

Direct-toChip Cooling: A Practical Guide for High-Density Data Centers

Learn how DTC cooling works, where it fits, and what to evaluate before deployment.

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Frequently Asked Questions About Direct-to-Chip Cooling

Direct-to-Chip (DTC) cooling helps data centers manage the higher heat loads created by AI, high-performance computing (HPC), and other compute-intensive workloads.

This eBook explains what DTC cooling is, how it works, where it fits, and what organizations should evaluate before deploying it in new or existing data centers.

The questions are organized into four practical chapters, moving from foundational concepts to technology choices, risk management, and deployment planning.

Move from cooling fundamentals to a deployment-ready infrastructure plan.



Why DTC, Why Now

1 What is Direct-to-Chip Cooling?

DTC cooling is a liquid-cooling approach that moves coolant through cold plates mounted directly on high-heat components such as CPUs, GPUs, and accelerators.

The coolant absorbs heat at the chip level and carries it away through a liquid-cooling loop, making DTC cooling more efficient than relying only on traditional air cooling for high-density compute environments.

Key Takeaway

Liquid captures heat directly at the components creating it.



Source: [1]NIH.gov

Why DTC, Why Now

2 Why is DTC cooling becoming more important?

AI, HPC, and other compute-intensive workloads are driving higher chip operating temperatures and higher rack power densities.

As these densities increase, air cooling becomes less practical, less efficient, or difficult to scale. DTC cooling supports higher-density infrastructure by removing more heat through liquid while reducing dependence on high-volume airflow.

3 What are the main benefits of DTC cooling?

Potential benefits span capacity, energy use, and deployment flexibility

- Support for higher rack and chip power densities
- More effective heat removal from CPUs and GPUs
- Reduced dependence on server and data-hall airflow
- Potential reductions in cooling energy and fan energy
- Opportunities to use warmer cooling-water temperatures
- Greater flexibility for high-density AI and HPC deployments
- Potential for heat recovery or reuse in suitable facilities

To learn more see ✚ Q5: How does DTC cooling work?

