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Cabinet-Integrated Liquid Cooling Supports Rising Power Density and Maximum Sustainability for High-Performance Computing Data Center Environments

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Introduction

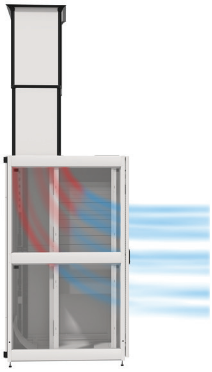
The demand for digital services and high-performance computing (HPC) technologies such as artificial intelligence (AI), machine learning (ML), and advanced data analytics is increasing rapidly. As a result, power density requirements in the data center industry are reaching new heights, rising from an average of 2.4 kilowatts (kW) in 2011 to 8.4 kW in 2020. With AI requiring nearly three times more power than traditional computing functions, today's HPC data centers frequently require rack densities of 50 kilowatts (kW) and above. This increase in power density leads to higher heat generation and necessitates effective cooling solutions to prevent equipment failure and costly downtime.

Data center cooling accounts for 30 to 50% of total energy consumption. Additionally, rising energy prices and the need to comply with increasingly stringent energy consumption regulations and sustainability goals drive the industry to seek more efficient cooling solutions. Initiatives such as the Energy Efficiency Directive (EED) in Europe and proposed legislation in the United States aim to reduce data center carbon emissions.

Liquid cooling technology has emerged as an efficient solution to address these challenges, removing heat more effectively than air to enable higher power densities and improved sustainability. The global data center liquid cooling market is projected to grow from $2.1 billion in 2022 to 6.4 billion by 2027, with water-based and dielectric fluid-based solutions gaining traction.

The Need for Liquid Cooling

Traditional air-based cooling methods, such as hot aisle/cold aisle configurations and containment solutions like cold aisle containment (CAC), hot aisle containment (HAC), and vertical exhaust ducts (VED), have been effective in managing heat in data centers with lower power densities. However, as power densities continue rising, these solutions become less efficient, requiring additional cooling capacity and lower supply temperatures. Moreover, not all data center spaces are suitable for containment solutions.



Liquid cooling offers better heat conduction capabilities than air and enables higher rack power densities without aisle containment, raised floors, or air handlers. As shown in Figure 1, standard 1U and 2U servers become increasingly difficult to cool via air as central processing unit (CPU) power increases from 300W to 400W. Only liquid cooling can cool equipment with a CPU power of 400W or higher.

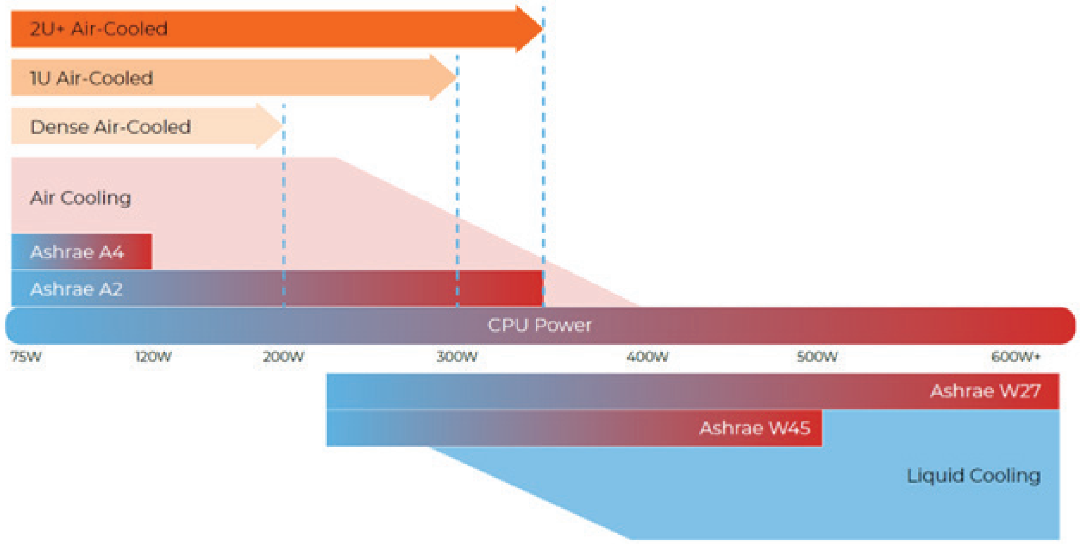


Figure 1: Transition from air cooling to liquid cooling based on CPU power and ASHRAE air-cooled and liquid-cooled classes for equipment operation. Source: ASHRAE

