

# Community-Scale Fractal DC Network

## Component Sourcing + Prior Art Reference Map

Compiled April 19, 2026 — for “Innovating Out Loud” article. References only; article not included.

This document accompanies “[Behavior is the Barrier: The Time for the Regenerative Data Center of the Future is Now](#)” (Innovating Out Loud, April 19, 2026). It maps the commercially available components, regulatory openings, deployed proof points, and prior art that collectively support the community-scale fractal data center architecture described in the article.

What this is: A reference map. Every component listed is commercially available or in a defined regulatory process. Every claim has a public source.

What this isn't: A deployment plan. The integrated product does not yet exist. Assembling it requires coalition work across utilities, developers, communities, and capital — the behavior design problem the companion article describes.

## Layer 1: AI-Grade Compute + Liquid Cooling Modules

### Commercially Available Products

| Product                            | Vendor              | Power Tier       | Form Factor                     | Key Specs                                                                                                    | Availability                       |
|------------------------------------|---------------------|------------------|---------------------------------|--------------------------------------------------------------------------------------------------------------|------------------------------------|
| Eaton + Flexnode NX Compute Module | Eaton / Flexnode    | 3.5–35 MW        | Prefabricated modular data hall | 800 VDC power architecture; 35% faster deployment vs. stick-build; turnkey from grid to chip                 | Jan 28, 2026 — ordering open       |
| Vertiv OneCore                     | Vertiv              | 5–250+ MW        | Hybrid prefabricated            | Full power/cooling/IT integration; single data hall 1,500 m <sup>2</sup> / 944 racks; 50 MW reference design | Aug 5, 2025 — globally available   |
| Cannon T4                          | Cannon Technologies | 0.5–5 MW per pod | ISO-compatible modular pod      | Tier 4 resilience; underground/warehouse/greenfield deployable; pay-as-you-grow                              | 8–12 week lead time, ordering open |
| NVIDIA GB300 NVL72                 | NVIDIA / Supermicro | ~120 kW per rack | Rack-scale liquid cooled        | Warm-water DLC at 45°C supply; no chiller required; dry cooler heat rejection                                | Available now                      |
| NVIDIA Vera Rubin NVL72            | NVIDIA              | ~160 kW per rack | Rack-scale liquid cooled        | Successor to GB300; warm-water DLC; 72 Rubin GPUs; can heat ~160 homes per rack                              | H2 2026 shipping                   |

### Notes on Liquid Cooling (DLC at 45°C)

The GB300 and Vera Rubin NVL72 both support warm-water direct liquid cooling (DLC) at 45°C supply temperature — the threshold enabling dry-cooler (adiabatic) heat rejection without a chiller, and heat offtake to district systems above 50°C with a small heat pump boost. This eliminates the chiller capital cost entirely and is what makes the heat reuse interface viable at community scale.

## Layer 2: Grid-Interactive BESS + UPS Stack

### Commercially Available Products

| Product                                  | Vendor          | Scale                          | Key Specs                                                                                                                      | Availability                                       |
|------------------------------------------|-----------------|--------------------------------|--------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------|
| Vertiv EnergyCore Grid                   | Vertiv          | 5 MW+                          | Utility-grade BESS; designed for data center interconnection; North America; integrates with grid services                     | Dec 3, 2025 — North America available              |
| Vertiv EnergyCore Grid + CPower VPP      | Vertiv + CPower | 5 MW+                          | Behind-the-meter BESS enrolled as virtual power plant resource; demand response monetization platform                          | Apr 14, 2026 — commercially deploying              |
| Eaton UPS (9355 / 93PM series)           | Eaton           | 10 kW–4 MW per unit; stackable | Grid-interactive; bidirectional inverter; demand response capable; used in Eaton/Flexnode NX Compute modules                   | Deployed, commercially available                   |
| Verrus Grid-Interactive DC Architecture  | Verrus          | 2–20 MW                        | NREL-validated; novel power flow management; long-duration battery storage; CLR design; fastest grid interconnection in market | Commercially available; NREL validated Jun 2025    |
| Lancium CLR (Controllable Load Resource) | Lancium         | Grid-scale                     | Curtailable load management protocol; royalty-free license to ERCOT Apr 2025                                                   | ERCOT only (royalty-free); other markets — IP RISK |

