



**INDUSTRY
OVERVIEW
SEGMENTS**

AIDATA CENTERS:

ADVANCED COOLING &
THERMAL MANAGEMENT FOR AI
DATA CENTERS

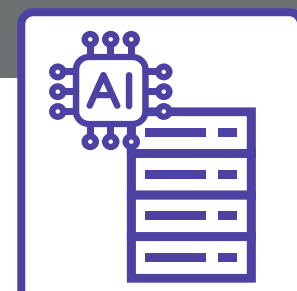
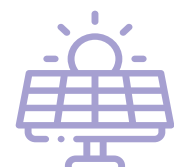
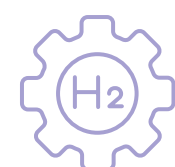
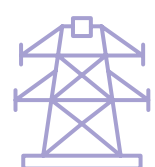


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Executive Summary

The explosive growth of AI data centers in the United States and worldwide is revolutionizing the cooling and thermal management manufacturing sector. Data centers require advanced, scalable, and highly energy-efficient cooling systems to dissipate the tremendous heat produced by high-density servers, graphics processing units (GPUs), and custom AI hardware.

The data center cooling market is projected to surge from around \$20 billion in 2024 to \$56 billion by 2030, driven by AI, high-performance computing, and hyperscale cloud deployments. Investments in cooling and thermal management doubled in the last year alone, underscoring the urgency to meet AI's unprecedented heat loads while achieving sustainability goals.

Key regional markets—such as Virginia, Texas, and California—are seeing accelerated development, with expansion also moving into less saturated rural areas. Even as industry opportunities abound, operators encounter challenges in regulatory compliance, land and resource use, and the integration of new technologies with legacy infrastructure. Technological innovation—especially in liquid cooling, direct-to-chip systems, and IoT-enabled maintenance—is rapidly advancing data center efficiency and environmental performance.

Cooling infrastructure includes a diverse variety of components: air economizers, cold aisle containment, precision air conditioners, in-row and rear-door cooling, dry coolers, direct-to-chip cold plates, immersion tanks, and thermal energy storage systems. Integral fluid handling, such as pumps, valves, and manifolds, alongside sophisticated sensors and monitoring systems, enables precise temperature regulation and leak detection.

This dynamic market creates significant opportunities for small and medium-sized manufacturers specializing in these components. As AI drives record demand for energy and water-efficient data centers, manufacturers able to deliver scalable, energy-saving, and ultra-reliable cooling solutions can play a central role in shaping the next generation of digital infrastructure.



Source: [Google](#)



What is Advanced Cooling and Thermal Energy Management Support for an AI Data Center?

AI data centers are beginning to proliferate throughout our region and the United States. For small and medium-sized manufacturers, the construction and maintenance of advanced cooling and thermal energy management systems for AI data centers presents a potential market opportunity, as described in [Catalyst Connection's Energy & Manufacturing in Appalachia](#) (EMA) program's [Overview of AI Data Centers](#).

AI data centers require cooling and energy management due to the intense heat generated by processing massive volumes of data with high-density servers, GPUs, and custom AI chips. Unlike traditional data centers, AI workloads often require parallel processing and continuous computation, pushing hardware to its thermal limits.

Without advanced cooling and thermal management, the risk of overheating increases, leading to potential hardware failures, reduced performance, and costly downtime. Effective cooling is therefore critical to maintaining optimal operating conditions, ensuring reliability, and protecting valuable IT assets.

Cooling systems are supported by coolant distribution units, pumps, and sensors that monitor and optimize temperature in real time. Additionally, hot/cold aisle containment structures physically separate hot and cold airflows, improving efficiency and reducing energy consumption.

The overall AI data center cooling market breaks into these submarkets:

By Cooling Technology

- **Air Cooling:** Most traditional, includes computer room air conditioning (CRAC), computer room air handlers (CRAH), precision air conditioning, direct expansion (DX) cooling, evaporative cooling, and free cooling.
- **Liquid Cooling:** Includes direct-to-chip liquid cooling, immersion cooling, chilled water systems, and coolant distribution units. Growing fastest due to AI and high-density demands.
- **Hybrid Cooling:** Combines air and liquid cooling for optimized performance and efficiency.

By System Location

- **Room-Based Cooling:** Cools entire rooms using CRAC/CRAH units, prevalent in legacy and retrofit data centers.
- **Row-Based Cooling:** Cooling units placed between rows of server racks, targeting specific equipment rows for more efficient cooling.
- **Rack-Based Cooling:** Cooling directly integrated into or attached to individual server racks, including rear-door heat exchangers.
- **In-Rack/Direct-to-Chip Cooling:** Direct delivery of liquid coolant to hot components for precision thermal management.



What is Advanced Cooling and Thermal Energy Management Support for an AI Data Center?

By Application/Rack Density

- **Low Rack Density (<5 kW):** Traditional data centers, less intensive cooling needed.
- **Medium Rack Density (5–9 kW):** Most common, requiring enhanced airflow.
- **High Rack Density (>9 kW, up to 80+ kW):** AI and hyperscale data centers, demanding advanced cooling solutions (liquid, immersion).

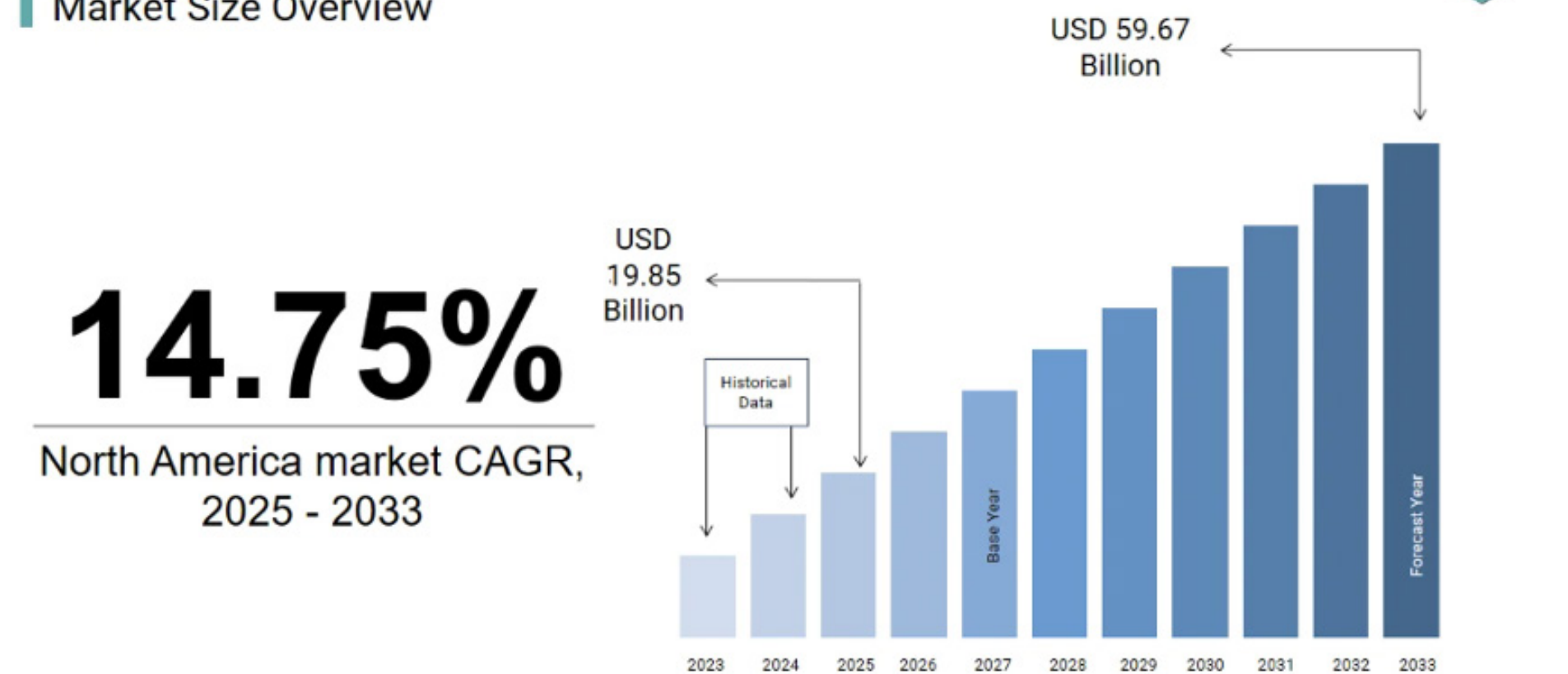
Beyond the cooling hardware, AI data centers integrate sophisticated energy management technologies to further enhance thermal performance. These include:

- **Building automation systems** equipped with AI and IoT sensors continuously monitor environmental conditions, adjusting cooling output as needed to minimize energy waste.
- **Power distribution units (PDUs), uninterruptible power supplies (UPS), and backup generators** ensure the uninterrupted operation of cooling systems during power fluctuations or outages.

