional agreements, not firm supply

IEA, 'DATA CENTRE ELECTRICITY USE SURGED IN 2025' · AS-OF 2026-04

115 MW (contracted)

Google–Fervo 24/7 enhanced-geothermal PPA, delivered on the local grid

GOOGLE · AS-OF 2025-05-13

THE CARBON COST OF SPEED

~82 GW

Behind-the-meter generation — largely gas turbines and engines — announced since January 2025

If gas beats the utility date, price a sunset/redeployment route; otherwise the bridge can lock in fuel and emissions exposure. An announcement is not operating capacity.

CLEANVIEW · AS-OF 2026-07

THE SOCIAL-LICENSE FRONT

Water, in three numbers

~560B L (2023) → ~1,200B L/yr (2030)

IEA: global data-center water consumption, 2023 and 2030

IEA, ENERGY AND AI · AS-OF IEA ENERGY AND AI (APRIL 2025)

~80–90% (≈83% at 6 cycles)

Share of withdrawn water consumed — derived from cycles of concentration

US DOE FEMP, BEST MANAGEMENT PRACTICE 10: COOLING TOWER MANAGEMENT · AS-OF 2026

~900M gal

Water used by Loudoun County data centers in 2023 — the county-hearing number

VIRGINIA CONSERVATION NETWORK, RESPONSIBLE DATA CENTER DEVELOPMENT · AS-OF 2023

THE IRREVERSIBLE FORK

Evaporate the water, or spend the energy?

Open evaporative (towers)

— Wet-bulb access can lower the required lift; compare annual equipment curves

— Evaporation and blowdown; a Legionella control program

— Reclaimed supply needs chemistry and discharge rights; potable demand can provoke basin opposition

— Seasonal supply and drought limits can constrain the delivered cooling duty

Closed-loop / dry (zero-evap)

— Non-evaporative rejection cuts process-water demand

— Hot-weather electrical duty follows the equipment curves

— Heat-rejection footprint, capital and maintenance still count

— Closed TCS/FWS loops do not prove dry heat rejection

SO WHAT

The plant fixes long-lived water rights, hot-weather electrical duty and maintenance exposure. Price annual bins and drought operation before committing.

DESIGNING IT OUT

~0.27 L/kWh

Microsoft's FY2025 cooling-and-humidification WUE

FY25 WUE: 0.27 L/kWh, full-year owned/controlled fleet. The separate December 2024 design estimate exceeds 125 ML avoided cooling water per site; pilots target 2026.

MICROSOFT DATACENTERS, MEASURING ENERGY AND WATER EFFICIENCY, FY25 TABLE AND METHODOLOGY · AS-OF FY2025 (2024-07-01–2025-06-30)

ACT III

Close the loops: heat and embodied carbon

Waste heat is the only byproduct someone will pay to take away, and the carbon locked into concrete and silicon is the emission no operations team can meter. Both are decided years before the first server boots.

HEAT SOMEONE PAYS FOR

Reuse at city scale — and by mandate

~113 GWh (2025, reported)

Stockholm’s Open District Heating: heat recovered in 2025 (reported)

TIDNINGEN ENERGI, AUGUST 2026, AS REPORTED BY KURIR, 2026-10-13 · AS-OF 2025

~100,000 MWh/yr

Heat Meta's Odense facility was set to deliver each year (2020 target)

FACEBOOK ENGINEERING, 2020-07-07 · AS-OF 2020-07

10% / 15% / 20% by applicable start-date cohort

Germany's mandatory reuse factor for new data centers — rising through 2028

GERMAN FEDERAL MINISTRY OF JUSTICE · AS-OF 2023-11-13

HEAT GRADE IS THE MASTER VARIABLE

80–100 °C

What a conventional district-heating network needs — set against your loop temperature

Any return below it carries a heat-pump lift whose electricity eats into the delivered energy. The loop temperature you choose for cooling silently prices every reuse deal for the building's life.

