TECHNOLOGY BRIEF

Data Center Memory and Storage Hierarchy
Intel® Optane™ Technology

# Reimagining Memory and Storage in the Data Center

**Innovative new technologies from Intel are transforming the memory and storage hierarchy.**

## High Stakes in the Data Center

Mountains of data promise valuable insights and innovation for businesses that rethink and redesign their system architectures. But companies that don't re-architect might find themselves scrambling just to keep from being buried in the avalanche of data.

The problem is not just in storing raw data, though. For businesses to stay competitive, they need to quickly and cost-effectively access and process all that data for business insights, research, artificial intelligence (AI), and other uses. Both memory and storage are required to enable this level of processing, and companies struggle to balance high costs against limited capacities and performance constraints.

The challenge is even more daunting because different types of memory and storage are required for different workloads. Furthermore, multiple technologies might be used together to achieve the optimal tradeoff in cost versus performance.

Intel is addressing these challenges with new memory and storage technologies that empower businesses to reimagine their data center architectures.

## Gaps in the Memory and Storage Hierarchy

Historically, memory and storage solutions have been limited by density, performance, and cost. This limitation has been felt across all kinds of organizations, from retail to government to healthcare to finance. For example, cloud service providers (CSPs) can struggle to meet service-level agreements (SLAs) as data loads increase. Financial-services companies can run up against capacity and performance limits for rapidly processing high volumes of transactions. And enterprise businesses can't keep pace with in-memory analytics needs stemming from customer, inventory, social media, and Internet of Things (IoT) data—primarily due to the high costs and limited capacity of dynamic RAM (DRAM).

To manage data efficiently and effectively, businesses need to determine which infrastructure components best match their needs and budgets. That's no easy task because each technology in the hierarchy has its strengths and weaknesses:

- DRAM is great for performance, but it's expensive, volatile, and has limited scalability.
- Flash storage (NAND) is non-volatile and less expensive than DRAM, but it lacks DRAM's performance.
- Spinning hard-disk drives (HDDs) provide massive storage at the lowest price, but physical discs bring well-understood total cost of ownership (TCO) issues around reliability, physical space requirements, cooling, and power.

Collectively, these traditional storage options have left significant gaps in the memory and storage continuum in the data center, thus limiting the performance of applications. Ever-increasing amounts of data, and the need to access more of it quickly, have further magnified the problem.

In particular, two memory and storage gaps stand out for organizations trying to transform their data centers:

- Between costly, low-capacity DRAM and more affordable NAND-based solid-state drives (SSDs)
- Between slower NAND SSDs and lower-cost, but less reliable, HDDs

Organizations have not had viable options that balance cost, capacity, and performance to bridge those gaps—until now (see Figure 1).