POWER • HEAT • COOLING

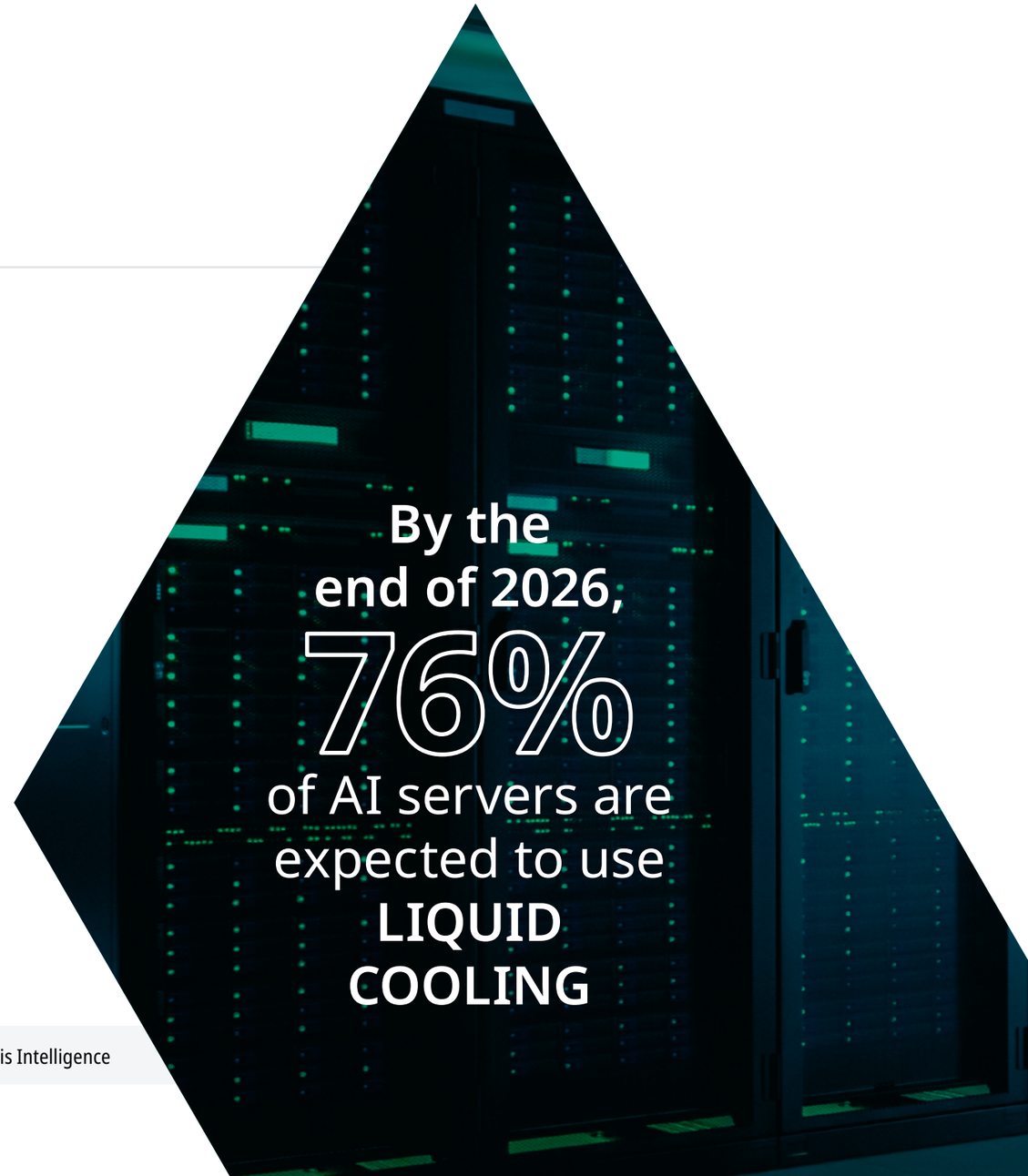
Why DTC, Why Now

4 Is DTC cooling the future of data-center cooling?

DTC cooling is becoming an increasingly important option as compute densities rise, particularly for data centers that need to support higher-density AI, HPC, and accelerated computing workloads.

It is unlikely to replace every form of air cooling. Many data centers are expected to use a combination of DTC liquid cooling and air cooling based on workload, rack density, facility design, and lifecycle requirements.

The future is hybrid. Liquid addresses concentrated component heat while air continues supporting other server and room loads.



Source: [2]Axis Intelligence

How DTC Works

5 How does DTC cooling work?

A typical system circulates coolant through cold plates attached to processors or other high-heat components. The warmed coolant leaves the server and transfers its heat through a Coolant Distribution Unit (CDU) or another heat-exchange system. After the heat is removed, the cooled coolant is recirculated back into the server.

A typical cooling loop includes:

- Cold plates
- Supply and return piping or tubing
- Manifolds and quick-disconnect fittings
- Pumps and CDUs
- Heat exchangers
- Sensors and controls
- Facility water or another heat-rejection system



Key Takeaway

DTC moves heat through a controlled liquid loop from the chip to the facility heat-removal system.

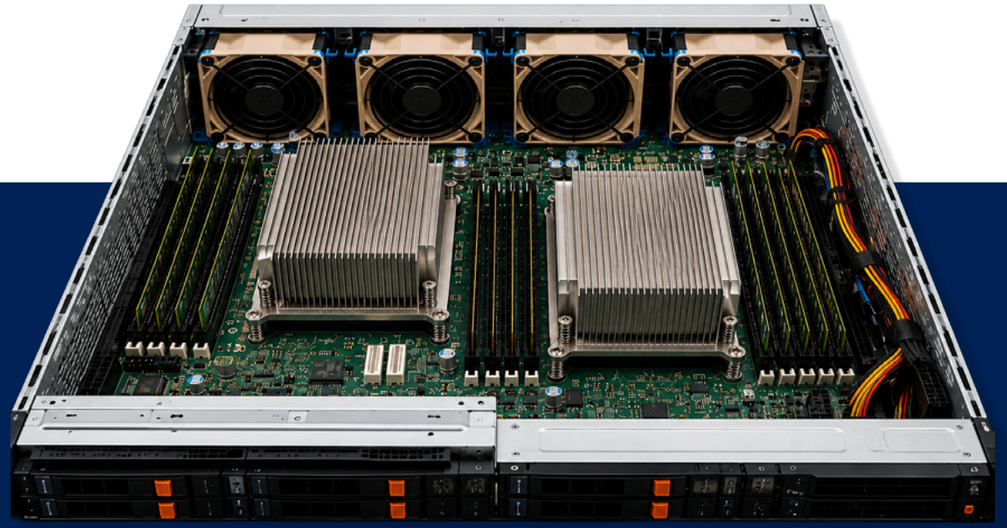
How DTC Works

6 What is a cold plate?

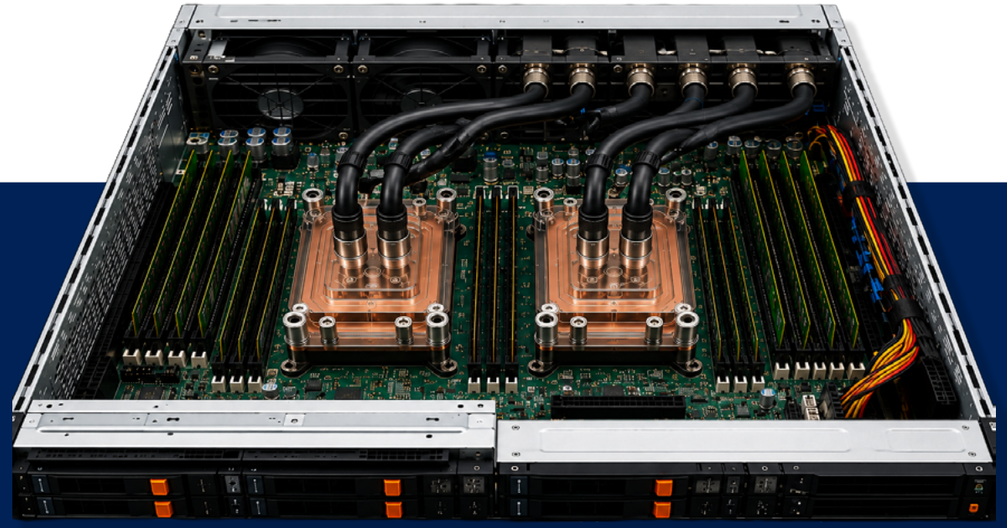
A cold plate is a heat-transfer device mounted directly on a heat-generating component such as a CPU or GPU.