### FERC Regulatory Context (Critical Timing)

- **FERC Docket RM26-4-000** — Large Load Interconnection rulemaking. Action deadline: end of June 2026. Curtailable loads proposed to receive expedited interconnection (as fast as 60 days vs. multi-year queue).
- **FERC ANOPR (Oct 23, 2025)** — DOE directed FERC to fast-track new rules; DOE set April 30, 2026 deadline (FERC slipped to June but actively moving).
- **SPP HILL program** — Hyperscale Interruptible Large Load program approved Jan 2026; first mechanism allowing curtailable interconnection in SPP territory. Already operational.
- **PJM revisions** — Ongoing; full mechanism expected ~2027.
- **Camus / Princeton flexible interconnection study** (Google-backed) — Blueprint submitted to FERC showing fast-track data center interconnection via demand flexibility commitments.
- **IFP Interconnection Principle 7** — FERC's proposed Principle 7 gives curtailable loads preferential queue treatment.
- **Duke University grid headroom report** — 76–126 GW of flexible load capacity exists on the US grid today, systematically underutilized.

## Layer 3: Inter-Cluster Networking (the Fractal Layer)

*This is the architectural inversion of Microsoft Fairwater: many small community nodes connected by the same AI WAN principle, acting as a distributed supercomputer.*

### Commercially Available Hardware

| Product                   | Vendor             | Throughput       | Reach          | Key Specs                                                                                                                                         | Availability                      |
|---------------------------|--------------------|------------------|----------------|---------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------|
| Cisco 8223                | Cisco              | 51.2 Tbps        | Up to 1,000 km | Silicon One P200; 800GE coherent optics; deep buffer for AI traffic bursts; post-quantum MACsec; scale-across architecture for inter-DC AI WAN    | Shipping to hyperscalers Oct 2025 |
| Broadcom Jericho4         | Broadcom           | 51.2 Tbps        | 100+ km RoCE   | 3.2 Tbps HyperPorts; 36,000 HyperPorts per system; RoCE v2 at 100 km+; interconnects 1M+ XPU; UEC-compliant; designed for smaller distributed DCs | Shipping Aug 4, 2025              |
| Nokia 7250 IXR-6e/10e/18e | Nokia              | Terabit-scale    | WAN            | Jericho4-based; data center spine + WAN deployment; modular fixed chassis                                                                         | Available                         |
| Zayo dark fiber           | Zayo               | 400G–800G        | National US    | ~130,000 route miles US; enterprise and hyperscale dark fiber leases                                                                              | Available; \$1.27B US market 2026 |
| Lumen dark fiber          | Lumen Technologies | 400G–800G        | National US    | Large US dark fiber footprint; infrastructure-as-a-service model                                                                                  | Available                         |
| Crown Castle fiber        | Crown Castle       | Metro + regional | Regional US    | Dense metro and regional dark fiber; strong community/edge coverage                                                                               | Available                         |

### Microsoft Fairwater Proof Point

- **What it demonstrates:** Wisconsin (Fairwater 1) + Atlanta (Fairwater 2), ~700 miles apart, connected via 120,000 miles of owned/repurposed dark fiber; MRC multipath routing protocol; functions as a single distributed supercomputer. Each site must be a “clean, well-structured unit” — the abstraction boundary that enables cross-site coordination.
- **The inversion:** Microsoft required hundreds-of-thousands-of-GPU megasites as nodes. The article’s argument is many small community inference clusters as nodes, connected by the same AI WAN principle — using hardware (Cisco 8223, Broadcom Jericho4) purpose-built for exactly this use case and commercially available today.
- **SPAN + NVIDIA XFRA (Apr 15, 2026)** — Further proof of edge-scale distributed inference: SPAN and NVIDIA announced “backyard AI data centers” with integrated batteries, starting Nevada/Arizona.