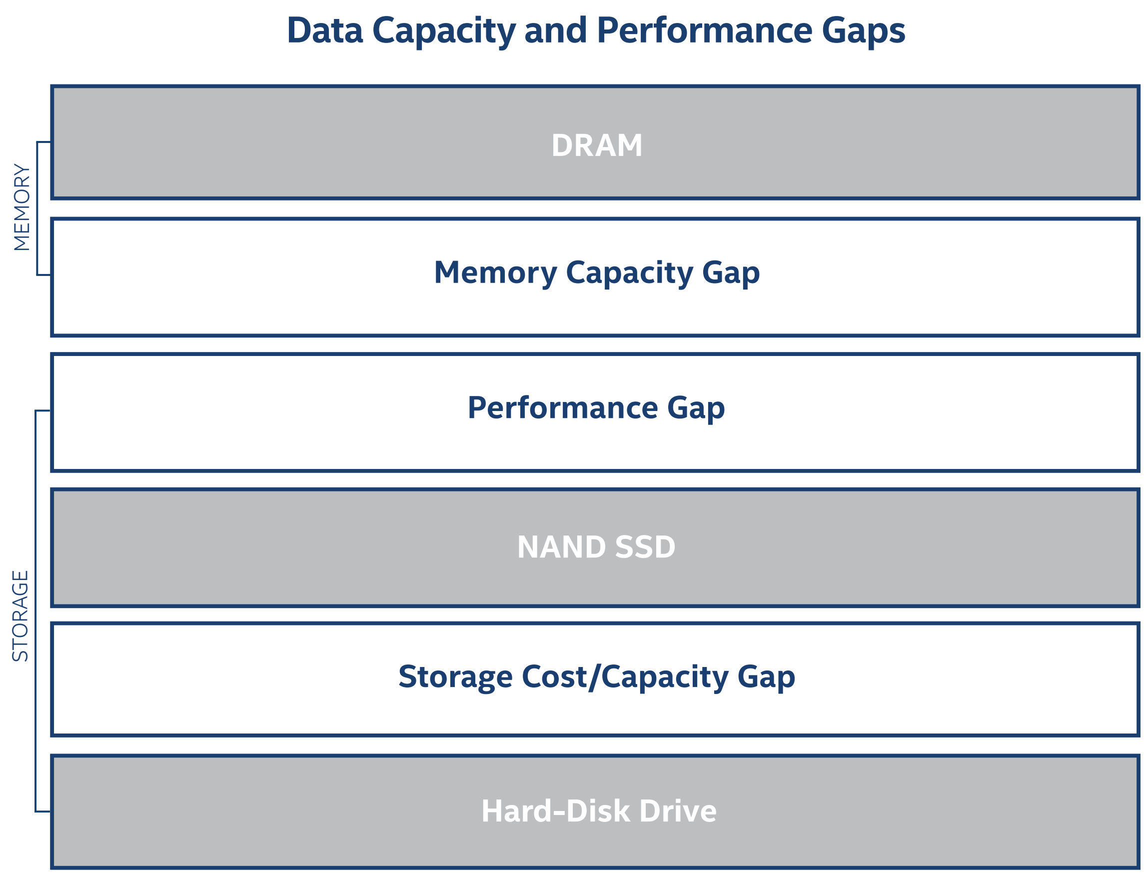


**Figure 1.** The traditional memory and storage continuum leaves large gaps in capacity, cost, and performance

## Closing the Gaps with Intel Technologies

Intel eliminates data center memory and storage gaps with solutions designed to provide high performance, capacity, and reliability. These solutions deliver low latency and greater operational value than traditional options. Three product families in particular are designed to close cost and performance gaps in the data center with flexibility for new data tiers:

- **Intel® Optane™ DC Persistent Memory** represents a new class of memory and storage technology that offers high capacity, affordability, and persistence. It allows organizations to maintain larger amounts of data closer to the processor, so workloads and services can be optimized to reduce latencies and enhance performance.
- **Intel® Optane™ DC SSDs** combine attributes of memory and storage with high throughput, low latency, high quality-of-service (QoS), and high endurance.
- **Intel® QLC 3D NAND SSDs**, such as the Intel® SSD D5-P4320, offer the highest Peripheral Component Interconnect Express* (PCIe*) data-volume density on the market at a price that makes them ideal HDD replacements for storing less frequently accessed data.

These innovative products let you reimagine data center configurations to handle modern workloads and keep your business competitive. Each product is described in detail below, with real-world examples of the performance, capacity, and cost benefits they provide.

## Intel® Optane™ Technology Creates a New Tier in the Data Hierarchy

Businesses must rethink solutions in previously unimagined ways, adapting to new technologies and evolving to meet their clients' needs. Intel Optane technology is a new, non-volatile storage option based on Intel® 3D XPoint™ technology that modernizes the existing data center architecture with a new tier in the memory and storage hierarchy, filling the gap between high-performing volatile memory and lower-performing, but affordable, NAND storage. Intel Optane technology is unique in its combination of low latency, high quality of service (QoS), high endurance, and high throughput.

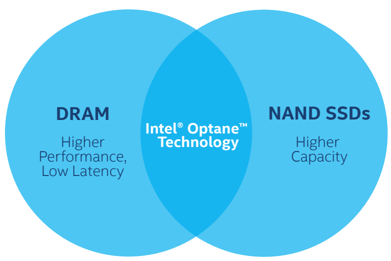


**Figure 2**. Intel® Optane™ technology combines the performance benefits of DRAM with the capacity benefits of NAND SSDs

Intel Optane technology is ideal for handling "working data": data that needs to be close to the CPU for rapid access. Working data is about getting much faster access to much more data for real-time analytics, financial transactions, flight reservations, and other use cases that require predictably fast read-response times—when average response times are not good enough. In working data, predictable and consistent performance are important even from the first requests.