Together, these components create a resilient and efficient thermal management ecosystem that enables AI data centers to meet escalating computational demands while maintaining sustainability and operational excellence.

North America Data Center Cooling Market

Market Size Overview



www.marketdataforecast.com

Source: Market Data Forecast Analysis

Source: Market Data Forecast, 2025

Industry Overview

TABLE: DATA CENTER COOLING SUBMARKET MARKET SIZE ESTIMATES, BILLIONS OF US DOLLARS

MARKET	2024 VALUE (USD)	2030-2034 PROJECTIONS (USD)	COMPOUND ANNUAL GROWTH RATE (CAGR)
Composite Market	\$16.32–22.13B ^{[1][8]}	\$40.72–56.15B (2030) ^{[1][8]}	16–21%, all segments

COOLING TECHNOLOGY

Air Cooling	\$12–15B ^{[1][2]}	\$17–22B (2030) ^{[1][3]}	6–8%, legacy/declining
Liquid Cooling	\$5.38B ^{[4][5]}	\$17.77B (2030) ^[4] , \$21.14B (2032) ^[5]	21.6–34%, rapid growth
Hybrid Cooling	~\$4–6B ^[7]	\$15–20B (2034) ^[7]	15–20%, gaining share
Room-Based	~\$12B ^[2]	\$32–36B (2033, North America only) ^[2]	10–12%, dominant share

SYSTEM LOCATION

Row-Based	\$2–4B ^[2]	\$5–10B (2033) ^[2]	6–8%, legacy/declining
Rack-Based	\$1.5–3B ^[2]	\$5–7B (2033) ^[2]	18+%, direct cooling

MARKET SIZE & GROWTH FORECASTS

Current and Future Market Value: Estimates for the market value of the U.S. and global advanced cooling and thermal management markets for data centers vary substantially, and no estimate is available for installed capacity. The table below provides an overview of the current and potential future data center cooling market and submarkets.

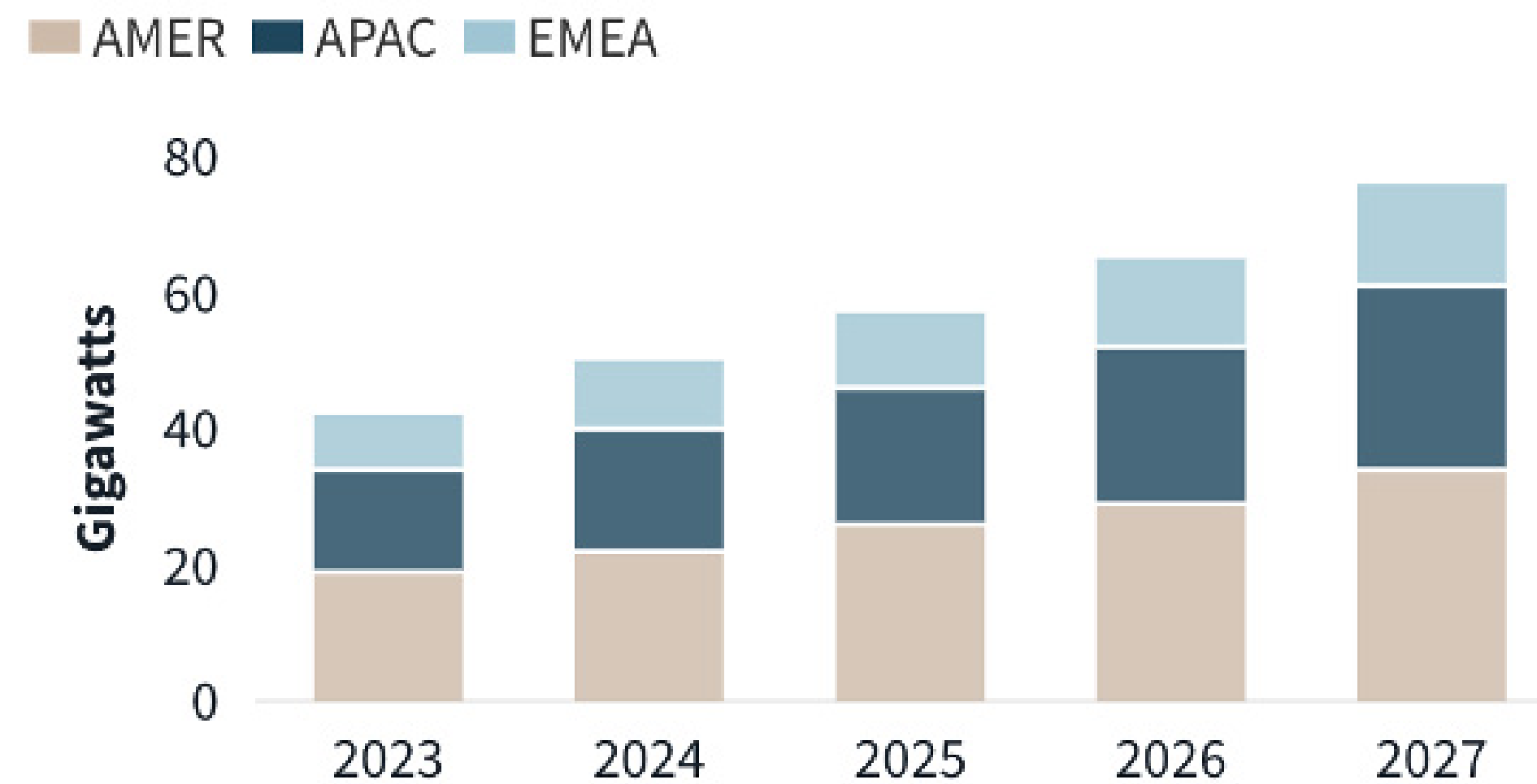
Investment Trends: As the application of AI in data centers has surged, so have the rack power densities. While a typical data center rack uses 5–9 kW of power, those for AI applications can be 5 to 10 times higher. The resulting heat generated, which can account for up to 40% of a data center’s energy consumption, has led companies managing AI data centers to increase their investment in cooling and thermal management to achieve higher reliability, performance, and sustainability goals.

Data Sources:

1. [Grand View Research – Data Center Cooling Market Size 2030](#)
2. [MarketDataForecast – North America Data Center Cooling Market](#)
3. [MarketsandMarkets – Data Center Cooling Market](#)
4. [Grand View Research – Data Center Liquid Cooling Market Report](#)
5. [MarketsandMarkets – Data Center Liquid Cooling Market worth \\$21.14 billion by 2032](#)
6. [BusinessWire – Hybrid Cooling Market for Data Centers](#)
7. [Arizton – Data Center Cooling Market Size, Share, Analysis](#)
8. [Precedence Research – Data Center Cooling Market Size to Hit USD 226.39 Billion by 2034](#)
9. [ResearchNester – Data Center Liquid Cooling Market size to hit \\$89.77 billion by 2037](#)

Global data center capacity projected to grow at 15% per year but this will not be sufficient to meet growing demand

Data center capacity (gigawatts) 2023-2027



Source: JLL Research, 2024, Structure Research
Note: Capacity includes hyperscale and colocation