Coolant flows through internal channels in the plate, absorbing heat from the component and carrying it into the liquid-cooling loop.

Cold plates are in direct contact with the CPUs Heat is transferred directly from the CPU to the coolant, then carried away by the liquid to a heat exchanger.



Server with Heatsink (Air Cooling)



Server with Direct-to-Chip (Liquid Cooling)

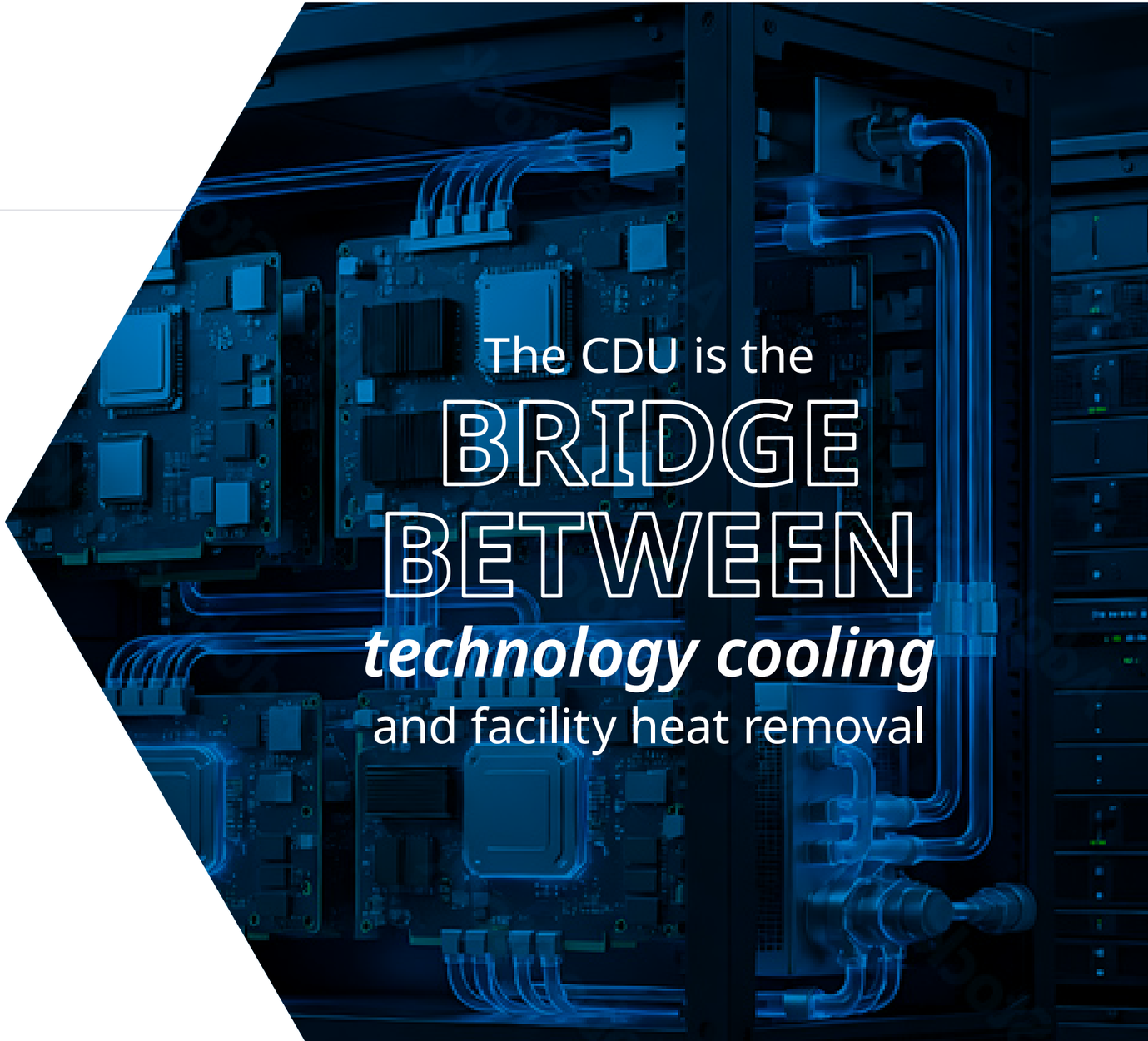
How DTC Works

7 What is a CDU?

A Coolant Distribution Unit (CDU) manages coolant circulation between IT equipment and the facility's heat-removal infrastructure.