## Layer 4: Heat Offtake Interface Components

### Commercially Available Products

| Product                                      | Vendor             | Application                                 | Key Specs                                                                                    | Availability           |
|----------------------------------------------|--------------------|---------------------------------------------|----------------------------------------------------------------------------------------------|------------------------|
| Tranter GT-165 gasketed plate heat exchanger | Tranter            | District heating                            | LMTD as low as 1°K; optimized for district heating/cooling; high efficiency at 45–70°C range | Commercially available |
| SWEP brazed plate heat exchanger             | SWEP (Dover Corp.) | District heating / aquaculture / industrial | Ultra-compact; megawatt-scale models; district energy applications                           | Commercially available |

### Heat Reuse Deployed System References

- **Microsoft surplus heat → Holstebro district heating, Denmark (2024)** — Microsoft’s Esbjerg campus routes waste heat into the municipal district heating network, serving thousands of homes. Demonstrates the exact heat offtake model.
- **Mine water cooling (Data Center Ridge, Wise County VA)** — \$3M DOE grant to cool data centers with mine water at <55°F via closed-loop pool. Demonstrates the cold-source / thermal sink interface from the other direction.

### Technical Note on Heat Offtake at 45°C DLC

The GB300/Vera Rubin NVL72 warm-water DLC output (45°C supply, ~55°C return) sits at the edge of direct district heating usability. Most European district systems accept 60–75°C delivery. A small heat pump bridge closes the gap. At community scale (2–10 MW thermal), the Tranter GT-165 or SWEP brazed plate handles primary-to-secondary fluid isolation and temperature conditioning. Aquaculture and greenhouse applications are usable at lower temperatures (30–45°C) without any heat pump.

## Layer 5: Prior Art Map

### Patents — Modular Data Center Form Factor

| Patent           | Title                                | Assignee                 | Filed | Status                   | Relevance                                                                                                                                              |
|------------------|--------------------------------------|--------------------------|-------|--------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------|
| US7278273B1      | Modular data center                  | Google                   | 2003  | EXPIRED Jan 2024         | Foundational ISO container form factor — free to use. Establishes prior art baseline for all modular DC claims.                                        |
| US20090229194 A1 | Portable modular data center         | (multiple)               | 2008  | Expired / limited claims | Portable/truck-deliverable DC; overlaps System 1 form factor. Know what's in scope.                                                                    |
| US10853460B2     | Modular DC with moving rack assembly | Vapor IO                 | 2018  | Active                   | Truck-deployable, edge-deployable modular DC with rack mobility. Most relevant active patent to System 1 form factor. Review claims before publishing. |
| US20100251629 A1 | Modular Computing Environments       | (Microsoft / HP related) | 2009  | Expired                  | Early modular DC cooling systems; DLC precursor. Background prior art.                                                                                 |

### Patents — Liquid Cooling

| Patent                            | Title                                                        | Assignee      | Filed   | Status           | Relevance                                                                                              |
|-----------------------------------|--------------------------------------------------------------|---------------|---------|------------------|--------------------------------------------------------------------------------------------------------|
| US11825636B2                      | Integrated rack architecture for two-phase immersion cooling | (generalized) | ~2020   | Active           | Two-phase immersion rack integration. Distinguish from: System 1 uses single-phase DLC, not immersion. |
| US11895808B2                      | Intelligent refrigeration-assisted DC liquid cooling         | (generalized) | ~2021   | Active           | Refrigerant-assisted hybrid cooling; relevant to chiller-free DLC architecture.                        |
| US12200909B2                      | Rack form-factor reservoir for DC cooling                    | (generalized) | ~2022   | Active           | Fluid reservoir in rack form factor; DLC architecture component.                                       |
| US11399449B2                      | Server rack cooling arrangement                              | (generalized) | ~2020   | Active           | Rack enclosure cooling; sealed interior. Distinguish from: System 1 is open-air DLC, not sealed.       |
| Iceotope portfolio (200+ patents) | Precision immersion cooling                                  | Iceotope      | Various | Active — IP RISK | 109 granted, 99 pending as of 2025. If System 1 uses rack-level liquid cooling, audit for overlap.     |