Types of Liquid Cooling

Liquid cooling solutions can be categorized into three main types:

Rear Door Heat Exchangers

This solution involves using liquid-filled coils in the rear door of the cabinet, where hot exhaust air from the equipment passes through the coils and is returned to the room at ambient temperature. The heated liquid is returned to the Coolant Distribution Unit where it is cooled typically via a chilled water loop and pumped back through the coil. Rear door heat exchangers can be either active or passive, with active ones incorporating integrated fans. This solution requires plumbing for the cabinet but supports standard IT equipment and can mount to traditional 19" EIA cabinets.

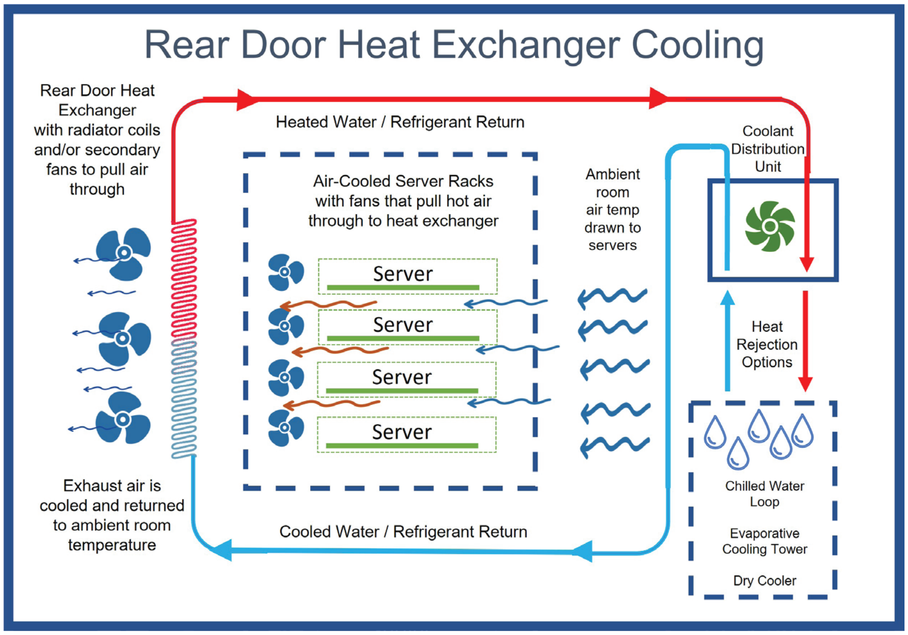


Figure 2: Rear door heat exchanger liquid cooling solution

Liquid Immersion Cooling

In this approach, electronic components are submerged in a coolant, typically a dielectric fluid, contained in a tank or sealed enclosure. Immersion cooling requires specially adapted servers and IT equipment, and the nature of the rack orientation requires equipment to be lowered in and out vertically, typically via an overhead lift. Immersion cooling can be single-phase or two-phase, with the latter offering enhanced cooling capabilities through evaporation and condensation. Immersion cooling typically rejects heat via a heat exchanger and the building chilled water loop.