Depending on the design, a CDU can provide pumping, heat exchange, filtration, pressure control, temperature control, monitoring, and leak-detection functions.

CDUs may serve individual racks, groups of racks, or larger portions of a data hall.



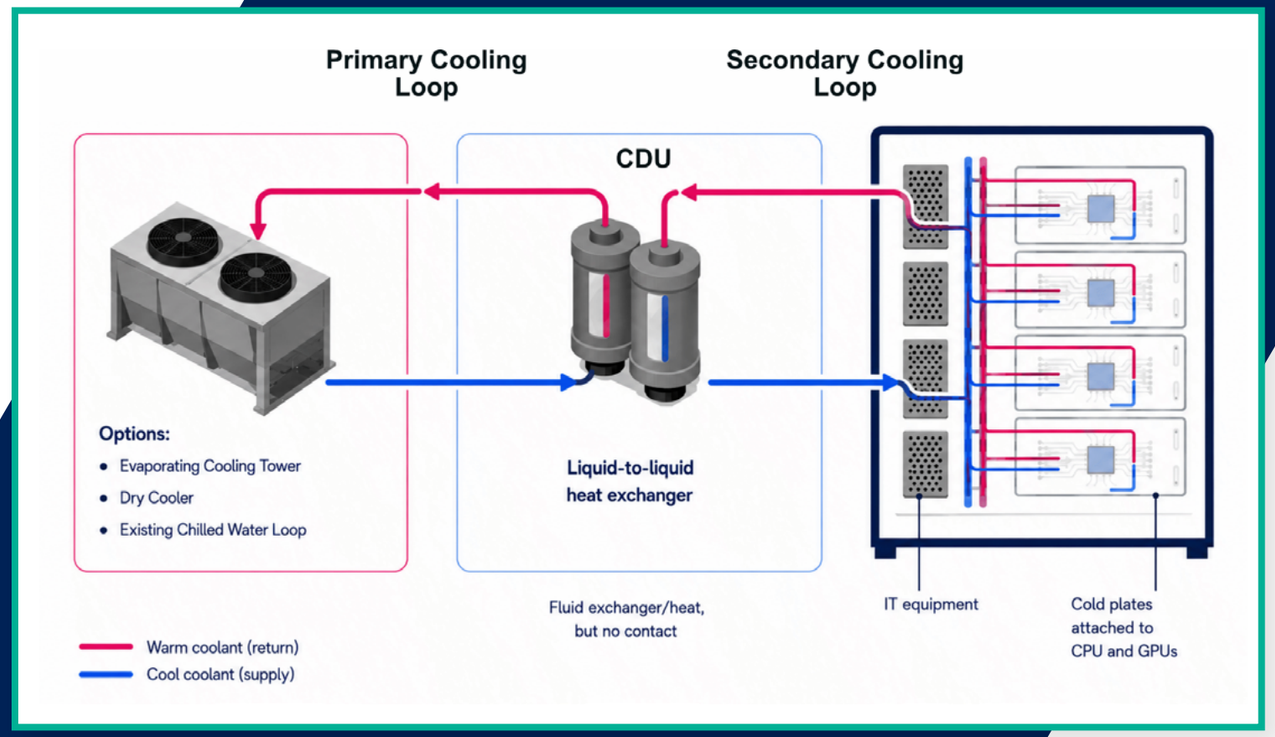
How DTC Works

8 What are primary and secondary cooling loops?

Terminology varies by system, but a DTC installation commonly separates facility water from the coolant circulating through IT equipment.

The facility or primary loop carries heat toward the building's heat-removal system. The secondary cooling system, or technology cooling loop, circulates coolant through CDUs, manifolds, servers, and cold plates.

A heat exchanger can isolate the two loops while allowing heat to transfer between them.



How DTC Works

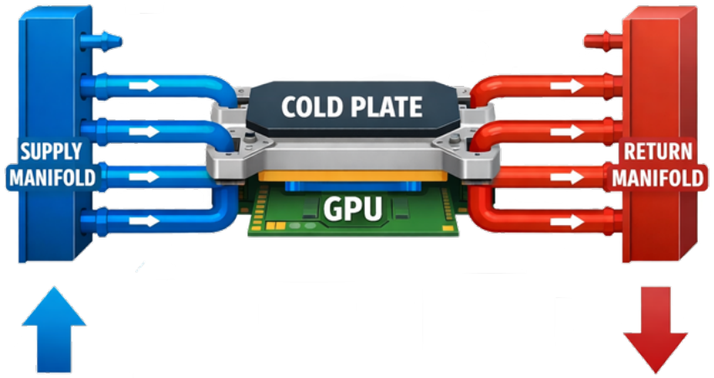
9 What is the difference between single-phase and two-phase cooling?