### Patents — Grid Integration + Demand Response

| Patent          | Title                                                      | Assignee                 | Filed | Status | Relevance                                                                                                                                |
|-----------------|------------------------------------------------------------|--------------------------|-------|--------|------------------------------------------------------------------------------------------------------------------------------------------|
| CN105518964A    | Grid-interactive UPS with bidirectional battery-to-grid    | Eaton                    | 2014  | Active | Bidirectional UPS battery discharge to grid; foundational for UPS-as-BESS architecture. Eaton's own prior art.                           |
| WO2020236826 A1 | Grid Ancillary Service with UPS (GAUPS)                    | (academic/institutional) | 2020  | Active | Four-quadrant inverter UPS providing grid ancillary services; directly maps to the CLR-from-day-one design.                              |
| US10497072B2    | Optimal battery sizing for BTM demand response             | (Eaton-adjacent)         | ~2017 | Active | BTM BESS sizing methodology for demand response; foundational for sizing the BESS layer.                                                 |
| US9715261B2     | Continuous dynamic balancing of generation and consumption | (grid operator)          | ~2014 | Active | Centralized controller for curtailable load management across distributed loads. Background prior art for the fractal CLR control plane. |

| Patent                | Title                                                                                                | Assignee | Filed     | Status           | Relevance                                                                                                                                                                                                            |
|-----------------------|------------------------------------------------------------------------------------------------------|----------|-----------|------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Lancium CLR portfolio | Method and System for Dynamic Power Delivery; System of Critical Datacenters; Granular Power Ramping | Lancium  | 2017–2022 | Active — IP RISK | Most comprehensive active patent portfolio on DC CLR operation. Royalty-free ONLY in ERCOT (since Apr 2025). PJM, MISO, SPP: licensing required. Do not publish a commercial CLR architecture without flagging this. |

## Patents — Heat Reuse

| Patent      | Title                                               | Assignee              | Filed | Status | Relevance                                                                                                                           |
|-------------|-----------------------------------------------------|-----------------------|-------|--------|-------------------------------------------------------------------------------------------------------------------------------------|
| US8522569B2 | Utilization of DC waste heat for heat-driven engine | (academic/commercial) | 2009  | Active | Waste heat → adsorption chiller or heat-driven engine. System 1 uses simpler direct heat exchange — background reference, not risk. |

## Patents — Workload Distribution + Fractal Compute Network

| Patent          | Title                                                                      | Assignee      | Filed | Status  | Relevance                                                                                                                                                                                  |
|-----------------|----------------------------------------------------------------------------|---------------|-------|---------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| US11853936B2    | Minimizing environmental impact of workloads (DC migration for renewables) | Microsoft     | 2021  | Active  | Geographically distributed workload migration across DC nodes based on renewable availability. Directly maps to the fractal inference network's scheduling layer. Key Microsoft prior art. |
| US20090276771A1 | Globally Distributed Utility Computing Cloud                               | (generalized) | 2008  | Expired | Early distributed cloud computing architecture; background prior art establishing distributed node concept. Now in public domain.                                                          |

