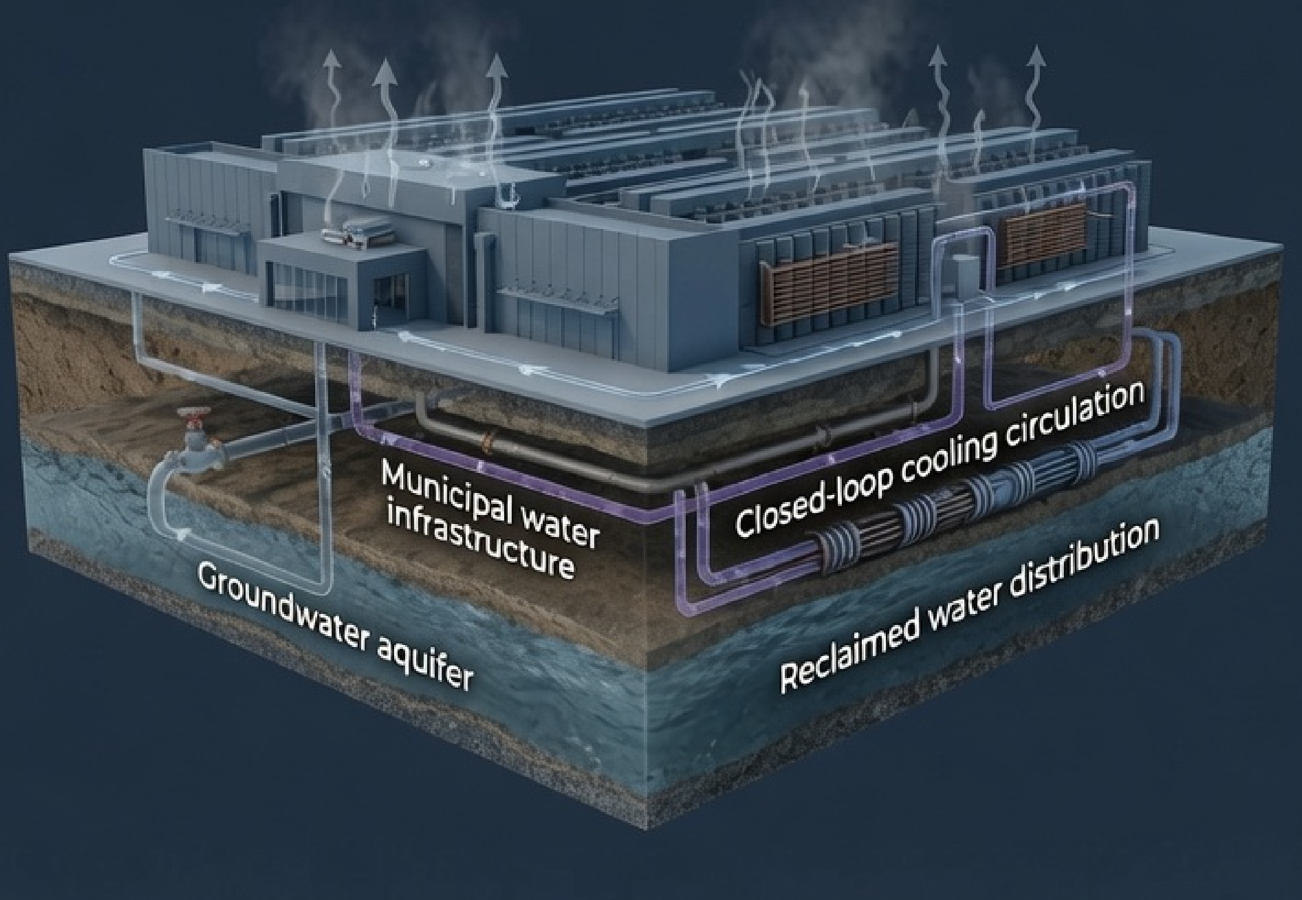
Data Centers, Water, and the Thermodynamic Record

A Technical Brief for the Informed Public.



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Abstract

Public concern over data center water and energy consumption has generated a significant volume of misinformation, much of it rooted in legitimate but misapplied anxiety about environmental stewardship. This document establishes the thermodynamic and industrial record on three core questions: whether data centers "destroy" water, whether their cooling systems pose a net threat to local water tables, and whether the industry is technologically converging toward zero-impact operation. The short answers are no, conditionally yes (a localized infrastructure problem, not a planetary one), and yes at an accelerating rate. What follows is the technical basis for each of those conclusions.