Single-phase and two-phase describe what happens to the coolant as it absorbs heat from IT equipment.

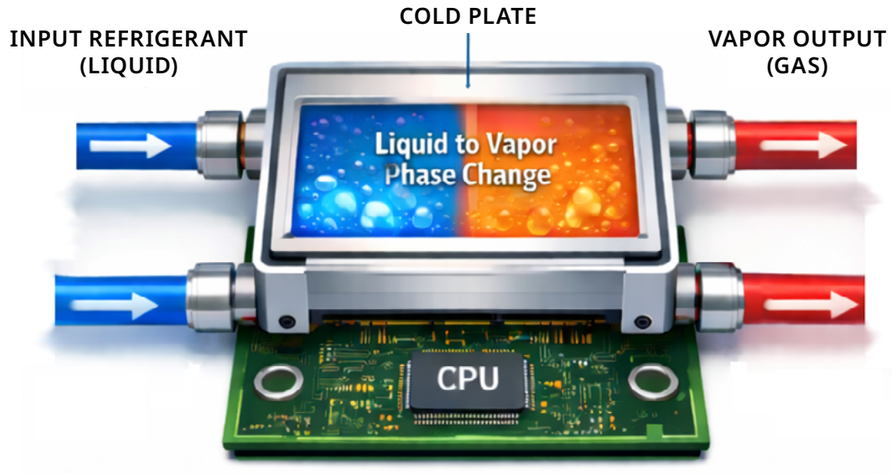
In a **single-phase cooling system,** the coolant remains a liquid throughout the cooling loop. Liquid flows through cold plates attached to CPUs, GPUs, or other high-heat components, absorbs heat, and returns at a higher temperature without changing phase. The heat is then transferred to another cooling loop or heat-removal system. Water or water-based mixtures are commonly used in single-phase systems.

In a **two-phase cooling system,** the coolant changes phase as it absorbs heat. A liquid refrigerant or dielectric fluid enters the cold plate and partially or fully vaporizes as it absorbs heat from the component. The vapor is then carried away from the IT equipment, condensed back into a liquid, and recirculated.