Both Intel® Optane™ DC persistent memory and Intel® Optane™ DC SSDs are built on Intel Optane technology. But, as described below, each has a different form factor, and they can be used separately or together in the data center to offer innovative new memory and storage options for businesses.

### Intel Optane DC Persistent Memory Lets You Extend or Displace Costly DRAM

Intel Optane DC persistent memory is an industry-disrupting product that fills the gap between DRAM and Intel Optane DC SSDs. For companies that rely on in-memory processing of data, Intel Optane DC persistent memory opens the door to accessing much higher quantities of "hot" data for AI, analytics, high performance computing (HPC), and other uses.

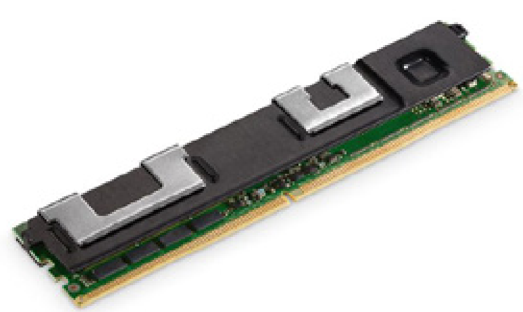

**Figure 3**. Intel® Optane™ DC persistent memory module

Unlike traditional DRAM, Intel Optane DC persistent memory combines high density, affordability, and persistence. By expanding affordable system memory capacities (greater than 3 TB per CPU socket), businesses can better optimize their data center workloads by moving larger amounts of data closer to the processor and minimizing the higher latency of accessing data from traditional non-volatile system storage.

Intel Optane DC persistent memory will be widely available in 2019, with the release of the next-generation Intel® Xeon® processor Scalable family.

### The Intel® Optane™ SSD DC P4800X Tackles Working Data in the Data Center

Intel® Optane™ SSD DC P4800X drives look like standard SSDs, but because they are built on Intel Optane technology, they are not NAND-based. The unique architecture of the Intel Optane SSD DC P4800X provides breakthrough performance that is both faster and more consistent than NAND-based SSDs. NAND-based drives typically have fast read times but slow write times—and even slower write times under the stress of high-frequency operations. In contrast, Intel Optane DC SSDs are architected to perform writes at the byte- or page-level for faster and much more predictable performance, with more balanced read and write performance, and with no need for garbage collection.

The Intel Optane SSD DC P4800X maintains consistent read-response times regardless of the write throughput applied to the drive. The graph in Figure 4 shows just how much lower the latency of an Intel Optane DC SSD is compared to a current generation Intel® 3D NAND SSD, especially under the pressure of increasing random-write operations. Unlike NAND-based SSDs, the latency of Intel Optane DC SSDs remains consistently low for all write requests.[1]

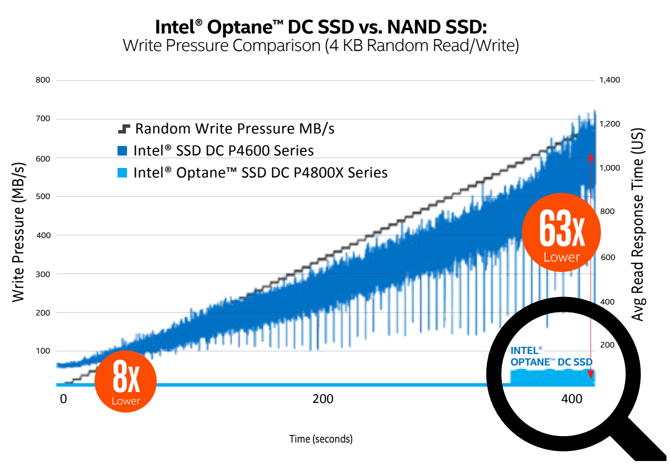


**Figure 4.** The Intel® Optane™ SSD DC P4800X provides consistently low latency compared to an Intel® 3D NAND SSD[1]

The combination of low, consistent latency and high endurance allows Intel Optane DC SSDs to function much more efficiently as caching devices than NAND-based solutions.