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1. Framing the Problem Correctly

Before evaluating impact, the nature of the concern must be precisely stated. The claims circulating in public discourse fall into two categories:

Legitimate local concerns:

- Aquifer and water-table draw-down in regions where data centers pull from limited groundwater
- Aesthetic and quality-of-life disruption when large industrial facilities are sited adjacent to residential areas
- Municipal infrastructure strain from very large facilities drawing on shared water systems

Scientifically unsupported claims:

- That data centers "destroy" or "consume" water in any permanent sense
- That industrial cooling meaningfully alters the global water supply
- That the industry is uniformly resistant to reform

This document addresses both categories honestly. The legitimate concerns are real and deserve thoughtful local policy responses. The scientifically unsupported claims require correction.

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2. The Water Myth: Phase Change Is Not Destruction

The single most important clarification in this entire discussion is thermodynamic: **data centers do not destroy water.**

Water destruction would require splitting the H_2O molecule into hydrogen and oxygen gases through electrolysis or combustion — a process that is not occurring in any commercial data center cooling system. What actually happens is a **phase change**: liquid water is converted to water vapor via absorbed heat and released into the atmosphere.

This is chemically and physically identical to what the sun does to a lake surface. The mechanism is the same; only the scale and location differ.

The Borrow-and-Return Cycle

Water vapor has an atmospheric residence time of approximately **8 to 10 days**, governed by the Clausius-Clapeyron relation — the thermodynamic law describing the relationship between temperature and the maximum moisture air can hold. Once saturation is reached, water condenses and returns to the surface as precipitation, typically within that 8-to-10-day window and generally downwind of the source.

This is in sharp contrast to carbon dioxide, which is non-condensable at Earth's atmospheric temperatures and accumulates for centuries. Water vapor is self-limiting: it cannot accumulate indefinitely because the atmosphere self-corrects through precipitation. Every gallon evaporated from a cooling tower is borrowed from the local water cycle and returned to Earth within days.

The Global Water Balance

The Earth's hydrological system handles an estimated 496,000 cubic kilometers of evaporation per year — approximately **359 trillion gallons per day** driven by solar energy alone. The entire U.S. data center industry's evaporative output (50 to 200 million gallons per day) represents a fraction too small to express meaningfully against that baseline. The global volume of water is, for all practical purposes, constant.

Note on the real driver of atmospheric moisture: The mechanism that actually increases global atmospheric water vapor is not industrial steam emission but planetary warming from long-lived greenhouse gases. For every 1°C of mean surface temperature increase, the atmosphere can hold approximately 7% more water vapor (Clausius-Clapeyron). This is a distinct and important issue — but it is a consequence of carbon emissions, not a consequence of data center cooling towers.

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3. Nuclear and Data Center Water Volumes in Perspective

To ground the comparison, a brief look at the two largest industrial water users in the energy and compute sectors.

Nuclear Power

The United States operates approximately 95 reactors across roughly 54 nuclear power plants. Large reactors using once-through cooling (drawing directly from a river or ocean, passing water through the plant, and returning it — as San Onofre did on the California coast) move roughly **400,000 to 600,000 gallons per minute per**

reactor through the system, depending on reactor size and design. The World Nuclear Association documents this range, and NRC technical specifications for the GE BWR-4 design confirm a total circulating water flow of 573,600 gallons per minute for that reactor class specifically. Using a representative figure of 500,000 gallons per minute across 95 reactors yields a theoretical maximum circulation of approximately **68.4 billion gallons per day**.

Critically: this is **flow**, not consumption. The vast majority of that water is returned to its source at a slightly elevated temperature. Evaporative loss in once-through systems is a small fraction of total flow. Reactors using cooling towers (which recirculate water in a closed loop and only lose water to evaporation) consume far less per unit of generation.

AI Data Centers

The entire U.S. data center industry directly consumes an estimated **50 million to 200 million gallons of water per day** through evaporative cooling processes — water that does not return to the source. Individual hyperscale AI facilities can each draw up to **5 million gallons per day**.

The difference in scale is real and significant: nuclear flow rates dwarf data center consumption numerically. But the more useful comparison is against the **local water system**, not the global one — which is where the legitimate concern lives.