SINGLE-PHASE COOLING



TWO-PHASE COOLING



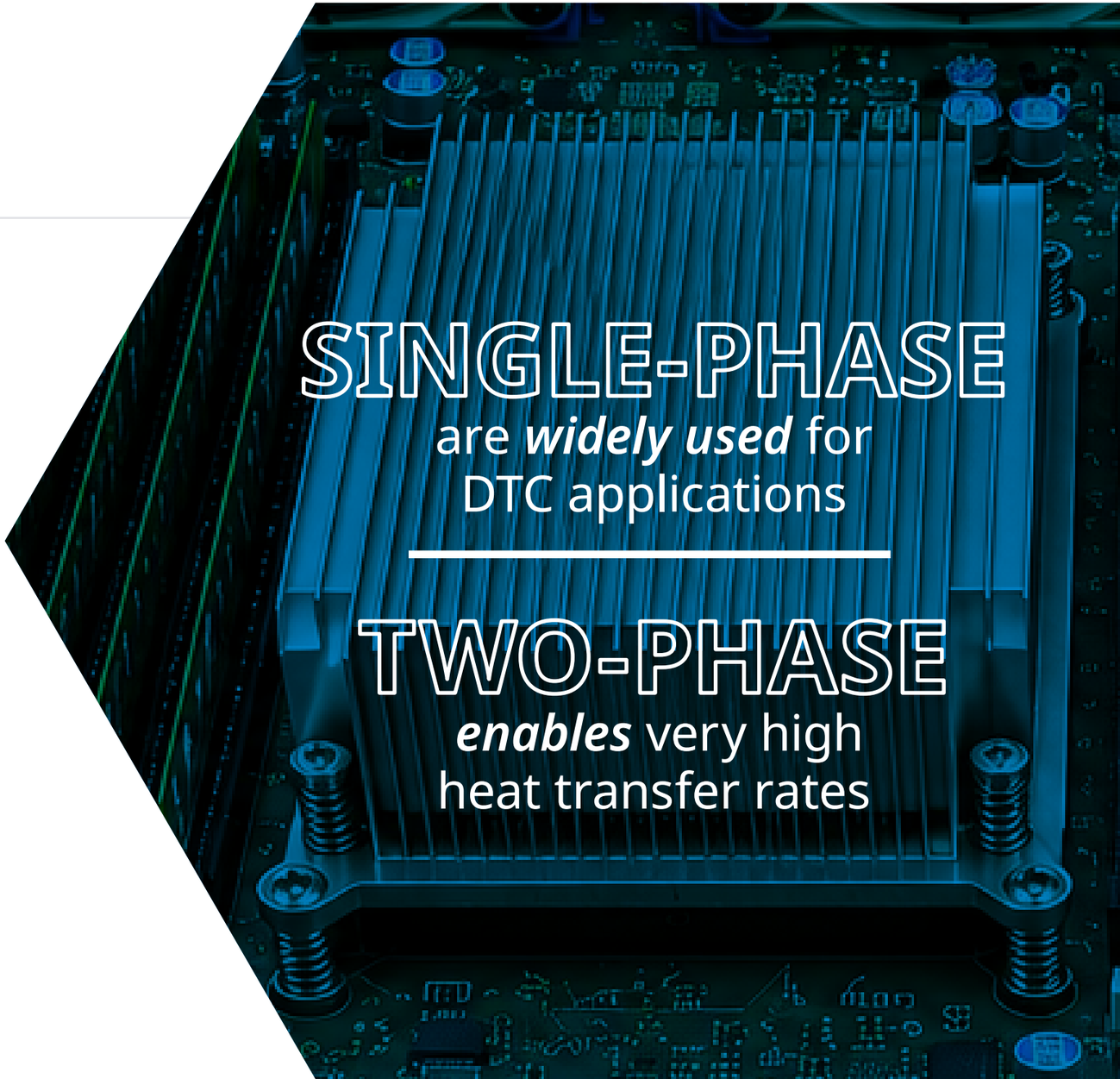
How DTC Works

10 Which approach should an organization use?

Both approaches can provide high heat-transfer performance, but they have different infrastructure and operating requirements.

Single-phase systems generally use pumps to circulate liquid and are widely used for DTC applications. Two-phase systems can enable very high heat-transfer rates, but may require specialized fluids, pressure management, controls, condensers, and service procedures.

The appropriate approach depends on chip heat flux, rack density, server compatibility, facility infrastructure, efficiency objectives, maintenance requirements, cost, and the cooling technology supported by the IT equipment.



Design and Safety

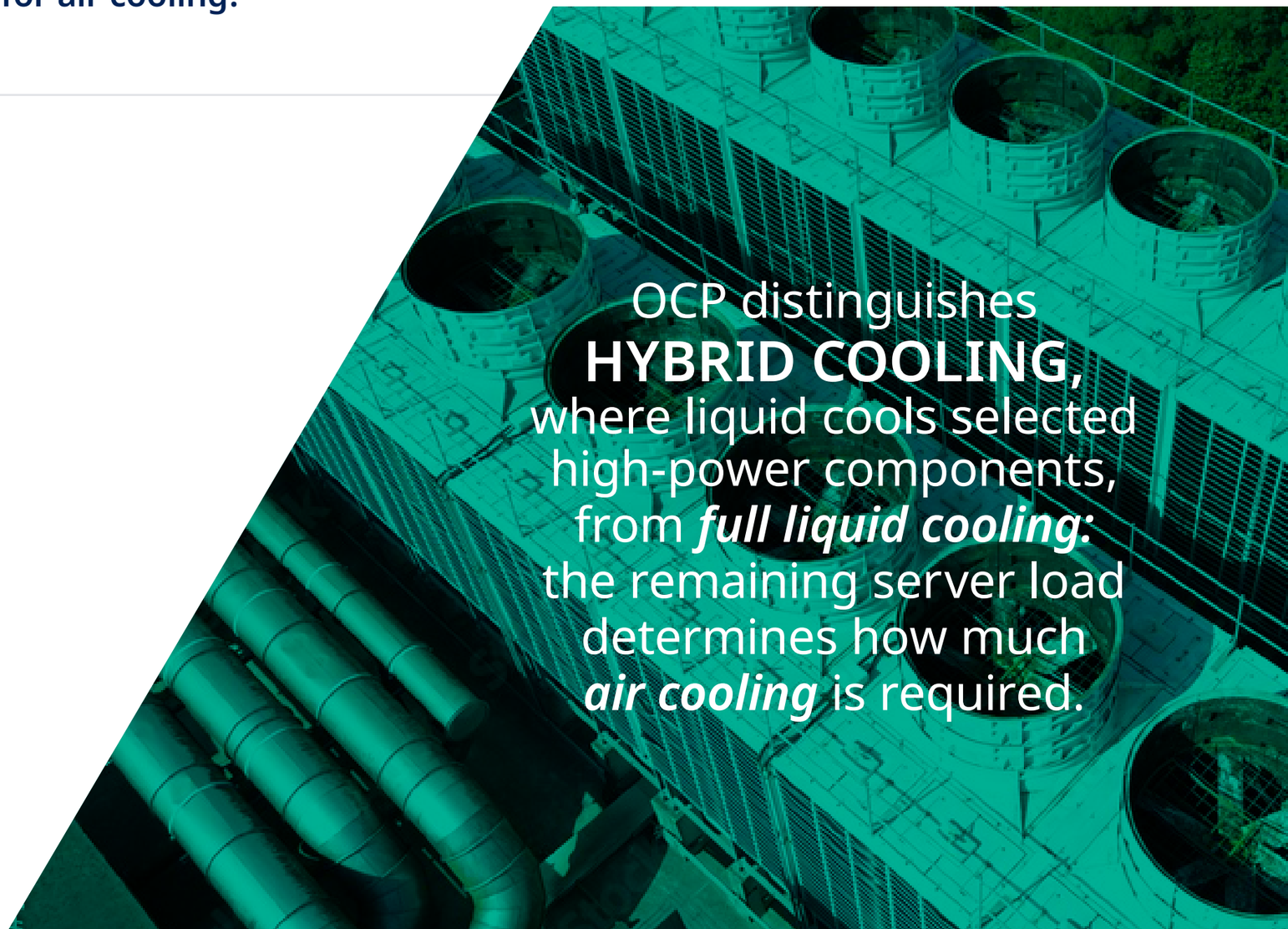
11 Does DTC cooling eliminate the need for air cooling?