A study from Evaluator Group demonstrated the impact of replacing an all-NAND-flash write caching and storage solution with Intel Optane DC SSDs in the caching layer. Testing found that a system built on Intel Xeon Scalable processors, using Intel Optane SSD DC P4800X drives for the caching layer, delivered up to 3x better price/performance levels than previous-generation systems and storage media, as measured by the IOmark-VM* benchmark.[2]

The Intel Optane SSD DC P4800X also provides much greater endurance than NAND-based drives. A comparison of two currently shipping drives, for example, shows up to 60 drive writes per day (DWPD) for the Intel Optane SSD DC P4800X compared to just 3 DWPD for the NAND-based Intel® SSD DC P4600.[3] This makes Intel Optane DC SSDs much more durable in high-traffic caching environments.

Intel Optane DC persistent memory can also be combined with Intel Optane DC SSDs to create an entirely new, flexible, memory-like tier, as shown in Figure 5. Valuable data traditionally trapped in slower NAND storage can be quickly accessed and acted upon.

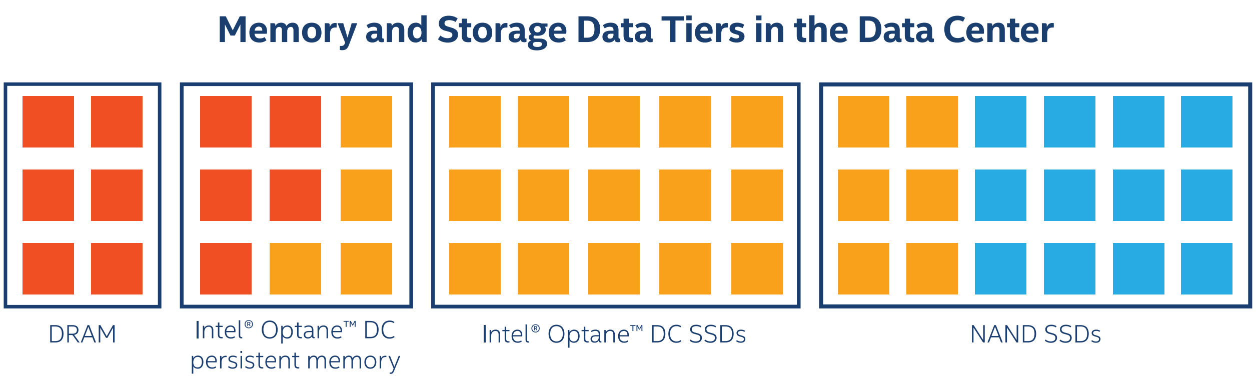


**Figure 5.** Intel® Optane™ DC persistent memory can be combined with Intel Optane DC SSDs to create a whole new tier for handling hot working data and warm capacity data for in-memory analytics (red = "hot" data, yellow = "warm" data, and blue = "cold" data)

## Optimize Software to Take Advantage of Intel Optane Technology Performance

Significant improvements in performance can be achieved simply by adding Intel Optane DC SSDs to an existing data center infrastructure, but software optimizations can generate even greater performance results for applications running on Intel Optane technology. Open source software, in particular, matches well with Intel Optane DC SSDs because developers can modify applications to take advantage of the benefits offered by the Intel Optane SSD DC P4800X.

At Oracle, for example, a performance architect optimized MySQL* for the Intel Optane SSD DC P4800X, which resulted in a 5x performance improvement on heavy input/output (I/O)-bound workloads. The Oracle architect also achieved 1 million reads from a single Intel Optane DC SSD.[4]

In another example, optimizations to Direct I/O* demonstrated up to 48 percent greater efficiency in Java 10* compared to Buffered I/O*.[5] These optimizations have significant implications for organizations that run AI workloads or databases that rely on Java, such as Cassandra* or Apache HBase*.