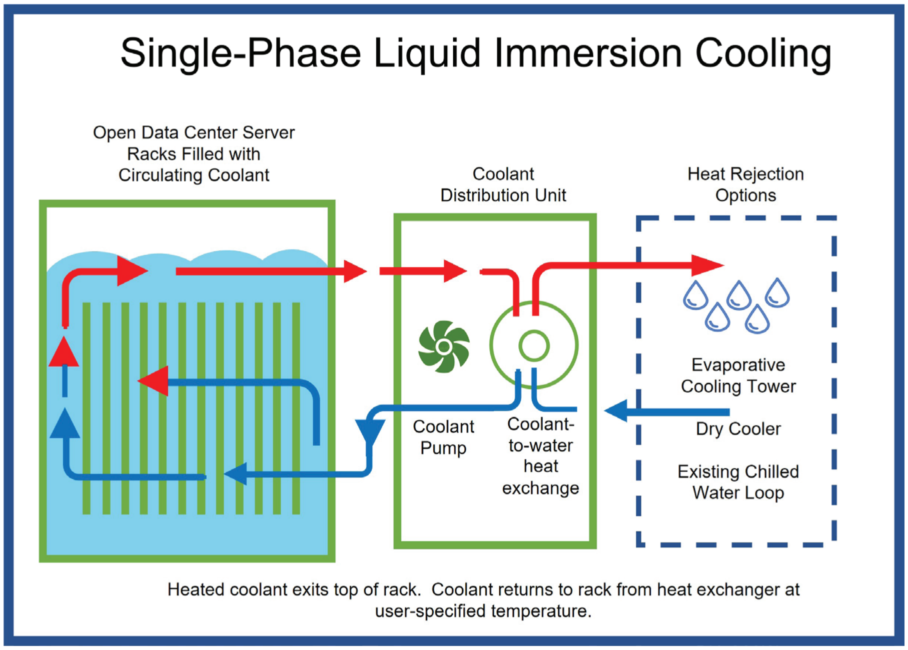


Figure 3: Single-phase liquid immersion cooling solution

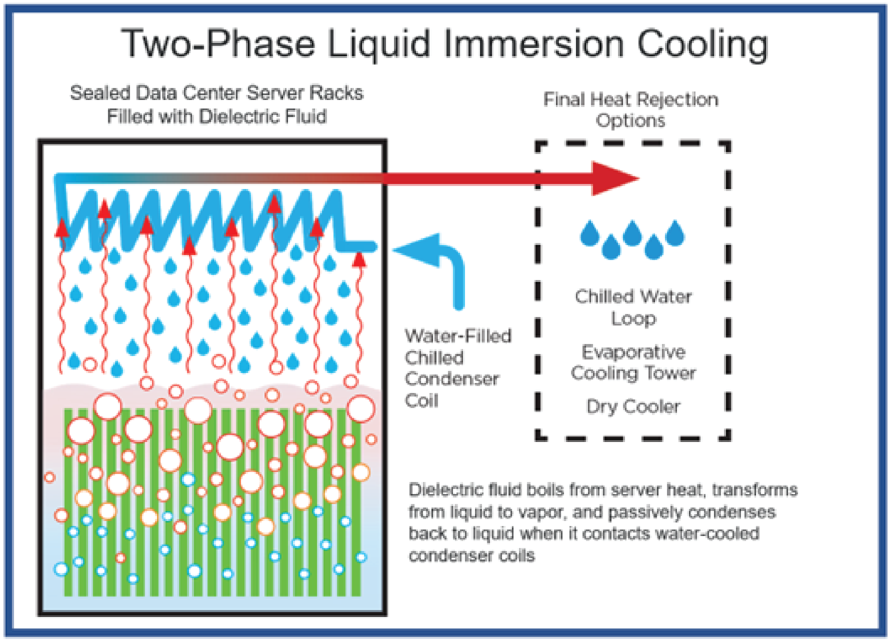


Figure 4: Two-phase liquid immersion cooling solution

Direct On-Chip Cooling

Also referred to as cold plate or direct liquid cooling, direct on-chip cooling provides the most efficient heat transfer with the ability to cool CPU power up to 1000 W. As shown in Figure 5, direct on-chip cooling involves pumping chilled water or dielectric fluid to cold plates that attach to heat-generating components within the equipment, such as CPUs, graphical processing units (GPUs), and field programmable gate arrays (FPGAs). Direct on-chip cooling can be single or two-phase, with two-phase systems always using dielectric fluid.