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4. The Legitimate Local Issue: Infrastructure Bottlenecks

The water-table draw-down concern is valid but requires precise framing. If a data center pumps millions of gallons per day from a small regional aquifer faster than the aquifer's natural recharge rate, the local water table drops. This is:

- **Not permanent water destruction** — the water has not left the planet; it has left the local ground
- **A real infrastructure and resource-allocation problem** — one with documented precedent in regions like the American Southwest
- **Entirely solvable with existing technology** — and increasingly being solved by the industry itself

The correct policy target is **siting regulation and sourcing requirements**, not blanket opposition to data center construction.

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5. The Purple Pipe Solution: Turning Sewage Into a Resource

The most compelling counterpoint to the water-drain narrative is what a growing segment of the industry is actually doing: **treating municipal sewage as a resource rather than competing with drinking water at all.**

How Reclaimed Water Systems Work

1. **Intake:** Instead of tapping potable municipal water supplies, the facility connects to the outfall of a local wastewater treatment plant, ingesting treated sewage effluent that would otherwise be discharged into local waterways.
2. **On-Site Purification:** The data center treats this water further using advanced filtration and reverse osmosis, bringing it to the purity standards required to prevent scaling and corrosion in cooling equipment.
3. **Evaporative Use:** A portion of the now-purified water enters the evaporative cooling loop and exits as water vapor.
4. **Blowdown Return:** The remaining water, concentrated with natural minerals from evaporation cycles, is treated to remove contaminants and **returned to the municipal system** — cleaner than it arrived.

The net effect: the facility intercepts a waste stream, extracts the cooling utility from it, and returns clean surplus water to the municipality. The local drinking water supply is not touched.

Industry Adoption

Amazon Web Services (AWS) has deployed this reclaimed wastewater architecture — often called “purple pipe” infrastructure for the color of the pipes used to differentiate reclaimed from potable water — at documented scale. As of mid-2026, AWS operates **26 US data centers running on 100% reclaimed water**, part of a broader global footprint of **24 facilities worldwide** already on recycled water supply. The company is expanding this program to **120+ US locations by 2030**. AWS reports that this infrastructure has preserved **530 million gallons of drinking water annually** that would otherwise have been drawn from municipal potable supplies. Google has implemented similar programs. These are operational, verified deployments — not sustainability pledges. *(Source: Amazon Sustainability, Natural Resources/Water — sustainability.aboutamazon.com/natural-resources/water)*

The existence of this model should significantly reshape the public conversation. The question communities should be asking is not “should we allow data centers” but “should we require purple pipe sourcing for all new data center construction near municipal centers.” The technology exists and is already proven at scale.

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6. Closed-Loop Cooling: The Physics-Forced Transition

The most consequential development in data center infrastructure is a transition being driven not by environmental altruism but by **the physics of modern AI hardware**. This distinction matters for public communication: the industry is not cleaning up its act because of public pressure alone; it is being forced to by thermodynamics.

The Air Cooling Wall

Legacy data center cooling relied on moving large volumes of cold air across server racks. This approach has a hard physical limit: air cooling becomes inadequate at approximately **30 to 35 kilowatts per rack**.

Modern AI compute clusters packed with dense GPU arrays are running at **40 to well over 100 kilowatts per rack**. Air simply does not have the thermal mass to carry that much heat away fast enough. Facilities that attempt to run next-generation AI hardware on air cooling face hardware throttling, failure rates, and efficiency losses that make the approach economically nonviable.

The shift to liquid cooling is, therefore, a structural inevitability — not a choice.

The Two Leading Technologies

Direct-to-Chip (DTC) Liquid Cooling Coolant is routed through sealed cold plates bolted directly to the processor package. Heat transfers into the liquid (which has orders of magnitude greater thermal mass than air), and the now-hot liquid is pumped to a remote heat exchanger where it is cooled and recirculated. The system is sealed; no water contacts the outside environment.

Immersion Cooling Server hardware is submerged in specialized dielectric fluid (electrically non-conductive). Heat transfers directly from all surfaces of the hardware into the surrounding fluid. The fluid is then circulated through a sealed heat exchanger. No air movement is required whatsoever; fans are eliminated entirely.

Both technologies operate as **completely sealed loops**. There is no evaporative surface. There is no atmospheric discharge. The Water Usage Effectiveness (WUE) metric — liters of water consumed per kilowatt-hour of IT load — is **0.0** for a properly sealed system.