Software architects can use existing tools and development kits to optimize performance for Intel Optane technology. Use the following resources from Intel to get started:

- Storage Performance Development Kit (SPDK): https://spdk.io/
- Persistent Memory Development Kit (PMDK): https://pmem.io/pmdk/
- Access to bare-metal servers with Intel Optane DC SSDs: acceleratewithoptane.com

## Extend Memory with Intel® Memory Drive Technology

Intel® Optane™ DC SSDs can also be configured as extended memory by using Intel Memory Drive Technology. Intel Memory Drive Technology transparently integrates an SSD into the memory subsystem and makes it appear like DRAM, with no changes required to the operating system or applications. Intel Memory Drive Technology can be used to displace a portion of DRAM and reduce overall memory cost, or to grow the memory pool beyond DRAM capacities when large system memory capacities are required.

In fact, Apache Spark* performance is 5x faster by adding Intel® Memory Drive Technology software with an Intel® Optane™ SSD DC P4800X.[4]

## Reduce the Capacity Storage Gap with Intel® QLC 3D NAND SSDs

As NAND technology increases in efficiency and declines in price, the need for mechanical drives continues to decline. The latest breakthrough, Intel® QLC 3D NAND SSDs, might relegate spinning discs to only the coldest of data-storage scenarios.

Intel QLC 3D NAND SSDs are designed to provide flash reliability at higher densities and an affordable price point. These benefits help remove barriers to replacing traditional HDDs, which are typically slower, less reliable, more power hungry, require more cooling, and take up a larger data footprint compared to flash drives.

### Intel® QLC 3D NAND SSDs vs. Hard-Disk Drives


**Figure 6.** By converting from HDDs to Intel® QLC 3D NAND SSDs, businesses can achieve significant savings in power, cooling, and service, with a smaller data center footprint[7,8]

Intel QLC 3D NAND SSDs can be combined with Intel Optane technology to accelerate the speed of frequently accessed data, while using the price and capacity benefits of flash technology over HDDs for massive capacity storage. That lets organizations fill the storage cost/capacity gap between Intel Optane DC SSDs and HDDs. Moreover, because Intel QLC 3D NAND SSDs offer high reliability with affordability, many organizations can use them to replace HDDs.

### Consolidate Data with Innovative New Form Factors from Intel

Intel is also closing the storage cost/capacity gap with innovative new form factors. Winner of a Gold International Design Excellence Award in 2018, Intel's 3D NAND "ruler" form factor for SSDs improves density, manageability, and serviceability in tandem with an efficient thermal design that is revolutionizing server architecture.

Because of the unique shape and characteristics of the drive, based on EDSFF, vendors like Supermicro are able to fit 32 Intel "ruler" drives at 32 TB each into a single 1U server, providing up to one petabyte of data per server.[9]


## Reimagine Data Center Storage

Intel technologies enable modern businesses to rapidly and flexibly store, process, and manage massive quantities of data for analytics, AI, HPC, and other workloads by filling the memory and storage gaps with a complete range of options—from Intel Optane DC persistent memory and the Intel Optane SSD DC P4800X to Intel QLC 3D NAND SSDs and high-capacity "ruler" form factor drives.

Together, Intel storage technologies and products offer data center architects flexibility to match performance, capacity, reliability, and affordability to their business applications and workloads. It's time to reimagine memory and storage with Intel Optane technology and Intel QLC 3D NAND technology.

## Learn More

Reimagine your data center with Intel storage technologies.
Visit intel.com/content/www/us/en/storage to get started.

[1] Performance results are based on testing as of July 24, 2018, and may not reflect all publicly available security updates. See configuration disclosure for details. No product can be absolutely secure. Source: Intel-tested: Average read latency measured at queue depth 1 (QD1) during 4K random-write workload. Measured using FIO 3.1*. Common configuration: Intel® 2U Server System, CentOS 7.5*, kernel 4.17.6-1.el7.x86_64, 2 x Intel® Xeon® Gold 6154 processor at 3.0 GHz (18 cores), 256 GB DDR4 RAM at 2,666 MHz. Configuration: 375 GB Intel® Optane™ SSD DC P4800X and 1.6 TB Intel® SSD DC P4600. Latency: Average read latency measured at QD1 during 4K random-write operations using FIO 3.1. Intel Microcode: 0x2000043; system BIOS: 00.01.0013; Intel® Management Engine (Intel® ME) firmware: 04.00.04.294; baseboard management controller (BMC) firmware: 1.43.91f76955; FRUSDR: 1.43. SSDs tested were commercially available at time of test. The benchmark results may need to be revised as additional testing is conducted.