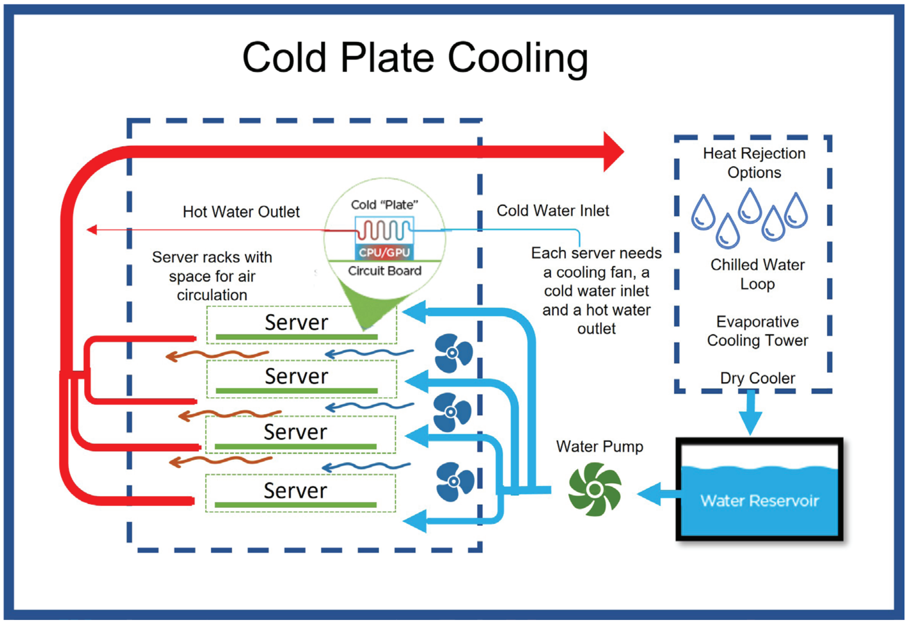


Figure 5: Direct on-chip, or cold plate, cooling solution

Two-Phase Direct On-Chip, Closed-Loop Dielectric Liquid Cooling – The Optimum Choice

When selecting a liquid cooling solution for high rack power densities and improved efficiency, several factors should be considered, including ease of adoption, deployment cost, reliability, efficiency, and sustainability. Based on these factors, two-phase direct on-chip liquid cooling is the optimum liquid cooling method.

Two-phase direct on-chip dielectric liquid cooling systems are comprised of three main components:

- Cold Plates sit on the processors in the server and allow the dielectric fluid to boil and vaporize the heat away from the processors and servers, never making direct contact with electronics.
- Distribution manifolds distribute the dielectric fluid to the cold plates via outlet ports and returns vaporized fluid back to the HRU via inlet ports.
- Heat Rejection Units (HRUs) moves the dielectric fluid to the servers via manifolds and ensures efficient condensation of the vapor and rejection of the heat it contains. HRUs are self-contained, fully autonomous units that have independent sensors, pumps, controllers, and multi-level leak detection and prevention that support higher rack power densities. They utilize air or water as their cooling source, depending on the data center's design and specifications.