Efficiency Comparison

Metric	Traditional Evaporative Air	Direct-to-Chip Liquid	Immersion Cooling
Water Consumption	2M–5M Gal / MW / Year	~0 (Sealed)	~0 (Sealed)
Power Usage Effectiveness (PUE)	1.40–1.60	1.15–1.30	1.05–1.15
Cooling Energy (% of total)	30–40% of facility power	1–3% of facility power	<1% of facility power
WUE (L/kWh)	1.0–2.0	~0.0	~0.0

The cooling energy reduction of 25 to 40 percent from a legacy air-cooled facility to a modern closed-loop facility translates directly into lower grid demand and lower operating cost. Closed-loop is not a premium sustainability feature — it is the economically dominant architecture for high-density compute.

The Capital vs. Operating Cost Equation

Closed-loop infrastructure carries a CAPEX (capital expenditure) premium of approximately **5 to 15 percent** over equivalent air-cooled construction. Specialized dielectric immersion fluids alone can run from $9,600 to $60,000 per tank depending on chemical formulation.

However, a 10-year Total Cost of Ownership (TCO) analysis consistently shows closed-loop systems are **cheaper over time** once rack density exceeds 40–50 kW — which all new AI compute facilities do. The 25–40% reduction in cooling energy cost absorbs the capital premium within the first few operating years.

The economics and the environmental outcomes are aligned. This convergence is what makes the closed-loop transition durable rather than dependent on regulatory pressure or corporate virtue signaling.

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7. Refrigerant Evolution: The Regulatory and Engineering Baseline

One specific technical concern that arises in community discussions involves the refrigerants used in large-scale cooling equipment. It is worth establishing the current regulatory and engineering reality clearly.

What Data Centers Actually Use (and Don't)

A common point of confusion: **R-404A is not ammonia**. R-404A is a synthetic hydrofluorocarbon (HFC) blend composed of R-125, R-143a, and R-134a. It was designed for commercial low-temperature refrigeration (supermarket freezer cases, not HVAC or data center cooling). It was not a standard data center refrigerant even before the current phase-down.

Ammonia (R-717) is a natural refrigerant with entirely different chemistry. It is used in large industrial chiller plants — kept in sealed, remote mechanical rooms specifically because of its toxicity. It has never been used in direct server cooling.

The Regulatory Phase-Down

Under the EPA's American Innovation and Manufacturing (AIM) Act, high-Global Warming Potential (GWP) HFCs are subject to aggressive phase-down. R-404A carries a GWP of 3,920 — meaning over a 100-year period it is 3,920 times more potent as a greenhouse gas than CO_2 by mass. Its phase-out from new commercial refrigeration installations is underway.

The AIM Act's Technology Transitions rules require data center cooling, computer room air conditioning (CRAC), and IT equipment chillers to migrate to refrigerants with GWP below 700 for new installations. *Note: EPA proposed targeted relief from certain Technology Transitions requirements in 2025–2026 (docket EPA-HQ-OAR-2025-0005); the overall HFC phase-down direction and GWP thresholds remain in force, but specific implementation timelines for some subsectors are under regulatory revision. Operators and local jurisdictions should consult current EPA guidance* *at epa.gov/climate-hfcs-reduction/technology-transitions-hfc-restrictions-sector.* The dominant modern alternatives are:

- **R-32** — GWP 675; highest thermal capacity among compliant synthetic options
- **R-454B** — GWP 466; balanced performance, tracking close to the legacy R-410A it replaces
- **R-1233zd(E) / R-1234ze** — Hydrofluoroolefins (HFOs) with GWPs near or equal to 1; used in large centrifugal chillers at the facility level

Thermal Performance Comparison

Understanding why the industry uses specific refrigerants requires a look at liquid specific heat capacity — how much thermal energy a fluid can absorb per unit of mass. Higher is better for cooling efficiency.

Refrigerant	Type	Liquid Specific Heat at 25°C (kJ/kg·K)	Status
R-717 (Ammonia)	Natural	~4.78	Industrial chiller plants only; toxic
R-32	A2L HFC	~1.91	Modern compliant choice; mildly flammable
R-454B	A2L Blend	~1.68	Transition fluid replacing R-410A
R-410A	Legacy HFC	~1.65	Phasing out; exceeds GWP threshold
R-404A	Legacy HFC	~1.54	Phasing out; not a DC refrigerant anyway
R-1233zd / R-1234ze	HFO	~1.18–1.39	Near-zero GWP; large centrifugal chillers

The industry is legally and technologically transitioning to compliant alternatives. This is not a future commitment — it is current procurement reality for any operator building or retrofitting facilities today.