## Academic Papers

| Paper                                                                                                 | Authors / Source             | Published                             | Key Finding                                                                                                                                                                                    |
|-------------------------------------------------------------------------------------------------------|------------------------------|---------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| To Defer or To Shift? The Role of AI Data Center Flexibility on Grid Investment and Operational Costs | Princeton / Camus-affiliated | arXiv 2604.05376, Apr 7, 2026         | Geographically shiftable AI workloads reduce grid investment and operational costs by 3–21% — quantitative proof that the fractal network is simultaneously a compute asset and a grid asset.  |
| Demonstrating the Data Center as a Flexible Grid Asset                                                | NREL / Verrus                | NREL Technical Report 94844, Jun 2025 | NREL validates Verrus grid-interactive DC design; demonstrates CLR operation reduces interconnection time significantly; first independent validation of the grid-interactive DC architecture. |
| Concentrated Siting and Regional Power Stress                                                         | (arXiv)                      | arXiv 2604.06198, Apr 2026            | Concentrated hyperscale siting causes measurable regional grid stress; distributed siting is the structural countermeasure.                                                                    |
| Optimizing Resource Allocation for Geographically-Distributed Inference by LLMs                       | (academic)                   | arXiv 2512.21884, Dec 2025            | Multi-site inference optimization framework; establishes the scheduling theory for distributed inference nodes.                                                                                |
| Demand Response Opportunities and Enabling Technologies for Data Centers                              | LBNL / Grid Integration      | LBNL, 2023                            | 25% demand savings achievable at DC level with minimal operational impact; foundational for the demand response value case.                                                                    |

## Deployed Systems — Proof Points

| System                                              | Operator         | Location                      | Scale                  | What It Proves                                                                                                                                                                  |
|-----------------------------------------------------|------------------|-------------------------------|------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Fairwater AI Superfactory                           | Microsoft        | Wisconsin + Atlanta (~700 mi) | 100K+ GPUs             | Two physically separate DCs acting as a single distributed supercomputer via dedicated AI WAN (120K mi dark fiber, MRC multipath routing). The fractal principle at hyperscale. |
| Microsoft grid-interactive UPS, Dublin              | Microsoft        | Dublin, Ireland               | DC-scale battery fleet | DC UPS batteries providing grid frequency response to support wind farm integration. First major tech company deployment of grid-interactive UPS at DC scale.                   |
| Microsoft surplus heat → Holstebro district heating | Microsoft        | Esbjerg / Holstebro, Denmark  | Campus-scale thermal   | DC waste heat routed to municipal district heating network, serving thousands of homes. Direct proof of heat offtake interface at community scale.                              |
| Verrus grid-interactive DC (NREL-validated)         | Verrus           | Nevada (NREL validation)      | 2–20 MW                | First NREL-validated CLR data center; demonstrates grid interconnection in weeks, not years; production architecture for the BESS + CLR layer.                                  |
| Lancium CLR deployments, ERCOT                      | Lancium          | Texas (ERCOT)                 | Grid-scale             | Flexible DC operating as curtailable load at utility scale; CLR protocol now royalty-free within ERCOT via Apr 2025 license.                                                    |
| CoreSite Inference Zones                            | CoreSite         | US (multiple)                 | Edge colocation        | Commercial product framing distributed inference nodes as a distinct asset class — validates the market category the article is naming.                                         |
| SPAN + NVIDIA XFRA edge nodes                       | SPAN / NVIDIA    | Nevada / Arizona              | Sub-MW edge            | “Backyard AI data centers” with integrated batteries; Apr 15, 2026 announcement; validates the sub-community-scale fractal node concept.                                        |
| Data Center Ridge mine water cooling                | Energy Delta Lab | Wise County, VA               | 1 GW planned           | \$3M DOE-funded mine water cooling loop; validates the thermal interface between existing infrastructure and compute clusters.                                                  |

## IP Risk Summary

| Risk                                      | Detail                                                                                                                                                                       | Mitigation                                                                                                                                                                                       |
|-------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Lancium CLR portfolio                     | Active patents on flexible DC + CLR operation; royalty-free ONLY in ERCOT (Apr 2025 license). PJM, MISO, SPP require licensing or avoidance.                                 | Article should reference Lancium as a deployed proof point and note the IP landscape. Any commercial deployment outside ERCOT needs patent counsel.                                              |
| Iceotope immersion cooling portfolio      | 200+ patents (109 granted); active coverage of rack-level liquid cooling configurations.                                                                                     | System 1 uses warm-water DLC (not immersion). Audit overlap if the article describes any immersion variant.                                                                                      |
| Vapor IO modular DC (US10853460B2)        | Active patent on truck-deployable, rack-mobile modular DC.                                                                                                                   | System 1's form factor is modular but rack movement is not the claim. Review claims for overlap with flatbed-deliverable architecture.                                                           |
| Google modular DC (US7278273B1)           | EXPIRED Jan 2024. ISO container form factor, prior art base.                                                                                                                 | No risk — free to use, cite as baseline.                                                                                                                                                         |
| No one has patented the integrated system | The community-scale fractal inference cluster — as an integrated system combining modular compute + CLR BESS + heat offtake + inter-cluster AI WAN — has no existing patent. | Publishing the integrated thesis establishes prior art and timestamps the concept. This is a publication strategy, not a patent strategy, and publishing is the right move to get the work done. |