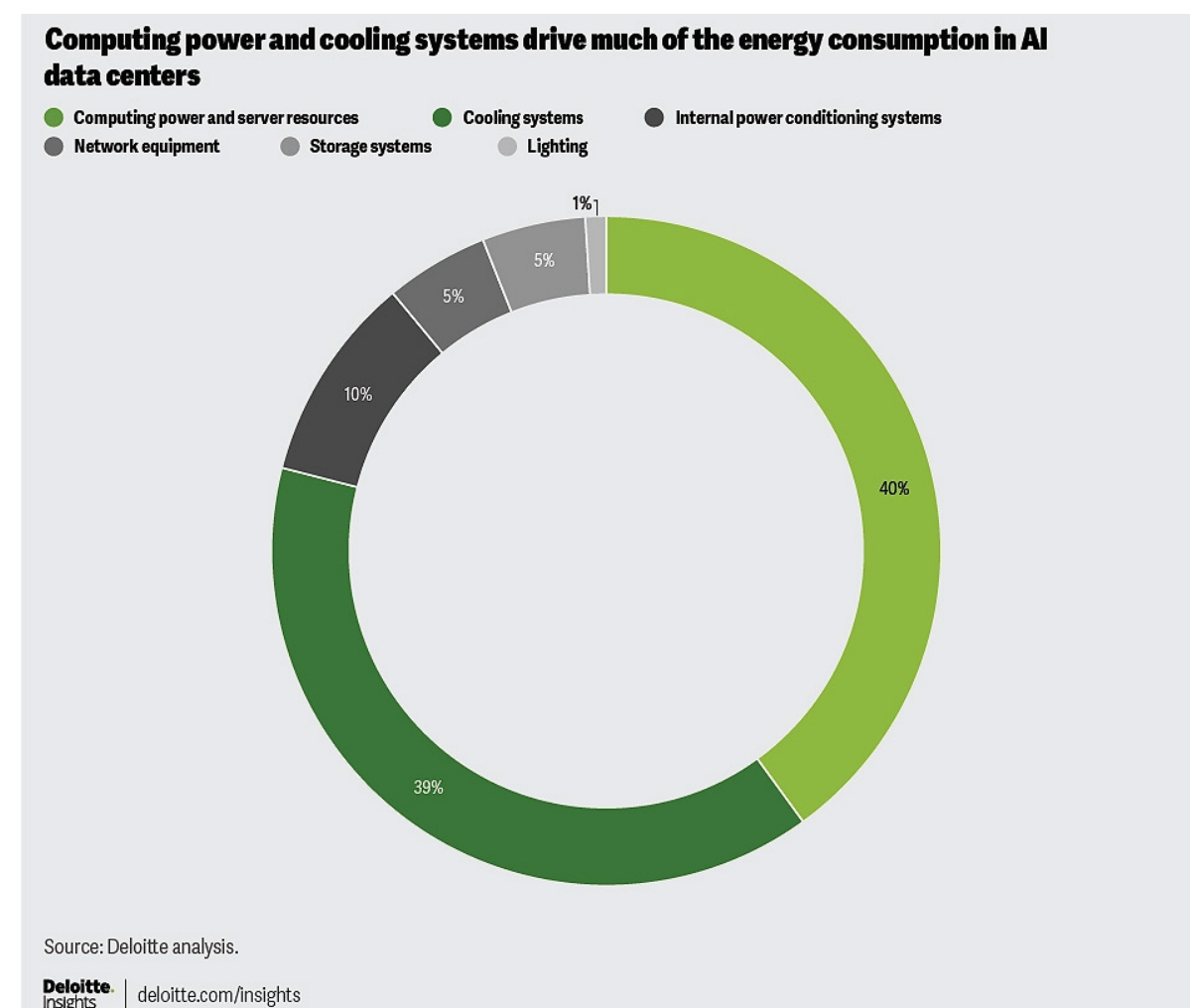
Source: JLL, 2024 (AMER=Americas; APAC=Asia Pacific; EMEA=Europe, Middle East, and Africa)

Industry Overview

Leading States: The leading states are Virginia, California, and Texas; however, AI data centers are also moving to other rural regions as these markets become increasingly saturated.

Emerging Markets: Power grid constraints, regulatory environments, and access to renewable energy are key factors influencing the concentration of new AI data centers—and thus advanced cooling and thermal management investments. Emerging markets include [Indiana](#), [Michigan](#), [Missouri](#), [Nebraska](#), [Nevada](#), [North Carolina](#), [North Dakota](#), [Ohio](#), [Pennsylvania](#), [South Carolina](#), [South Dakota](#), [Utah](#), [West Virginia](#), and [Wisconsin](#).

International Markets: Looking at [international markets](#), the Asia-Pacific region is experiencing significant growth in AI data centers, with countries such as China, India, Malaysia, Thailand, Japan, South Korea, Australia, Singapore, Taiwan, Indonesia, and Vietnam. In South America, Brazil is a key player, as are cities in the Middle East, such as the UAE and Saudi Arabia. European cities emerging are Berlin, Düsseldorf, Helsinki, Lille, Lisbon, Munich, Oslo, Turin, Warsaw, Reykjavik, and Zurich.



Source: Deloitte, 2024

MARKET DRIVERS

Government Support: Support at the federal level for AI data centers is strong, led by a Trump Administration executive order and actions to provide more access to federal land for data centers and streamlined permitting. Support varies by state but overall is strong. For example,

- [New York](#) offers a tax exemption for data centers that purchase machinery, equipment, climate control systems, and power infrastructure.
- [Ohio](#) provides a partial or full state sales tax exemption on equipment (e.g., cooling systems) for data centers that meet minimum investment and payroll thresholds.
- [Pennsylvania](#) exempts certified data centers from state sales tax if they invest \$75 million and create 25 new jobs within the state.

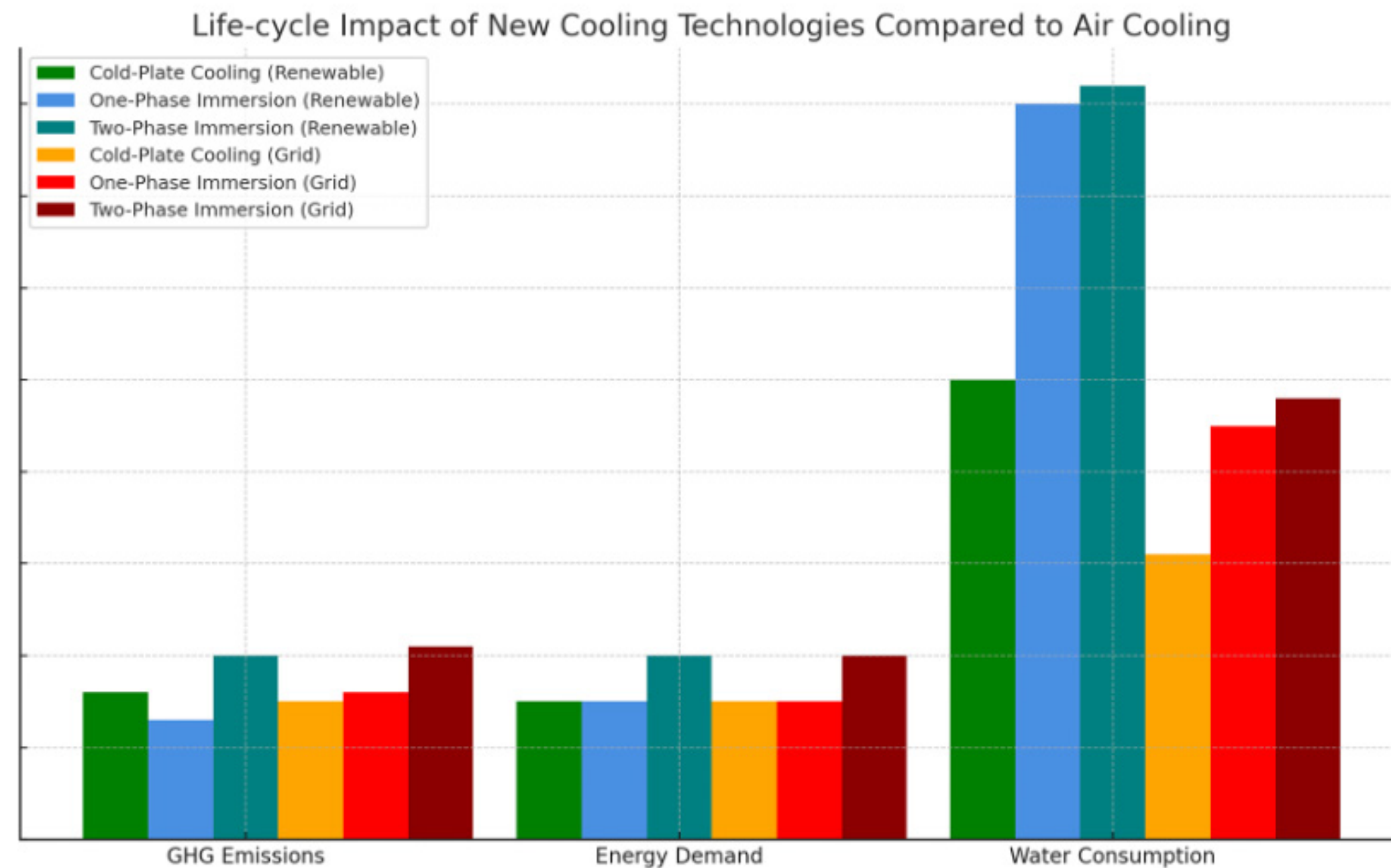
Environmental Goals: AI data centers seek to decrease the share of energy used for cooling, which can account for [38–40%](#) of total data center consumption

Technological Advancements: AI data centers are making progress as technologies advance, particularly liquid cooling and AI-optimized thermal management, leading to a [50% reduction](#) in power use effectiveness (PUE) and the development of new technologies to reduce water consumption.