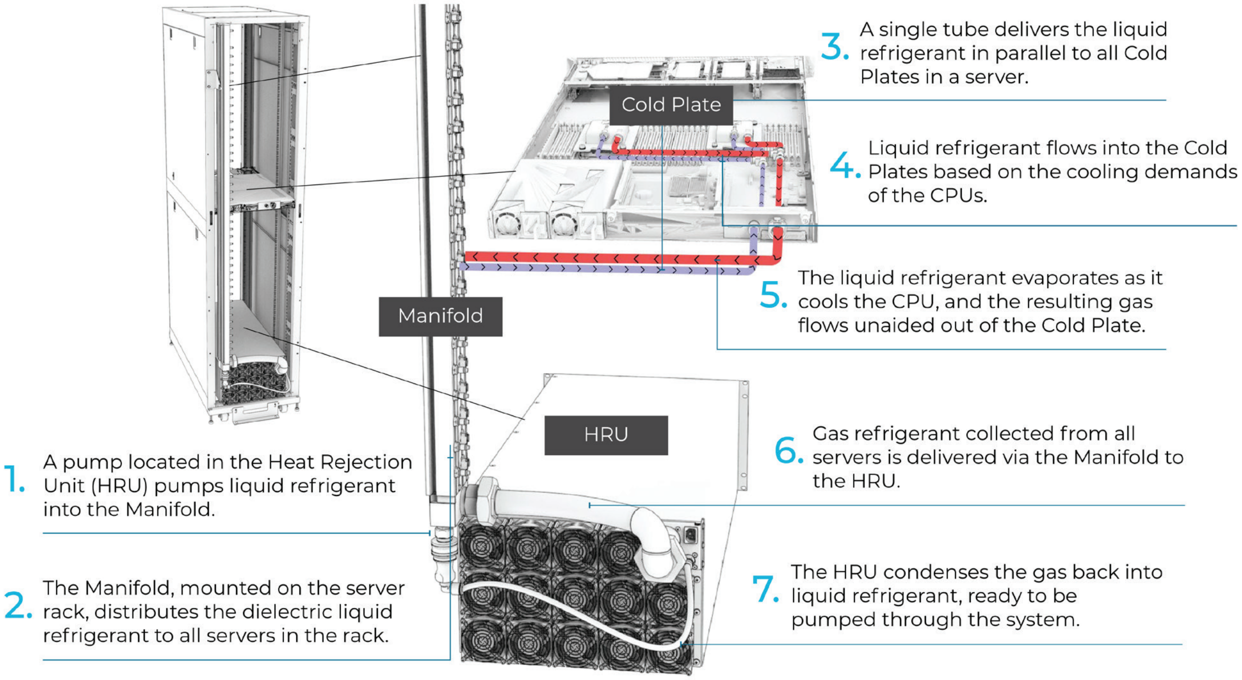


Figure 6: Two-phase direct on-chip, closed-loop dielectric liquid cooling solution with an air HRU

Two-phase direct on-chip liquid cooling is the most effective form of cooling because it is applied directly to the processors to extract and disperse heat. It increases server efficiency by lowering the power draw when the fans are not in use, allowing data centers to raise the ambient air temperature and save power and cooling costs. The highly efficient, two-phase boiling and condensation process uses no water in the system, so equipment is protected from corrosion and other water-related threats.

Two-phase direct on-chip liquid cooling offers several advantages:

- **Ease of Adoption** – It can be easily retrofitted into existing data center environments with minimal setup and disruption. Cold plates can replace server heat sinks, and servers can remain horizontally positioned within standard racks.
- **Lower Deployment Costs** – Compared to liquid immersion cooling, two-phase direct on-chip cooling requires less dielectric fluid, reducing costs and the risk of overloading weight capacities. The smaller footprint makes it more space efficient. A typical full, high-density rack uses only approximately three gallons of dielectric fluid.
- **Superior Reliability** – Leaks in a single-phase water-based cooling system affect the entire rack, causing all equipment to go offline. In contrast, leaks in a two-phase direct on-chip solution only impact individual servers. Dielectric fluid eliminates the risk of water damage, and any leaks dissipate harmlessly into the air.
- **Higher Efficiency** – Directly cooling heat-generating components improves efficiency, and dielectric fluid outperforms water in heat removal. The use of smaller tubing enhances power usage effectiveness (PUE) compared to other solutions.
- **Enhanced Sustainability** – Two-phase direct on-chip liquid cooling utilizes the temperature of hot vapor, ranging between 40 and 60°C (86 – 104°F), to extract heat from data center equipment. As shown in Figure 7, this heat can be expelled outside the data center or reused locally or externally through heat-reuse applications, significantly reducing the carbon footprint of the entire system and bringing data centers closer to achieving net-zero emissions.