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8. The Thermodynamic Synergy: Waste Heat as an Asset

Perhaps the most intellectually underappreciated development in this space is the emerging ability to **treat a data center's waste heat as a recoverable energy resource** rather than an environmental liability.

The Fundamental Identity

Every watt of electricity fed into a data center — into CPUs, GPUs, memory, networking — eventually degrades into thermal energy. A data center is, thermodynamically, a very sophisticated resistor. The power-to-heat ratio is an exact **1:1**: 1 watt of electrical input produces 1 watt of heat output, without exception.

This is in inverse contrast to a power plant, which attempts to convert heat *into* watts at an efficiency of approximately 35 to 50 percent (meaning 50 to 65 percent of the fuel energy is immediately wasted as heat into the environment).

Process	Input	Output	Efficiency Metric
Power Plant	High-grade heat (combustion/fission)	Electricity	Thermal efficiency: 35–50%
Data Center	Electricity	Computation + Heat (1:1)	PUE: 1.02–1.15 ideal

The Organic Rankine Cycle (ORC): Closing the Loop

Because data center waste heat is relatively low-temperature (35°C–70°C depending on cooling architecture), conventional steam turbines cannot use it — water's boiling point is too high. Instead, engineers use an **Organic Rankine Cycle**: a working fluid with a much lower boiling point is vaporized by the data center's waste heat, expands through a small turbine to generate electricity, then condenses and repeats the cycle.

At a waste heat temperature of 65°C (achievable with direct-to-chip liquid cooling), a specialized low-temperature ORC turbine operates at a thermal efficiency of approximately **5 to 8 percent**. This sounds modest but represents a profound shift in economic logic:

- Before closed-loop cooling: waste heat was low-grade (30°C air), thermodynamically useless, and cost additional electricity to remove
- After closed-loop cooling: waste heat exits as 65–70°C liquid, which can drive an ORC turbine

For a 100-megawatt data center facility, this translates to approximately **5 to 7 megawatts of continuous recovered power** — effectively free electricity that feeds back into the facility's own grid or local microgrid.

A secondary and already-deployed application is **district heating**: the hot liquid loop is piped to adjacent municipal buildings, greenhouses, or industrial facilities that need low-grade heat. Several European deployments (particularly in Scandinavia and Finland) already operate this model at commercial scale. The data center becomes a thermal utility for its neighbors rather than a thermal burden on them.

The Expansion Valve Replacement (Power Recovery)

A second, smaller-scale crossover: in standard refrigeration cycles, the expansion valve drops refrigerant pressure through simple throttling — wasting the pressure differential as friction and turbulence. Engineers are replacing expansion valves with **two-phase micro-turbines** that capture that pressure drop as mechanical work, converting it back into electricity to help power the compressor. This is a within-cycle efficiency gain that does not require external infrastructure.

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9. Energy Self-Sufficiency and the Grid Transition

Current Reality

Modern data centers remain substantially dependent on the public utility grid. However, a structural transition toward localized generation is accelerating — driven not by environmental mandates alone but by the fact that grid provisioning in high-demand regions cannot keep pace with AI infrastructure buildout timelines.

Northern Virginia alone hosts the world's highest concentration of data center capacity, and utility queues for large power connections now stretch years. Operators that cannot wait are building around the grid.

The Microgrid Model

The emerging architecture pairs on-site generation with grid connection in a hybrid microgrid:

- Large rooftop and adjacent solar arrays for daytime offset
- Utility-scale battery storage (4–8 hours of backup capacity)
- On-site natural gas or landfill gas generation for continuous baseline coverage
- Grid connection as a supplement and emergency backup rather than primary source

Industry projections (Uptime Institute, various operator sustainability reports) suggest that approximately **30 percent of data centers will utilize on-site generation as their primary power source by 2030** — though this figure should be treated as an industry estimate rather than a hard forecast.