To address these challenges, AI data centers deploy a range of advanced cooling and thermal management components. Key elements include,

- Direct-to-chip liquid cooling systems that circulate coolant directly over high-heat components like CPUs and GPUs,
- Immersion cooling tanks where entire servers are submerged in dielectric fluids, and
- Rear-door heat exchangers are mounted on server racks to dissipate heat at the source.

Industry Overview



Source: [Microsoft](#), 2025

CHALLENGES AND CONCERNS

Regulatory Hurdles: Many advanced cooling systems for AI data centers rely heavily on water. In drought-prone regions, [local or state regulations](#) now limit water intake, require water recycling, or mandate alternative technologies to reduce consumption. In addition, the use of [PFAS](#) chemicals, increasingly regulated in the United States and Europe, in some immersion cooling systems.

Social license to operate: Some [states](#) are discussing policies that would require data centers to meet [Power Usage Effectiveness \(PUE\)](#) targets (e.g., PUE < 1.3), which would compel AI data centers to adopt liquid cooling, immersion systems, or advanced airflow engineering. Germany has set Data centers may seek [Green Globe](#) certification, analogous to green building certification (e.g., [Chicago's Aligned Data Center](#)).

Environmental concerns: Environmental concerns other than energy and water consumption relevant to cooling and energy management include requirements to phase down the use of [hydrofluorocarbons \(HFCs\)](#), commonly used as refrigerants in traditional cooling systems,

Land use: While some [municipalities](#) treat data centers as industrial facilities during zoning, others are creating [specific land use regulations](#) for data centers. Some, for example, limit the ability to build a data center near residential or mixed-use areas, or require the establishment of buffer zones.



AI Data Center Cooling and Thermal Management Components

AI data center cooling and thermal management components are essential for overcoming the intense heat challenges presented by modern hardware. Together, they ensure safety, performance, and energy efficiency—cornerstones for future-proofing data centers in the AI era. Ideally, these components provide:

- **Equipment Protection:** They prevent overheating, which could cause hardware failure, fire, or data loss.
- **Performance Optimization:** AI servers operate at optimal performance only when kept within specific temperature ranges.
- **Energy and Cost Savings:** Efficient systems reduce cooling energy consumption, which can be 40% or more of a data center's total energy use.
- **Sustainability:** Advanced cooling reduces water and energy use, contributing to operational and environmental goals.
- **Scalability:** Modular and hybrid systems help data centers scale for future AI workloads without full overhauls.

Key components, which vary by cooling and energy management system, include:

AI-Driven Cooling Controls: Use sensors and algorithms to optimize cooling dynamically, minimize energy use, and adapt to fluctuating workload demands.

Chillers: Cool down water or coolant for use in liquid cooling loops and air conditioners; essential for maintaining optimal fluid temperatures.

Cold Plates: Directly mounted on processors (CPUs, GPUs) to absorb and transfer heat to a circulating liquid.

Coolant Distribution Units (CDU): Regulate and monitor coolant flow between servers and chillers/towers, enabling flexible and modular cooling architecture.

Cooling Towers: Reject heat from the liquid cooling system to the outside environment by evaporating water, further lowering coolant temperature.

Computer Room Air Conditioners (CRAC/CRAH): Traditional systems that blow cooled air across server racks and manage humidity.

Heat Reuse Systems: Collect waste heat for repurposing (such as facility heating), improving sustainability and reducing carbon footprint.

Hot/Cold Aisle Containment: Directs airflow efficiently by separating hot exhaust and cold intake, improving cooling effectiveness and energy efficiency.

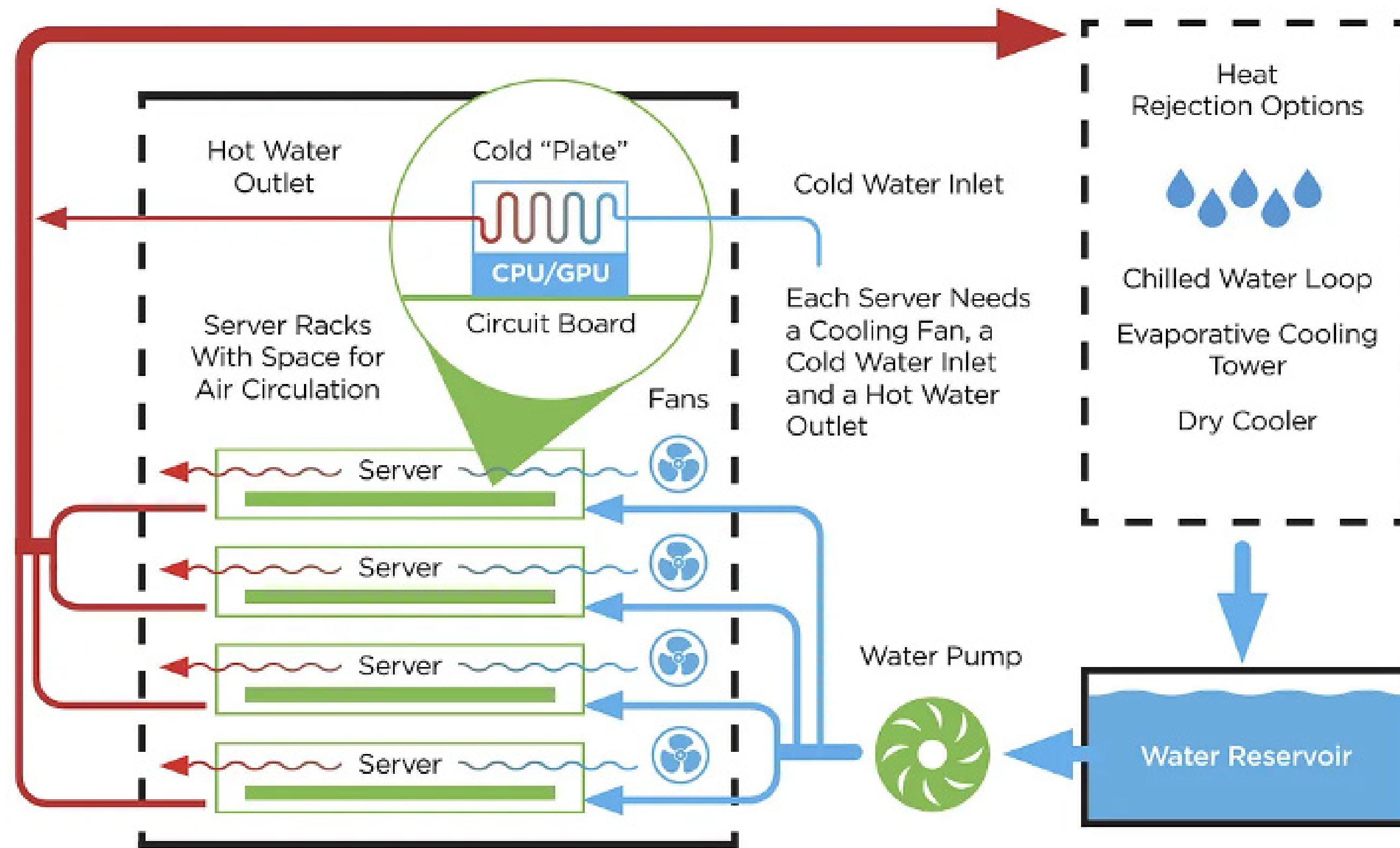
Immersion Cooling: Submerge entire servers in dielectric fluid for maximal direct heat absorption, lowering fan use and operational noise.

Liquid Cooling Systems: Circulate coolant to efficiently remove heat from densely packed hardware that air cooling cannot manage.

Rear-Door Heat Exchangers: Install at the back of racks to absorb heat before hot air is released into the server room, supplementing air or liquid cooling.