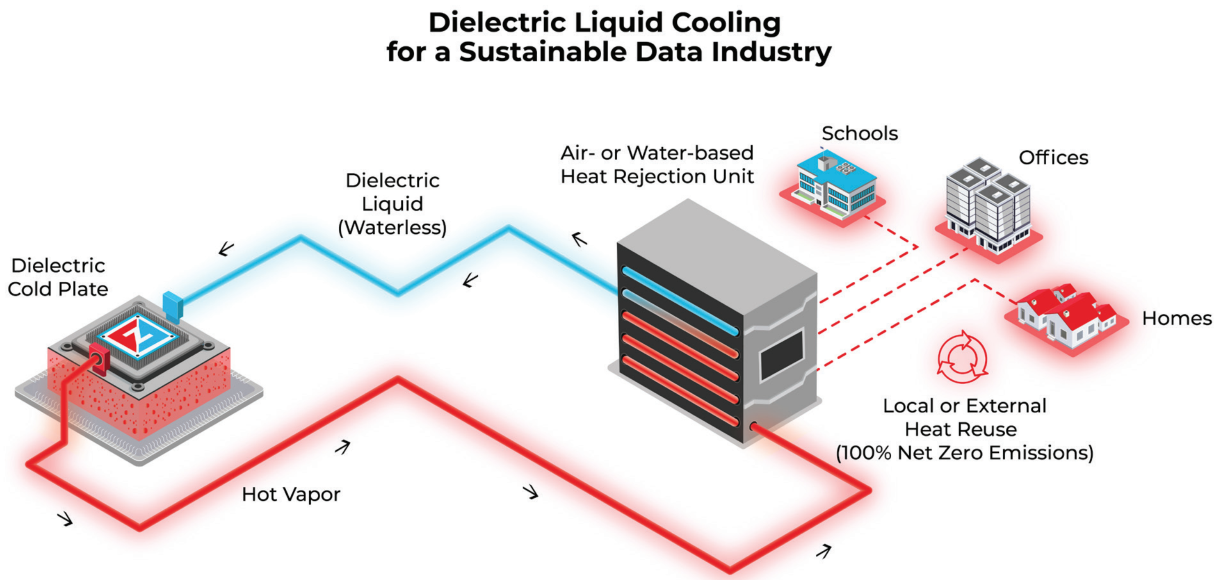


Figure 7: Local or external heat reuse for enhanced sustainability

The Value of an Integrated Cabinet Solution

An integrated cabinet solution is crucial for successfully implementing direct on-chip liquid cooling needed to meet next-generation computing demands. Cabinets must provide sufficient load capacity to support the weight of HRUs, network equipment, and components. Additionally, they must accommodate the manifold and inlet and outlet connections for the cold plates while providing space for mounting accessories like power distribution units (PDUs) and cable management. Ideally, an integrated cabinet solution should incorporate proactive power and environmental monitoring, secure access control, and comprehensive DCIM capabilities for data centers to optimize system performance, mitigate risks, and enhance overall efficiency.

- **Power Monitoring** – Incorporating intelligent PDUs into the integrated cabinet solution provides significant benefit for HPC data centers, improving overall efficiency and reliability. One of the key features of intelligent PDUs is their ability to provide real-time monitoring of power parameters and usage. This gives data center operators immediate visibility into power consumption, enabling them to make informed decisions regarding resource allocation and optimization.
- **Environmental Monitoring** – One of the most common causes of downtime is hardware failure resulting from exceeded temperature or humidity levels within the cabinet. The ability to monitor these environmental conditions and identify and address any issues before they result in downtime is a key component in any data center management strategy. Intelligent PDUs provisioned with environmental ports users can remotely monitor, record, and analyze environmental conditions at the cabinet level. This provides a simple, automated environmental monitoring solution that alerts critical thresholds to prevent downtime.
- **Secure Access Control** – Securing personal and business data from theft has become an issue of paramount importance. Access to IT equipment within cabinets must be properly controlled and managed. Incorporating a networked electronic access control solution into the integrated cabinet solution prevents unauthorized physical access. It can also provide administrators with an audit trail of all authorized and unauthorized access attempts.
- **Optimized Management** – Incorporating Data Center Infrastructure Management software—or DCIM—allows data center managers to gain better visibility into the health of data center assets and operation via a single dashboard. It can turn power usage measurements and alerts from intelligent PDUs, environmental monitoring, and access control into actionable information. DCIM can also help visualize trends in the room and cabinet, track usage against known capacity, identify areas for improvement, and measure results in a single interface.

Conclusion

As power densities in HPC data centers continue to rise, efficient cooling solutions become paramount. Liquid cooling technology offers superior heat dissipation capabilities, enabling higher rack power densities while reducing energy consumption and carbon emissions. Among various liquid cooling options, two-phase direct on-chip liquid cooling emerges as the most favorable choice due to its ease of adoption, lower deployment costs, superior reliability, higher efficiency, and enhanced sustainability.