Not necessarily. Many DTC systems are hybrid cooling systems. Coolant removes most of the heat generated by CPUs, GPUs, and other high-power components, while air continues to cool components such as memory, storage, power supplies, and networking hardware.

The percentage of server heat captured by liquid depends on the server and cooling-system design



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data center cooling
in our innovative
AI COOLING LAB



Design and Safety

12 What coolant is used?

plan for the ***heat*** that **LIQUID** ***captures*** and the **HEAT** that remains in the air

The appropriate coolant depends on the equipment and system design.

Treated water and water-based mixtures are common choices for single-phase DTC systems, while two-phase systems use a refrigerant or dielectric fluid. Evaluate coolant chemistry, water quality, corrosion control, biological growth, filtration, and maintenance requirements to ensure compatibility with cold plates, piping, seals, pumps, heat exchangers, and other wetted materials.

Evaluation criteria:

- **Coolant chemistry and water quality:** Confirm pH, conductivity, hardness, inhibitor levels, and contaminant limits meet equipment specifications because fluid condition directly affects heat transfer and component life.
- **Corrosion control:** Review coolant additives and the metals used throughout the loop to limit galvanic corrosion, deposits, and premature failure
- **Biological growth:** Determine whether biocides, closed-loop controls, or routine testing are needed because microbial growth can create biofilm, restrict flow, and reduce thermal performance.
- **Filtration:** Define particle-size limits, filter locations, and replacement intervals to prevent debris from clogging narrow cold-plate channels or damaging pumps.
- **Maintenance requirements** Establish sampling, fluid replacement, flushing, inspection, and recordkeeping procedures so coolant performance remains within specification over the system lifecycle.
- **Material compatibility:** Verify the coolant works with every wet material, including cold plates, piping, seals, pumps, and heat exchangers, to prevent swelling, embrittlement, leaks, and component degradation.

Design and Safety

13 Is introducing water inside a server safe?

DTC systems are engineered to manage liquid within and around IT equipment using purpose-built tubing, fittings, cold plates, monitoring, and operating controls. However, leaks remain a design and operational risk, so the cooling architecture should include detection, isolation, alarm, and maintenance procedures.

- Dripless quick-disconnect fittings
- Leak detection
- Pressure and flow monitoring
- Automated alarms and controls
- Appropriate coolant-loop pressure design
- Preventive inspection and maintenance
- Isolation valves and service procedures

14 What happens if there is a leak?

The response depends on the system design and the leak's severity.

Monitoring systems may detect moisture, abnormal pressure, or changes in flow and generate an alarm. Some systems can isolate affected equipment or shut down portions of the cooling loop.

Leak-response procedures should be incorporated into data center operating and maintenance plans.

Design the response before the event: detect, alarm, isolate, and maintain.

Watch our *Cool Smarter with Panduit Direct-to-Chip Cooling System* video

DETECT • ISOLATE • MAINTAIN

Design and Safety

15 Does DTC cooling improve data center efficiency?

Removing heat with liquid can require less energy than moving equivalent amounts of heat with large volumes of air. DTC cooling may also enable higher coolant temperatures, potentially increasing opportunities for economization and reducing compressor-based cooling.

Efficiency should be evaluated at the system level, including pumps, CDUs, remaining air cooling, facility water systems, and heat rejection:

Pumps: Measure pumping power across expected flow rates and pressure drops because excessive hydraulic resistance can offset part of the cooling-energy benefit.

CDUs: Evaluate heat-exchanger effectiveness, pump efficiency, controls, and operating range to confirm the unit can transfer the required heat efficiently under changing IT loads.

Remaining air cooling: Quantify the heat not captured by liquid and the fan or air-handling energy still required, since hybrid systems retain an air-cooling load.

Facility water systems: Review supply temperatures, flow capacity, water treatment, and distribution losses to ensure the building loop can support DTC without creating new energy or reliability constraints.