AI Data Center Cooling and Thermal Management Components

Liquid-to-Chip



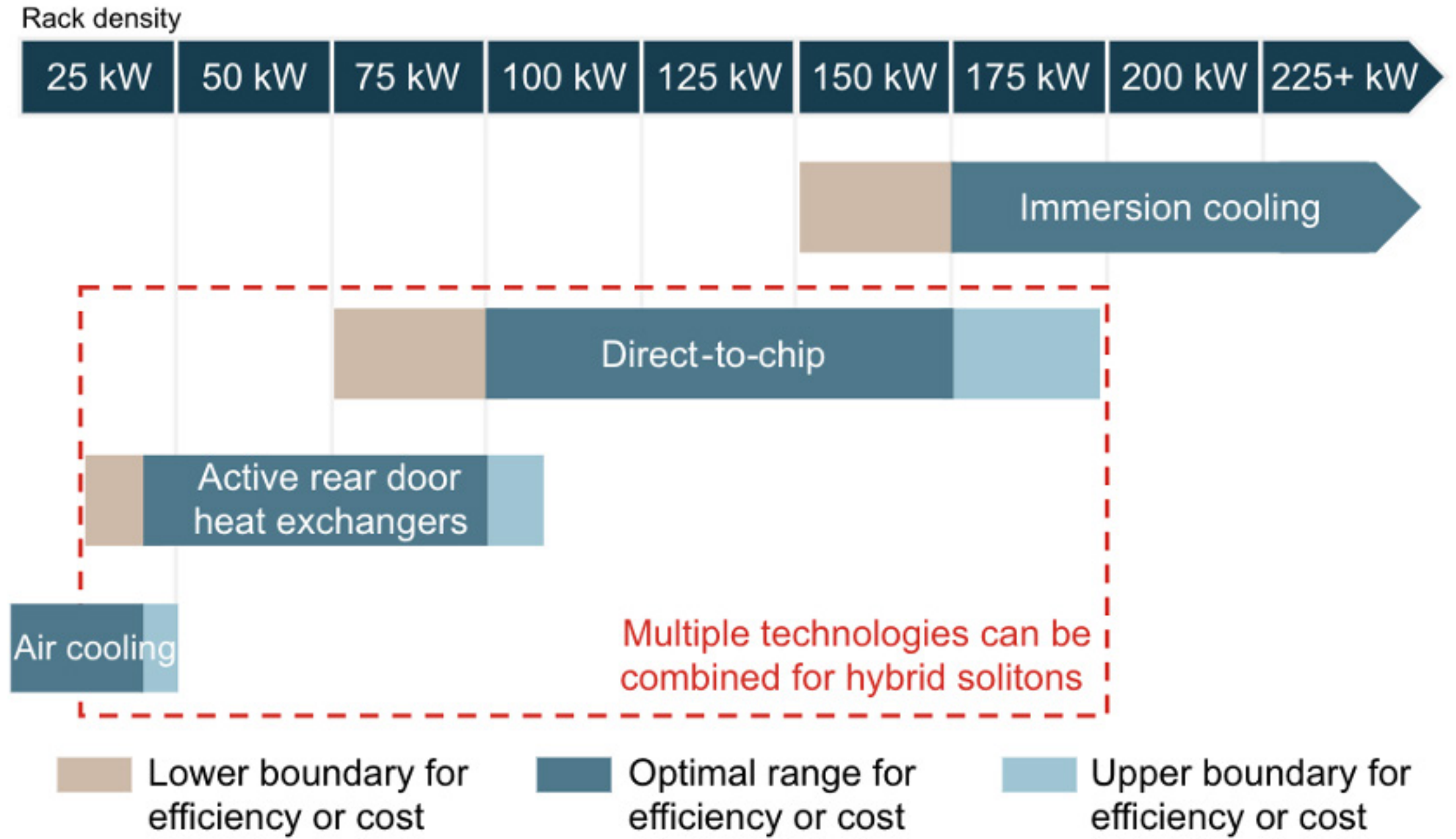
Source: Baycan, E., 2024



Advanced Cooling and Thermal Management Components of Typical AI Data Centers

Source: JLL, 2024

Applicable cooling technologies by rack density





Advanced Cooling and Thermal Management Components of Typical AI Data Centers

The following table organizes key components and technologies used in advanced cooling and thermal management systems for data centers according to their related North American Industry Classification System (NAICS) codes.

Each component is grouped into relevant subcategories—such as air handling and containment, pumps and fluid handling, piping and fabrication, sensing and controls, cooling equipment, and thermal interfaces—offering concise descriptions and highlighting their specific applications within the data center environment. Subcategories included:

- Air handling and containment
- Pumps and fluid handling
- Piping and fabrication
- Sensing and controls
- Cooling equipment
- Thermal interfaces

Together, these technologies and their supporting subcomponents enable precise temperature regulation, optimized energy consumption, and reliable operation for the intensive computational demands of modern AI workloads.

Advanced Cooling and Thermal Management Components of Typical AI Data Centers

AIR HANDLING & CONTAINMENT

COMPONENT	NAICS NUMBERS	NAICS NAME	DESCRIPTION	USE
Air Economizers	333415	Air-Conditioning and Warm Air Heating Equipment and Commercial and Industrial Refrigeration Equipment Manufacturing	Use outside air to cool the data center, reducing mechanical cooling needs.	Lower cooling costs and energy use.
Cold Aisle Containment	333415	Air-Conditioning and Warm Air Heating Equipment...	Physical barriers to contain cold air in server aisles.	Prevent cold/hot air mixing, improving efficiency.
Computer Room Air Conditioner (CRAC) Units	333415	Air-Conditioning and Warm Air Heating Equipment...	Precision air-conditioning units (air-cooled or refrigerant-based).	Provide precise temperature control for servers.
Computer Room Air Handler (CRAH) Units	333415	Air-Conditioning and Warm Air Heating Equipment...	Air-handling units using chilled water coils for heat removal.	Distribute cool air and manage airflow.
Direct Expansion (DX) Cooling Units	333415	Air-Conditioning and Warm Air Heating Equipment...	Systems using refrigerant that cycles directly through air handling units.	Small and edge data centers for spot cooling.
Dry Coolers (Fluid Coolers)	333415	Air-Conditioning and Warm Air Heating Equipment...	Air-cooled heat exchangers for removing heat from water/glycol loops.	Outdoor rejection of server heat into ambient air.
Hot Aisle Containment	333415	Air-Conditioning and Warm Air Heating Equipment...	Physical barriers to contain and direct hot air for return to cooling units.	Improve separation of hot/cold air streams.
In-Row Cooling Units	333415	Air-Conditioning and Warm Air Heating Equipment...	Cooling coils/blowers positioned between racks within the row.	Direct, localized cooling for high-density aisles.
Raised Floor Systems	238330	Flooring Contractors	Elevated flooring, space beneath used to distribute chilled air.	Enable flexible cooling and cabling layouts.
Rear Door Heat Exchangers	333415	Air-Conditioning and Warm Air Heating Equipment...	Warming/cooling coils on rear of racks to capture heat as it exits servers.	Precise rack-level heat removal.

Advanced Cooling and Thermal Management Components of Typical AI Data Centers

PUMPS, VALVES, & FLUID HANDLING

COMPONENT	NAICS NUMBERS	NAICS NAME	DESCRIPTION	USE
Chilled Water Distribution Pumps	333911	Pump and Pumping Equipment Manufacturing	Circulate chilled water between chiller, CRAHs/CRACs, and server racks.	Maintain cold water flow throughout the facility.
Flow Control Valves	332911	Industrial Valve Manufacturing	Regulate flow of liquid coolant to various thermal zones.	Control cooling to racks or chips as demand changes.
Immersion Cooling Pumps	333911	Pump and Pumping Equipment Manufacturing	Circulate dielectric fluid in immersion tanks.	Maintain liquid movement and thermal uniformity.
Liquid Distribution Manifolds	332919	Other Metal Valve and Pipe Fitting Manufacturing	Junctions for distributing coolant between cooling loops or racks.	Direct and balance coolant to multiple areas/racks.
Direct-to-Chip Manifolds	332919	Other Metal Valve and Pipe Fitting Manufacturing	Distribution blocks directing coolant to chip cold plates and from them.	Balance and distribute coolant in liquid loops.