With two-phase direct on-chip liquid cooling, data centers are no longer required to prioritize cooling over performance, allowing them to invest in higher-end processors and denser systems to support the evolving demands of high-performance computing. By integrating advanced liquid cooling technology with advanced cabinet systems, densely configured racks can support higher core counts and workloads, allowing data centers to utilize real estate more efficiently. And when also integrated with intelligent PDUs for power and environmental monitoring, access control for security, and DCIM for optimized management, the benefits are unmatched.

To facilitate the adoption of direct on-chip liquid cooling, Chatsworth Products (CPI) has partnered with ZutaCore® to offer a complete integrated solution. This solution combines CPI's ZetaFrame® cabinet and eConnect® PDUs with ZutaCore's HyperCool® direct on-chip dielectric liquid cooling solution.

- **The HyperCool solution** is a highly efficient closed-loop system that supports high rack power densities, up to 100 kW per rack, and is available with either air or water-based HRUs. It includes a manifold for distributing the cooling fluid and cold plates for heat transfer. The operation of this liquid cooling system is fully automated and self-regulated, continuously monitoring CPU temperature and coolant reserve levels to ensure optimal cooling performance. Additionally, the availability of HyperCool Software Defined Cooling allows for automated resource provisioning and management, further enhancing system performance and optimization.
- **The ZetaFrame® cabinet** provides the necessary structural support for the liquid cooling solution. With its high load capacity 4,000 lb. dynamic load rating, and wide form factor (800mm), the cabinet easily accommodates the ZutaCore direct on-chip dielectric liquid cooling solution, even when racks are fully loaded and used in conjunction with a shock pallet. It provides mounting space and provisions for the ZutaCore Heat Rejection Unit (HRU), manifold, PDUs, and other necessary accessories to optimize space utilization and simplify the deployment process. An RFID Electronic Lock Kit can be preinstalled in a cabinet for quick deployment and offers multiple methods of integration.
- **eConnect PDUs** enable real-time monitoring of power parameters and environmental conditions, maximizing availability, uptime, and energy efficiency. These PDUs are designed to support high rack power densities, accommodating up to 57kW on a single PDU. eConnect PDUs also support seamless software integration with the ZutaCore HyperCool solution, as well as cabinet access control for security. Power IQ® for eConnect, a DCIM software solution, utilizes measurements and alerts from the eConnect PDU, environmental monitoring, and access control to provide actionable information. It enables users to track power usage against known capacity, identify areas for improvement, and measure results in a user-friendly and robust interface.

Commitment to Sustainability

CPI and ZutaCore share a common commitment to environmental sustainability and reducing the carbon emissions associated with data centers. By leveraging two-phase direct on-chip liquid cooling technology, these companies aim to help customers achieve their data center power density requirements, comply with energy consumption regulations, and meet their sustainability goals. They collaborate closely with customers to deliver the right ZetaFrame-HyperCool integrated solution tailored to their specific needs.

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Todd Schneider is the Director of Product Management and Hyperscale Business Development at Chatsworth Products, Inc. Todd has over 25 years experience in the data center space covering a wide variety of functional areas including Product Management, Business Development, Sales Engineering and Product Development. His current roles focus on driving standard new product innovation to CPI's core offerings and delivering customer-centric, customized solutions for Hyperscale Operators. Schneider previously worked at Legrand, Electrorack and Wright Line.

Alison Deane
Vice President, Marketing, ZutaCore

Alison is an experienced marketing executive dedicated to promoting sustainability in the data industry through dielectric liquid cooling. Her career has taken her across Europe and the United States, where she has contributed to revenue growth through data-driven marketing strategies and innovative campaigns that resonate with customers in the Data Storage, SaaS, and Cloud markets. As Vice President of Marketing at ZutaCore, Alison is responsible for developing and implementing the company's global marketing strategy to build brand loyalty and advocacy. Before joining ZutaCore, she held senior marketing roles at several leading technology companies, where she developed expertise in demand generation, product marketing, and brand management. Outside work, Alison enjoys kickboxing and having fun with her sons, who share her passion for traveling, biking, and hiking.

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