## Quick-Reference: All Sources

### Vendor / Product Announcements

- [Eaton + Flexnode NX Compute Module \(Jan 28, 2026\)](#)
- [Vertiv OneCore global availability \(Aug 5, 2025\)](#)
- [Cannon T4 lead times](#)
- [Vertiv EnergyCore Grid launch \(Dec 3, 2025\)](#)
- [Vertiv + CPower VPP collaboration \(Apr 14, 2026\)](#)
- [Broadcom Jericho4 shipping \(Aug 4, 2025\)](#)
- [Cisco 8223 shipping to hyperscalers \(Oct 8, 2025\)](#)
- [Nokia 7250 IXR datasheet \(PDF\)](#)
- [SPAN + NVIDIA XFRA edge nodes \(Apr 15, 2026\)](#)
- [NVIDIA Vera Rubin NVL72 \(H2 2026\)](#)
- [Tranter GT-165 heat exchanger](#)
- [SWEP brazed plate heat exchangers for district energy](#)

### Regulatory + Policy

- [FERC RM26-4-000 June 2026 deadline \(H&K\)](#)
- [FERC ANOPR \(DOE directive, Oct 2025\)](#)
- [IFP Interconnection for AI \(Principle 7\)](#)
- [Camus/Princeton flexible interconnection blueprint \(Google-backed\)](#)
- [Duke University grid headroom report \(76–126 GW\)](#)
- [Lancium + ERCOT royalty-free CLR license \(Apr 11, 2025\)](#)

### Academic Papers

- [arXiv 2604.05376 — Geographically shiftable AI workloads \(3–21% grid cost reduction\)](#)
- [arXiv 2604.06198 — Concentrated siting and regional power stress](#)
- [arXiv 2512.21884 — Distributed LLM inference optimization](#)
- [NREL 94844 — Verrus grid-interactive DC validation](#)
- [LBNL demand response opportunities for data centers](#)

## Deployed Systems

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- [Microsoft Fairwater AI Superfactory](#)
- [Microsoft grid-interactive UPS, Dublin \(Energy Storage News\)](#)
- [Microsoft surplus heat → Denmark district heating](#)
- [Verrus NREL validation](#)
- [CoreSite Inference Zones](#)
- [Data Center Ridge mine water cooling \(DCD\)](#)

## Patent Database Entries

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- [US7278273B1 — Google modular DC \(EXPIRED Jan 2024\)](#)
- [US10853460B2 — Vapor IO mobile modular DC](#)
- [US11853936B2 — Microsoft workload migration for renewables](#)
- [US8522569B2 — DC waste heat → heat-driven engine](#)
- [US11825636B2 — Integrated rack two-phase immersion cooling](#)
- [US10497072B2 — Optimal BTM BESS sizing for demand response](#)
- [WO2020236826A1 — Grid Ancillary UPS \(GAUPS\)](#)
- [CN105518964A — Eaton grid-interactive UPS \(bidirectional\)](#)
- [US9715261B2 — Continuous dynamic load balancing](#)
- [US20090276771A1 — Globally distributed utility computing cloud \(EXPIRED\)](#)

*All products confirmed commercially available as of April 2026 unless noted. Lancium IP risk applies to non-ERCOT markets. Iceotope cooling patent audit recommended if any immersion variant is discussed.*