PIPING, FABRICATION, & WATER TREATMENT

COMPONENT	NAICS NUMBERS	NAICS NAME	DESCRIPTION	USE
Chilled Water Supply/Return Piping	332996	Fabricated Pipe and Pipe Fitting Manufacturing	Pipe systems carrying chilled water to and from racks and cooling units.	Deliver/remove chilled water for heat exchange.
Refrigerant Piping	332996	Fabricated Pipe and Pipe Fitting Manufacturing	Pipes that carry refrigerant between compressors, condensers, and cooling coils.	Transport working fluid for DX and traditional cooling.
Water Treatment Systems	333999	All Other Miscellaneous General Purpose Machinery Manufacturing	Treat water for cooling towers and chilled water loops.	Prevent corrosion, scaling, and biological growth.

Advanced Cooling and Thermal Management Components of Typical AI Data Centers

COOLING UNITS, HEAT EXCHANGERS & STORAGE

COMPONENT	NAICS NUMBERS	NAICS NAME	DESCRIPTION	USE
Chiller Plants	333415	Air-Conditioning and Warm Air Heating Equipment...	Centralized units that produce chilled water for large-scale cooling.	Main source of cold water for cooling loops.
Immersion Cooling Tanks	333415	Air-Conditioning and Warm Air Heating Equipment...	Sealed enclosures filled with dielectric liquid for submerging servers.	Enables direct heat exchange via immersion.
Liquid-to-Air Heat Exchangers	333415	Air-Conditioning and Warm Air Heating Equipment...	Transfer heat from circulating liquid to airstreams.	Expelling waste heat to outside air or heat recovery use.
Liquid-to-Liquid Heat Exchangers	333415	Air-Conditioning and Warm Air Heating Equipment...	Exchange heat between two liquid loops, e.g., primary and secondary circuits.	Efficient isolation of facility and IT coolant loops.
Server Internal Liquid Cooling	333415	Air-Conditioning and Warm Air Heating Equipment...	Pumped liquid/coolant loops inside server chassis.	High-efficiency cooling for hottest server components.
Thermal Energy Storage Systems	333415	Air-Conditioning and Warm Air Heating Equipment...	Store chilled water or ice for use during periods of high cooling demand.	Demand management and improved cooling efficiency.

Advanced Cooling and Thermal Management Components of Typical AI Data Centers

SENSORS, CONTROLS & MONITORING

COMPONENT	NAICS NUMBERS	NAICS NAME	DESCRIPTION	USE
Leak Detection Sensors	334512	Automatic Environmental Control Manufacturing	Electronic sensors for detecting water or coolant leak events.	Early warning to prevent equipment damage from leaks.
Monitoring and Control Systems	334512	Automatic Environmental Control Manufacturing	Electronic systems for managing, adjusting, and reporting cooling operations.	Optimize cooling, detect anomalies, and reduce energy use.
Variable Frequency Drives (VFDs)	335312	Motor and Generator Manufacturing	Adjust blower/pump speed based on real-time cooling demand.	Save energy and fine-tune cooling flow rates.

FANS, BLOWERS, & HEATSINKS

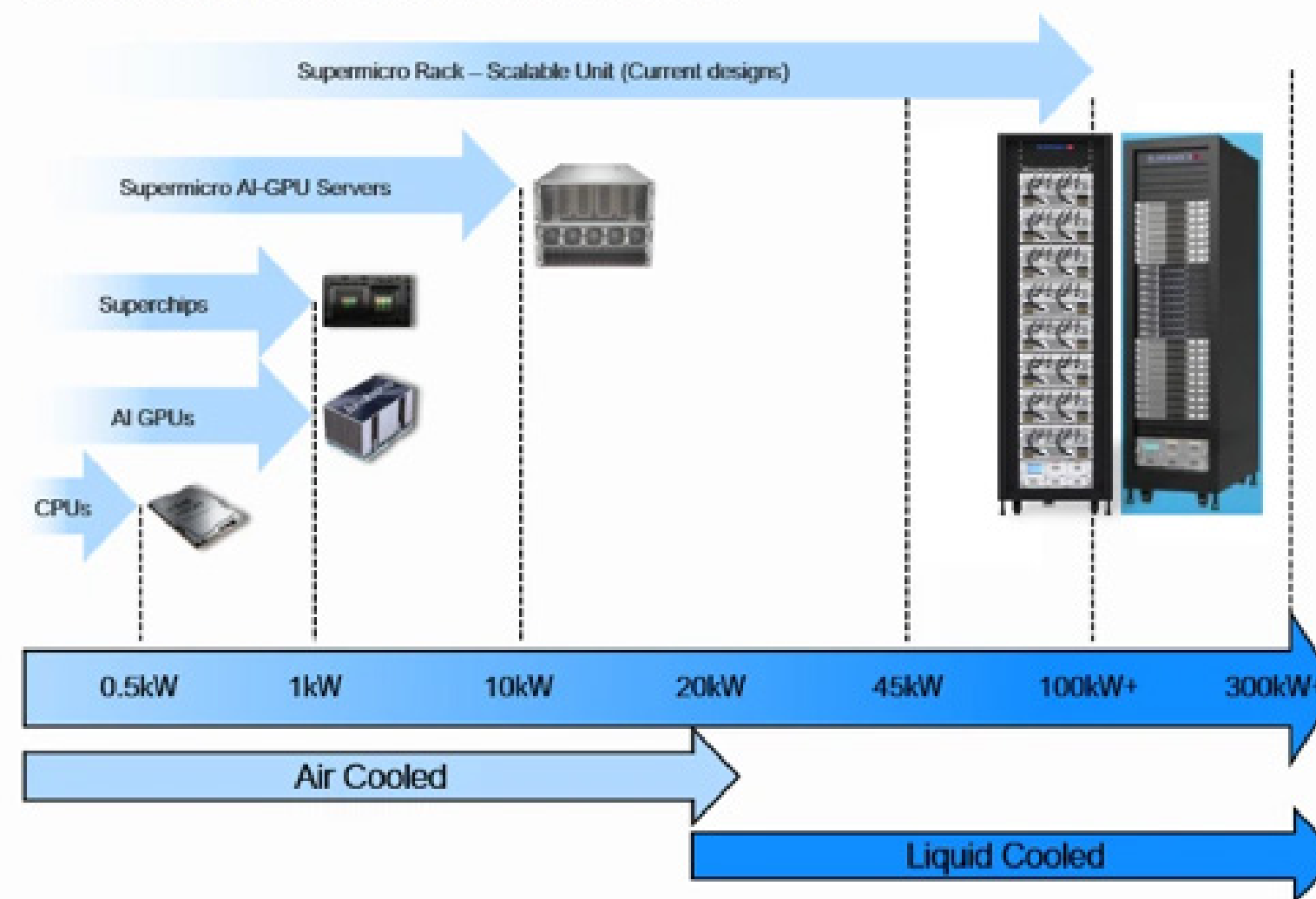
COMPONENT	NAICS NUMBERS	NAICS NAME	DESCRIPTION	USE
Fans and Blowers	333413	Industrial and Commercial Fan and Blower and Air Purification Equipment Manufacturing	Create airflow for heat dissipation in HVAC, rack, cooling unit, and chassis.	Circulate and direct air in data center infrastructure.
GPU/CPU Heatsinks	334413	Semiconductor and Related Device Manufacturing	Metal (often copper/aluminum) components for passive chip cooling.	First stage of removing heat from high-power devices.
Direct-to-Chip Cold Plates	333415	Air-Conditioning and Warm Air Heating Equipment...	Plates mounted directly on chips with liquid flowing through microchannels.	Maximize CPU/GPU heat transfer to coolant.

Advanced Cooling and Thermal Management Components of Typical AI Data Centers

The Opportunity: Liquid-Cooled Data Centers



Liquid-cooling vastly reduces power costs compared to air-cooling, reducing customer TCO while minimizing environmental impacts.