The Frontier Technologies

Hydrogen Fuel Cells: Microsoft has two documented hydrogen fuel cell pilots at data center facilities. The first, launched in late 2024 in partnership with ESB (Ireland's national energy utility), deployed a **250-kilowatt proton exchange membrane (PEM) fuel cell running on certified green hydrogen** at Microsoft's Dublin data center campus — the first step toward a complete zero-emission fuel supply chain in a key European market. The second, demonstrated in December 2025 in partnership with Caterpillar, involves a **3-megawatt hydrogen fuel cell system** providing over 48 hours of continuous backup power to a data center in **Cheyenne, Wyoming**. Both pilots represent a commercial inflection point: Microsoft is transitioning from validating the technology's viability to scaling prime power deployment. Fuel cells generate electricity through an electrochemical reaction (hydrogen + oxygen → water

+ electricity) with no combustion and zero CO_2 at point of use. *(Sources: Microsoft News, September 2024; Carbon Credits, September 2024)*

Small Modular Reactors (SMRs): Several hyperscalers have signed power purchase agreements or made direct investments in SMR development companies with the intent to site reactors directly adjacent to data center campuses. SMRs generate zero-carbon electricity at a scale (20–300 MW) well-matched to large individual facilities. This represents a potential full-circle convergence: the data center and the nuclear plant — both of which have faced public concern over resource consumption — become co-located infrastructure, with the reactor's waste heat potentially feeding the data center's ORC recovery loop.

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10. Policy Recommendations for Communities and Local Government

The technical record supports a nuanced and productive policy framework — one that neither blanket-bans data center development nor ignores legitimate local concerns.

What communities should require of new data center construction:

1. **Sourcing disclosure and aquifer protection:** New facilities near municipal water systems or in water-stressed regions should be required to document their water source and demonstrate that their draw rate does not exceed local aquifer recharge rates.
2. **Purple pipe mandates in suburban and peri-urban zones:** Where municipal wastewater infrastructure exists, require new data centers to draw from reclaimed effluent rather than potable water supplies. This is a proven, commercially available requirement — not a speculative ask.
3. **Closed-loop or dry-cooling mandates in arid regions:** Where water is genuinely scarce, require waterless cooling architectures. The technology exists and is already the economic optimum for high-density AI compute.
4. **GWP-compliant refrigerant requirements:** Require new facilities to use refrigerants meeting EPA AIM Act GWP thresholds (<700) regardless of whether the facility is in a jurisdiction that has adopted those rules by default.
5. **Waste heat utilization review:** For facilities above a threshold size (e.g., >50 MW), require an assessment of whether waste heat recovery (district heating, ORC generation) is viable given local geography and municipal infrastructure. Do not mandate it unconditionally, but require it to be evaluated.

What communities should not do:

- Oppose data center development on the basis that it "destroys" water — this is not supported by thermodynamics
- Apply uniform water-use concerns to facilities that are already using reclaimed wastewater
- Treat all data center cooling architectures as equivalent when the industry is actively differentiating between legacy and next-generation designs

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11. Conclusion

The narrative that data centers are quietly drying up the planet does not survive contact with the thermodynamic record. Water is not destroyed in cooling systems; it is phase-shifted and returned to the local water cycle within days. The global water volume is constant. Industrial steam does not accumulate in the atmosphere. These are not opinions; they are physical laws.

The legitimate concerns are local, infrastructural, and solvable: aquifer draw-down in water-stressed regions, aesthetic and quality-of-life impacts in residential zones, and municipal infrastructure strain. These deserve genuine policy attention — and increasingly, industry is getting ahead of them through reclaimed water sourcing, closed-loop cooling, and on-site power generation.

The technology trajectory is unambiguous. Closed-loop liquid cooling is becoming the structural baseline for AI infrastructure because the hardware demands it. The refrigerant chemistry is being reformed by regulation and physics simultaneously. The waste heat that was once a pure liability is becoming a recoverable asset through ORC generation and district heating. The grid dependency that made data centers vulnerable to public opposition is being partially displaced by on-site microgrids and, on the frontier, SMRs.

The honest brief for social media thinkers is this: the water destruction story is a myth, the environmental transformation is real and accelerating, and the productive community response is informed, specific policy engagement — not categorical opposition built on thermodynamic misunderstanding.

Appendix: Key Terms

Clausius-Clapeyron Relation — Thermodynamic equation describing the maximum water vapor the atmosphere can hold at a given temperature. Governs why water vapor self-limits through precipitation.

District Heating — System where waste heat from industrial processes is piped to nearby buildings for space heating or hot water, converting a liability into a shared utility.

Dielectric Fluid — Electrically non-conductive liquid used in immersion cooling; allows direct contact between fluid and energized electronics without short circuits.