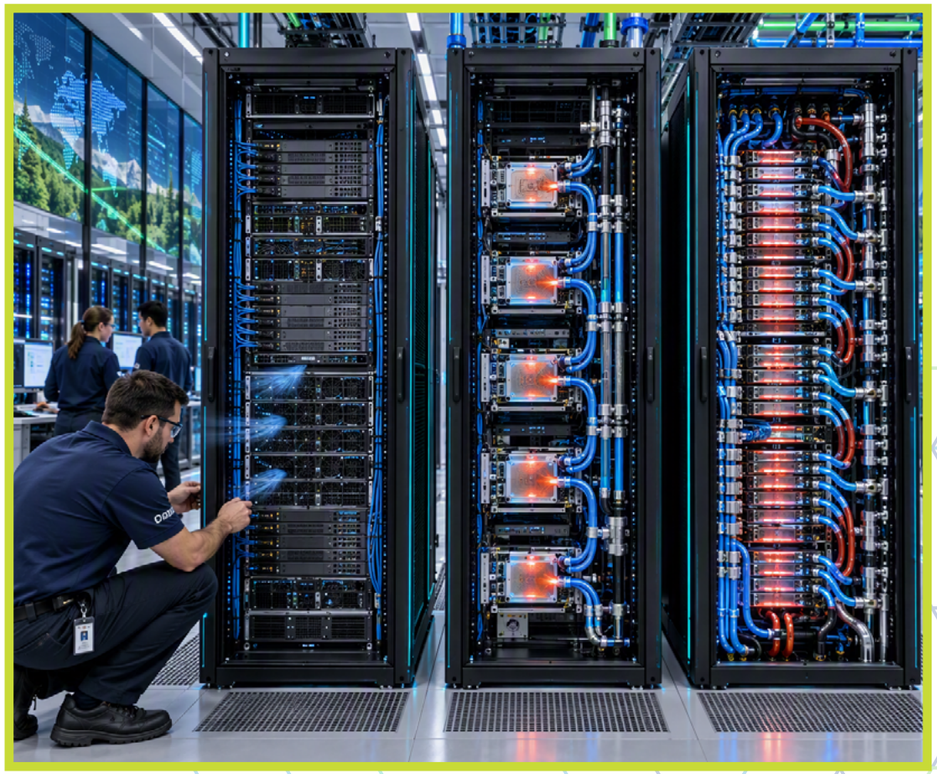
Heat rejection: Compare dry coolers, cooling towers, chillers, economizers, and heat-reuse options because climate and operating temperatures strongly influence total system energy and water use.

Design and Safety

16 How much rack density can it support?

There is no single maximum rack density. Capacity depends on the servers, percentage of heat captured by liquid, coolant temperatures, flow rates, CDU capacity, piping architecture, and facility heat-rejection system.

The cooling architecture should therefore be designed around the expected IT load and future density rather than a universal watts-per-rack threshold.



DESIGN

to expected load, ***liquid heat capture*** and future density

Plan With Confidence

17 Can Direct-to-Chip be retrofitted into an existing data center?

In many cases, direct-to-chip cooling can be retrofitted into an existing data center, but retrofit complexity varies considerably. Existing facilities may need changes to mechanical infrastructure, rack-level distribution, monitoring, service procedures, and heat removal. A successful retrofit assessment should evaluate both current requirements and expected future rack densities.

Existing facilities may require modification to:

- Facility water infrastructure
- Piping distribution
- CDUs
- Rack manifolds
- Leak detection
- Controls and monitoring
- Floor or overhead distribution
- Heat-rejection equipment
- Electrical and mechanical redundancy strategies



Plan With Confidence

18 What should organizations consider before deploying DTC cooling?

DTC cooling decisions should be made through a system-level evaluation of IT equipment, rack infrastructure, coolant distribution, facility water, controls, service procedures, and long-term capacity planning.

A practical DTC cooling readiness review should include expected rack densities, server compatibility, liquid heat-capture targets, CDU placement, rack manifold strategy, coolant chemistry, leak detection, maintenance access, facility-water capacity, redundancy, controls integration, and future expansion requirements.

It is also important to define responsibility boundaries between the IT equipment, rack infrastructure, CDU, facility piping, and heat-removal systems.

Evaluate your data center efficiency with our expert team



How Panduit Helps Businesses DTC Cooling with Confidence

For teams evaluating DTC cooling, the next step is to connect the cooling architecture to the broader physical infrastructure plan, including rack layout, cable pathways, power distribution, monitoring, service access, and future scalability.

For more than 70 years, Panduit has helped organizations solve complex infrastructure challenges through innovation, collaboration, and trusted engineering expertise. As the rapid adoption of AI reshapes data center design, Panduit is helping organizations prepare for a future where liquid cooling, higher rack densities, and greater energy efficiency are becoming the new standard.

Through purpose-built physical infrastructure solutions and advanced cooling expertise, Panduit supports customers throughout their liquid cooling journey, from assessment and deployment to optimization and scale.

With a long-standing commitment to safety, performance, and sustainability, Panduit is helping power the next generation of AI infrastructure.

Learn more at **panduit.com/dtc**

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Head back to the start.

We have the knowledge and experience to help you make the most of your infrastructure investment.

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