Up to **92%** Reduction of server cooling power

Up to **40%** reduction in electricity costs for entire data center

Up to **55%** reduction in data center server noise

Water has significantly higher thermal conductivity than air (molecules are closer together and have stronger bonds)

8/23/2024

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Better Faster Greener™ © 2024 Supermicro

Source: [Semiconductor Engineering](#), 2024



AI Data Center Advanced Cooling and Thermal Management Developers and Manufacturers

The major developers and manufacturers driving the future of efficient, sustainable AI data centers through innovations in adthermal management and intelligent energy usage are listed below in the following categories:

- **Precision Air and Modular Cooling Systems:** Use energy-efficient, scalable air-based cooling solutions with precise temperature and humidity control, designed to adapt flexibly to the evolving density and cooling demands of AI data centers.
- **Direct-to-Chip & Liquid Cooling:** Deliver coolant directly to high-heat components like CPUs and GPUs, maximizing thermal efficiency and reliability for dense, high-performance AI workloads.
- **Immersion Cooling (Single-Phase / Two-Phase):** Submerge hardware in specialized non-conductive liquids—single-phase systems keep the liquid stable, while two-phase systems leverage coolant evaporation for superior heat removal—offering high energy efficiency and density for AI environments.
- **Integrated Infrastructure, Management & Software Optimization:** Combine hardware infrastructure with AI-driven software and sensor-based platforms to optimize thermal performance, automate cooling operations, and integrate power management for enhanced sustainability and operational reliability in AI data centers.

PRECISION AIR AND MODULAR COOLING SYSTEMS

- **Airedale International Air Conditioning:** Specializes in energy-efficient precision cooling systems for high-density, mission-critical IT and AI workloads.
- **Daikin:** Supplies thermal management and air conditioning systems tailored for sustainable, large-scale, and AI-centric data centers.
- **Munters:** Develops sustainable, high-efficiency cooling systems for mission-critical applications, including evaporative and data center cooling products.

- **STULZ GmbH / STULZ:** Delivers/manufactures precision air conditioning and humidity (and modular cooling) systems optimized for high-density AI-centric data centers.
- **Trane Technologies:** Offers scalable modular cooling platforms, advanced liquid cooling units, and high-count air-cooled chillers for hyperscale and hybrid AI data center workloads.
- **USystems:** Provides highly efficient, scalable cooling solutions allowing for flexible deployment in rapidly evolving AI data environments.

DIRECT-TO-CHIP & LIQUID COOLING

- **Asetek:** Known for direct-to-chip liquid cooling solutions designed to efficiently manage heat in high-performance computing environments.
- **Boyd Corporation:** Delivers durable cooling systems, including Coolant Distribution Units (CDUs), liquid loops, and cold plates for next-level thermal performance in AI data centers.
- **CoolIT Systems:** Specializes in direct liquid cooling solutions for maximizing efficiency and reliability for high-density AI and HPC data centers.
- **Flex (in partnership with JetCool):** Delivers advanced liquid cooling technologies engineered specifically for AI server and high-density computing needs.
- **Gigabyte:** Provides pragmatic, incremental liquid-cooling solutions that target thermal hotspots while remaining compatible with existing infrastructure.
- **Motivair Corporation:** Supplies advanced liquid and air-based cooling technologies designed for AI supercomputing facilities (also immersion cooling).



AI Data Center Advanced Cooling and Thermal Management Developers and Manufacturers

IMMERSION COOLING

- **Asperitas:** Provides immersion liquid cooling systems that increase energy efficiency and reduce water usage in data centers.
- **Green Revolution Cooling (GRC):** Specializes in single-phase immersion cooling systems that lower cooling costs and reduce carbon footprint.
- **Iceotope:** Specializes in modular, sustainable immersion cooling systems, improving energy efficiency and reliability in AI and high-performance workloads.
- **LiquidStack:** Pioneers two-phase immersion cooling technology, enabling efficient thermal management in hyper-dense AI and HPC environments.
- **Submer:** Manufactures immersion cooling systems designed to enable ultra-efficient PUE and sustainability for AI data centers.

INTEGRATED INFRASTRUCTURE, MANAGEMENT & SOFTWARE OPTIMIZATION

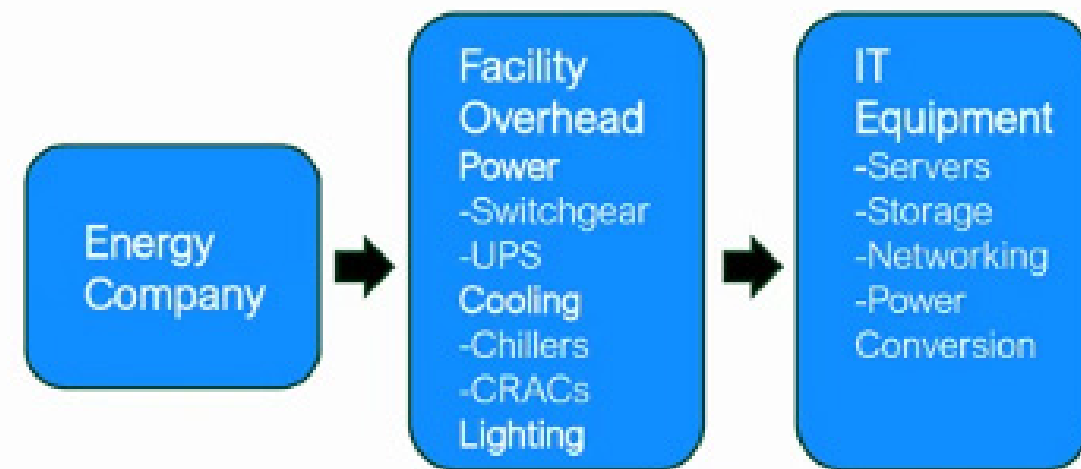
- **Axiado:** Offers AI-driven Dynamic Thermal Management (DTM) using real-time server workload data to optimize cooling and reduce energy costs.
- **Black Box Corporation:** Offers integrated infrastructure and precision cooling solutions tailored for data centers hosting high-density AI servers.
- **ByteBridge:** Provides advanced thermal management software and sensor-based monitoring for real-time control of temperature and airflow in AI data centers.

- **Coherent:** Provides innovative thermal management solutions ensuring efficient cooling for high-workload and AI-driven data centers.
- **Delta Electronics:** Manufactures modular, scalable cooling and power management solutions, including in-row and precision cooling.
- **EkkoSense:** Offers AI-driven optimization software for removing thermal risk and optimizing cooling capacity in real time.
- **Johnson Controls:** Delivers comprehensive hardware and software for datacenter thermal management, advanced building automation, and integrated fire and safety.
- **Modine:** Engineers advanced thermal management systems focused on precision and efficiency for mission-critical data center applications.
- **Schneider Electric:** Offers EcoStruxure modular liquid-cooled solutions; delivers "Grid to Chip, Chip to Chiller" advanced integrated thermal management for data centers.
- **Vertiv:** Supplies a range of core-to-edge thermal and liquid cooling products; a leader in AI-driven integrated liquid/air-based thermal management.



AI Data Center Advanced Cooling and Thermal Management Developers and Manufacturers

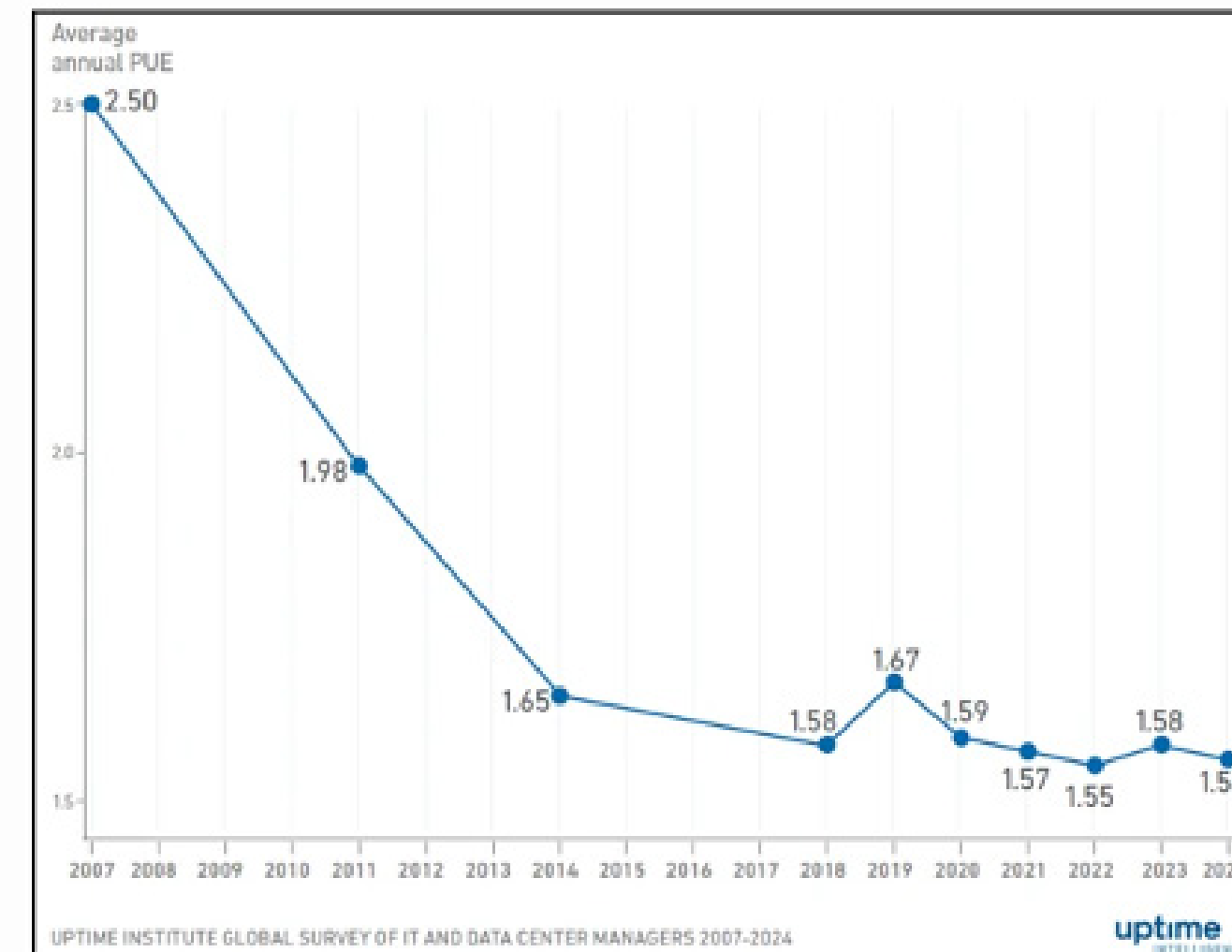
Data Center Power Efficiency (PUE)