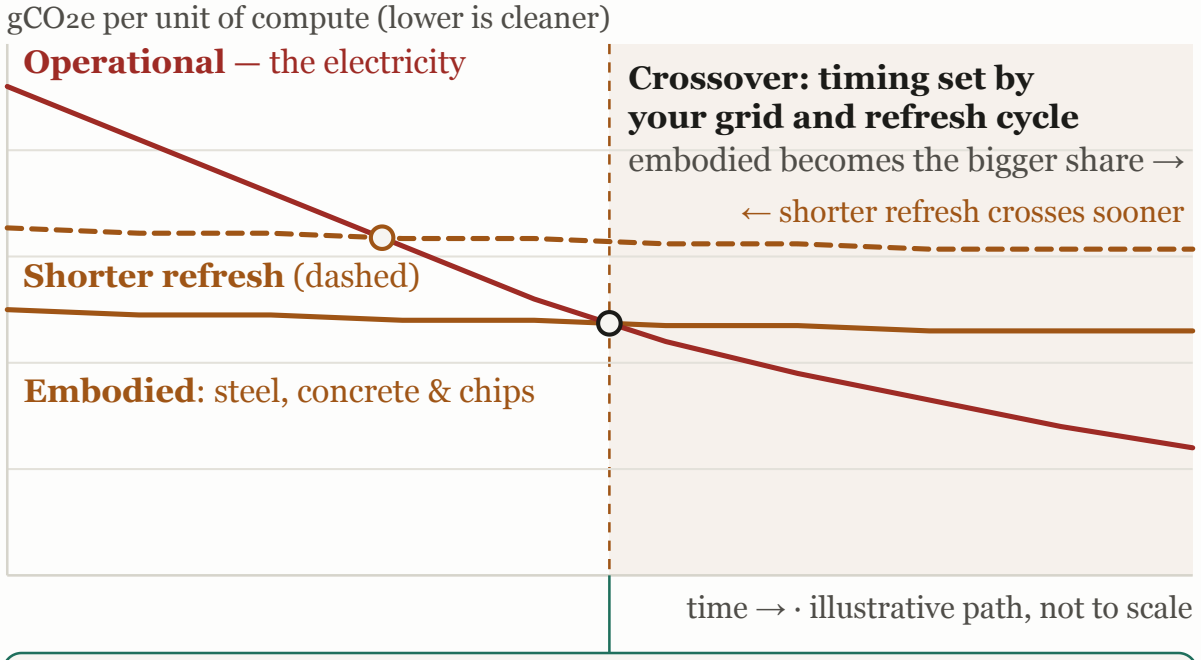
IEA DHC ANNEX TS1 FINAL REPORT · AS-OF 2017 IEA DHC REFERENCE

THE CLEAN-GRID PARADOX

When embodied carbon becomes the larger term

Embodied carbon can overtake operational

Carbon per unit of compute over time: on clean power, building can outweigh running.



On clean power, **the carbon spent building the thing can dominate.**
The levers that matter become refresh cadence and low-carbon construction.

Schematic · Source: Guide synthesis · as of August 2026

At the same delivered service, lower operating emissions make manufacturing a larger share; replacing hardware sooner can then increase lifecycle emissions.

THE EMBODIED LEDGER

Carbon you can't meter at the meter

50-80%

Embodied share of a building's whole-life emissions on clean power

ONE CLICK LCA, AS CITED BY OPNA · AS-OF 2025

18-36 mo

An aggressive first-owner refresh case — re-paying manufacturing carbon every cycle

GUIDE SCENARIO · AS-OF 2026

92%

Microsoft's server reuse-and-recycle rate — circularity as a measured program

MICROSOFT · AS-OF FY2025

ACT IV

The regulator and the grid

Disclosure became a design input, and the grid started paying for flexibility. The last two chapters decide what you must prove — and what you can sell.

VOLATILE — ENGINEER AGAINST THE DURABLE LINES ONLY

The 2026 disclosure map

REGIME	TRIGGER	STATUS, MID-2026
EU EED Article 12	Any EU site over the IT-power threshold	Live — records confidential, aggregates published; a pending rating act would add public per-site labels
California SB 253	Doing business in CA over the revenue bar	First Scope 1/2 report due; companion SB 261 under injunction
US SEC climate rule	(Was) large filers	2024 rule stayed; May 2026 full-rescission proposal pending in the chapter's dated record
GHG Protocol Scope 2	Every market-based claim	Hourly and deliverability proposals are not operative rules; joint-standard publication targeted for Q4 2028

FLEXIBILITY IS THE NEW CAPACITY

~98 GW

New load the existing US grid could absorb at half a percent annual curtailment

A studied curtailment envelope can use capacity unavailable to a firm peak request. Submit it with the interconnection request and price the resulting service terms.

DUKE NICHOLAS INSTITUTE, RETHINKING LOAD GROWTH, FEBRUARY 2025 · AS-OF 2025-02-11

THE TRADE, PRICED

What flexibility can unlock in practice

18 / 15 / 10 GW

Curtailment-enabled headroom at 0.5% in PJM, MISO, and ERCOT

DUKE NICHOLAS INSTITUTE, RETHINKING LOAD GROWTH, FEBRUARY 2025 · AS-OF 2025-02-11

~1 GW

Demand-response capacity Google has already contracted across US utilities

GOOGLE INFRASTRUCTURE BLOG · AS-OF 2026-03

Dec 18, 2025

FERC's Dec 2025 PJM direction: three limited-draw services; rights need effective tariff

FEDERAL ENERGY REGULATORY COMMISSION, DECEMBER 18, 2025 FACT SHEET ON PJM CO-LOCATION · AS-OF 2025-12-18

TAKE IT HOME

What to do Monday

01 Commission against a metric stack — PUE pinned by WUE, ERF, REF, and a useful-work denominator — with auditable boundaries.

02 Bank efficiency at scoping: cooling architecture, warm-water setpoint class, and power-chain topology are irreversible forks.

03 Decide matching granularity before contracting power — 24/7 hourly CFE changes who you sign with and what clean-firm you chase.

04 Resolve hot-day input, consumption, chemistry, discharge and drought rights before choosing evaporative or dry rejection.

05 Treat heat reuse and ERF as build-time decisions — loop temperature and offtaker proximity cannot be retrofitted cheaply.

06 Put embodied carbon and circularity in procurement terms — EPDs, recycled-content floors, take-back clauses — not the ESG report.

07 Price flexible service where the tariff and tenant rights allow it; include lost work, recovery, protected reserve and penalties.

THE DEFINITIVE GUIDE TO

AI Data *Centers*

This deck is the map. The guide is the territory — every number here is dated, sourced, and kept current in the full chapters.

Ch 15.1 The post-PUE metric stack and the boundary games

Ch 15.3 24/7 CFE, clean-firm procurement, and the Scope 2 hinge

Ch 15.4 The evaporate-or-design-out water fork, basin by basin

Ch 15.8 Firm vs flexible interconnection and grid services

READ THE FULL PART, WITH EVERY SOURCE AND DERIVATION, AT AIDATACENTERGUIDE.COM

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About these figures

Figures are resolved by reference from the guide's claim register at build time (Second edition · September 2026 (first published July 2026)) — a number appears here only as it appears, dated and sourced, at aidatacenterguide.com. Newer data may exist: check the live register.