Global Warming Potential (GWP) — Measure of how much heat a greenhouse gas traps over 100 years relative to CO_2 (GWP = 1). R-404A has GWP of 3,920; R-1234ze has GWP near 1.

Organic Rankine Cycle (ORC) — Power generation cycle using a low-boiling-point organic fluid instead of water/steam, enabling electricity generation from low-grade heat sources (35–150°C).

Power Usage Effectiveness (PUE) — Total facility power divided by IT equipment power. PUE of 1.0 = perfect (impossible); 1.5 = 50% of power goes to overhead; 1.05 = 5% overhead.

Purple Pipe — Industry term for reclaimed/recycled wastewater infrastructure. Named for the color convention used to identify non-potable reclaimed water distribution pipes.

Water Usage Effectiveness (WUE) — Liters of water consumed per kilowatt-hour of IT load. A sealed closed-loop system achieves WUE = 0.0.

This document was prepared as a public reference brief. All thermodynamic values are derived from peer-reviewed sources and published engineering standards. Industry adoption statistics and forward projections are drawn from operator sustainability reports, Uptime Institute surveys, and ASHRAE thermal guidelines and should be treated as estimates subject to revision. Regulatory references reflect EPA AIM Act rulemaking as published through mid-2026.

Appendix: Citations and Source References

1. AWS Purple Pipe / Reclaimed Water Program

Claim: 26 US data centers on 100% reclaimed water as of mid-2026; 120+ US locations by 2030; 530 million gallons of drinking water preserved annually. **Source:** Amazon Sustainability — Natural Resources / Water **URL:** https://sustainability.aboutamazon.com/natural-resources/water

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2. Nuclear Once-Through Cooling Flow Rates

Claim: 400,000–600,000 gallons per minute per reactor; representative average ~500,000 gal/min. **Primary Source:** World Nuclear Association — "Cooling Power Plants" **URL:** https://world-nuclear.org/information-library/current-and-future-generation/cooling-power-plants

Supporting Source (NRC Technical Specification): GE BWR-4 Circulating Water System — confirms 573,600 gallons per minute total flow for that reactor class. **URL:** https://www.nrc.gov/docs/ML1125/ML11258A375.pdf

Additional Reference: Union of Concerned Scientists — "Water for Nuclear" (notes ~46% of US reactors use once-through cooling) **URL:** https://www.ucs.org/resources/water-nuclear

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3. EPA AIM Act — HFC Technology Transitions / GWP Thresholds

Claim: HFC phase-down under the AIM Act; GWP <700 threshold for data center cooling equipment. **Primary Source:** EPA — Technology Transitions HFC Restrictions by Sector **URL:** https://www.epa.gov/climate-hfcs-reduction/technology-transitions-hfc-restrictions-sector

Note on Regulatory Status: EPA proposed targeted relief from certain Technology Transitions requirements in 2025 (Docket: EPA-HQ-OAR-2025-0005). The overall HFC phase-down and GWP direction remain in effect; specific subsector timelines are subject to ongoing revision. **Docket URL:** https://www.regulations.gov/document/EPA-HQ-OAR-2025-0005-0001

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4. Data Center WUE / Energy Benchmarks

Claim: WUE industry norms; PUE ranges for evaporative vs. liquid-cooled facilities. **Primary Source:** Lawrence Berkeley National Laboratory — *2024 United States Data Center Energy Usage Report* **URL:** https://eta-publications.lbl.gov/sites/default/files/2024-12/lbnl-2024-united-states-data-center-energy-usage-report_1.pdf

Supporting Source: Uptime Institute — Annual Global Data Center Survey and WUE Analysis **URL:** https://uptimeinstitute.com/resources/research-and-reports

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5. Microsoft Hydrogen Fuel Cell Pilots

Claim: 250 kW green hydrogen PEM fuel cell pilot in Dublin (late 2024) and 3 MW system in Cheyenne, Wyoming (December 2025). **Source 1:** Microsoft News — "Microsoft announces pioneering green hydrogen pilot project with ESB" (September 2024) **URL:** https://news.microsoft.com/source/emea/2024/09/microsoft-announces-pioneering-green-hydrogen-pilot-project-with-esb/

Source 2: Carbon Credits — "Microsoft and ESB Launch Groundbreaking Green Hydrogen Pilot to Decarbonize Dublin Data Centers" (September 2024) **URL:** https://carboncredits.com/microsoft-and-esb-launch-groundbreaking-green-hydrogen-pilot-to-decarbonize-dublin-data-centers/

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