PUE	Level of Efficiency
3.0	Very Inefficient
2.5	Inefficient
2.0	Average
1.5	Efficient
1.2	Very Efficient
1.05	Extremely Efficient

PUE of 1.0 means that the data center is perfectly efficient

$$\text{PUE} = \frac{\text{Total Facility Power}}{\text{IT Equipment Power}}$$



Source: Semiconductor Engineering, 2024



AI Data Center Trade Associations & Resources

TRADE ASSOCIATIONS

- **Air-Conditioning, Heating, and Refrigeration Institute:** AHRI represents manufacturers of HVAC and refrigeration equipment, setting performance standards and certifying system efficiency.
- **Air Movement and Control Association International:** AMCA develops standards and certifies equipment used for air movement and control in various HVAC and cooling applications.
- **American Society of Heating, Refrigerating and Air-Conditioning Engineers:** ASHRAE is the industry leader in technical standards, research, and best practices for building and data center cooling, liquid cooling, and environmental management.
- **Associated General Contractors of America:** AGC represents a broad range of construction firms, including those specializing in data center construction.
- **Association for Computer Operations Management:** AFCOM focuses on education, networking, and best practices for data center managers and IT infrastructure professionals, particularly in the context of emerging technologies.
- **Data Center Coalition:** DCC serves as the membership association for the data center industry, advocating for favorable business climates, policies, and investments that support the sector's growth and success. DCC engages in public policy advocacy, thought leadership, and community outreach to promote the economic and community-building impacts of data centers.
- **Global Immersion Cooling Association:** GICA promotes standards, research, and best practices specifically for immersion cooling technologies in high-density data centers.

- **Mechanical Contractors Association of America:** MCAA prepares mechanical contractors for opportunities in data centers.
- **Telecommunications Industry Association:** TIA develops standards and supports innovation in telecommunications and data center infrastructure, including advanced cooling and liquid cooling technologies.
- **Uptime Institute:** Uptime Institute (UI) is an independent advisory organization dedicated to enhancing the performance, efficiency, and reliability of business-critical infrastructure through innovation, collaboration, and impartial performance certifications. It is globally recognized for establishing and administering the Tier Standards & Certifications for data center design, construction, and operational sustainability.

FUNDING OPPORTUNITIES

DOE Manufacturing and Energy Supply Chains: The US Department of Energy's Manufacturing and Energy Supply Chains (MESC) office serves as the frontline of America's energy manufacturing deployment and supply chain security. Their mission is to enhance economic and national security by eliminating vulnerabilities in the United States' energy supply chains.

The MESC offers competitive grant opportunities for small to medium-sized manufacturers that focus on manufacturing expansion and workforce training. Efforts span battery storage, grid components, critical minerals processing and recycling, energy generation, nuclear power, buildings and energy efficiency, transportation, and industrial materials. Funding opportunities are announced periodically throughout the year. The office also publishes reports on supply chain needs, market opportunities, guidance documents, and factsheets.

Links

Arizton, [U.S. Data Center Cooling Market Landscape 2024-2029](#), August 2024.

Arizton, [The Global Data Center Cooling Market Report Size, Share, Trends, Drivers, Industry Analysis](#). June 2025.

Baycan, E., [Traditional and Modern Data Center Cooling Systems](#), April 24, 2024.

CBRE, [Global Data Center Trends 2025](#), June 24, 2025.

Deloitte, [As generative AI asks for more power, data centers seek more reliable, cleaner energy solutions](#), November 19, 2024

Grandview Research, [Data Center Cooling Market Size. . . 2025 - 2030](#), August 2024.

IDTechX, [Thermal Management for Data Centers 2025-2035: Technologies, Markets, and Opportunities](#),

JLL, [2025 Global Data Center Outlook](#), 2024.

Lightwave, [AI demands to drive the data center cooling market to \\$16.9B by 2028](#), June 18, 2024.

Market Data Forecast, [North America Data Center Cooling Market Size . . .2025 to 2033](#), April 2025.

Markets and Markets, [Data Center Cooling Market...Global Forecast to 2032](#), July 2025.

Markets and Markets, [Data Center Liquid Cooling Market worth \\$21.14 billion by 2032](#), Mar 28, 2025.

Microsoft, [Microsoft quantifies environmental impacts of datacenter cooling from 'cradle to grave' in new Nature study](#), May 1, 2025.

Perkins Cole, [Key Legal Issues of Data Center Development](#), April 30, 2025

Pharma Intelligence, [Data Center Cooling Market Size, Share Analysis, Growth Trends, and Forecast 2025-2032](#), May 2025.

Precedence Research, [Data Center Cooling Market Growth Driven by AI Workload Density and Heat Challenges](#), August 12, 2025.

Research and Markets, [U.S. Data Center Cooling Market Landscape 2024-2029](#), August 2024.

Research and Markets, [Succeeding in the Hybrid Cooling Market for Data Centers: Balancing Soaring Computing Demands with the Urgent Need for Energy Efficiency \(2025 Industry Report\)](#), March 19, 2025.

Research and Markets, [Data Center Cooling Research Report 2025](#), June 10, 2025.

Research Nester, [Data Center Liquid Cooling Market . . Forecast Report 2025-2037](#), Accessed August 2025.

Semiconductor Engineering, [Liquid Cooling, Meeting The Demands Of AI Data Centers](#), September 4, 2024

White and Case, [Cooling data centers: Keeping up with emerging technologies](#), February 10, 2025.

Wise Guy Reports, [Global Data Center Thermal Management Market Research Report](#), May 4, 2025.



AI Data Centers: Overview

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This report was drafted by Dr. Deborah D. Stine, founder of the Science & Technology Policy Academy. She previously served as the Executive Director of the President Obama's Council of Advisors on Science and Technology, a Science & Technology Specialist at the Congressional Research Service, a study director at the National Academies of Sciences, Engineering, and Medicine, and as a professor of the practice in engineering and public policy at Carnegie Mellon University. Contact Dr. Stine at deborah@scitechpolicyacademy.com.

The EMA program supports Appalachia in 156 counties of Maryland, New York, Ohio, Pennsylvania, and West Virginia. This program was established to help small and medium manufacturers be a part of this Energy Economy. This program is managed by Manufacturing Extension Partnership (MEP) organizations from five Appalachian states. The activities and intended outcomes of EMA align with the National Institute of Standards and Technology (NIST) MEP and its mission to enhance the productivity and technological performance of U.S. manufacturing.

Learn more about the Energy & Manufacturing in Appalachia program by visiting: <https://www.wemakeithere.org/energy/> and join the EMA [LinkedIn group](#). Contact EMA Program Manager, Tom Reed, directly at Tom@WeMakeItHere.org and (412) 918-4269 with any questions or assistance.