[2] Tests by The Evaluator Group, commissioned by Intel. See config details at https://www.evaluatorgroup.com/document/lab-insight-latest-intel-technologies-power-new-performance-levels-vmware-vsan-2018-update/.. Previous configuration: Intel® Xeon® E5-2699 v4 processor, ESXI ESXi600-201803001 Build 7967764, Ubuntu Linux 18.04, BIOS 2600WT SE5C610.86B.01.01.0024. Storage media: 1 3700 800GB SSD + 6 x S3510 1.6TB. Performance: 320 IOmark-VM, Price/Performance: $684/VM; Current configuration: Intel® Xeon® Gold 6154 processor, ESXI ESXi-6.7.0-8169922 Build 8169922, Ubuntu Linux 18.04, BIOS SE5C620.86B.00.01.0013.030920180427. Storage media: 2 x P4800X 375GB SSD + 5 x P4500 4TB SSD, Performance: 1152 IOmark-VM, Price/Performance: $216/VM. Storage media: 1 x P3700 + 4 x Seagate 1TB 10K HDD, Performance: 88 IOmark-VM-HC, Price/Performance: $2153 / IOmark-VM-HC; Current configuration: Storage media: 2 x P4800X SSD + 4 x P4500 4TB SSD, Performance: 704 IOmark-VM-HC. Price/Performance: $684 / IOmark-VM-HC.**. Price/Performance: $237 / IOmark-VM-HC. Performance results are based on testing as of August 20, 2018 and may not reflect all publicly available security updates. See configuration disclosure for details.

[3] Intel. See product specs on table in "Product Brief: Intel® Optane™ SSD DC P4800X". intel.com/content/www/us/en/solid-state-drives/optane-ssd-dc-p4800x-brief.html.

[4] Performance results are based on testing as of September 20, 2018, and may not reflect all publicly available security updates. See configuration disclosure for details. No component or product can be absolutely secure. Source: Intel. System configuration: Server Intel® Server System, 2 x Intel® Xeon® Gold 6154 processor, 384 GB DDR4 DRAM, database drives: 2 x Intel® Optane™ SSD DC P4800X (375 GB) and 1 x Intel® SSD DC P4510, 1 x Intel SSD DC S4510, CentOS 7.5* (kernel 4.18 (elrepo)), BIOS: SE5C620.86B.00.01.0014.070920180847, system product type: Intel® Server Board S2600WFT. MySQL Server 8.0.13*, Sysbench 1.0.15* configured for 70/30 read/write online transaction processing (OLTP) transaction split using a 100-GB database. 30 percent database memory provided to MySQL (30 GB).

[5] Performance results are based on testing as of July 2018 and may not reflect all publicly available security updates. See configuration disclosure for details. No product can be absolutely secure. Source: Intel: System configuration: Intel® Server Board S2600WFT white box, 2 x Intel® Xeon® Gold 6154 processor at 3.00 GHz with 36 vcores, 64 GB DIMM DDR4 synchronous 2,666 MHz (0.4 ns) (4 x 16 GB), 1 x NVM Express* (NVMe*) Peripheral Component Interconnect Express* (PCIe*) 750 GB Intel® Optane™ SSD DC P4800X (firmware version: E2010324), 1 x NVMe PCIe 4 TB Intel® SSD DC P4500 (firmware version: QDV10150), Intel® BIOS version: SE5C620.86B.00.01.0013.030920180427, CentOS 7.4* distribution with 4.15.7 kernel. See OpenJDK* info at: OpenJDK. "JDK 10." March 2018. http://openjdk.java.net/projects/jdk/10/.

[6] Source – Intel System Configuration for Management Node: S2600WFT Intel White Box, 2 sockets, Intel® Xeon® Gold 6140 CPU @ 2.30GHz, 18 cores per socket / 2 threads per core (total 72 vcores), CentOS 7.4* distribution with 4.15.12 kernel, HortonWorks* Data Platform 2.6.4, Spark 2.2.0*. Baseline Config: 192GB DDR4 (each on 3 worker nodes) IMDT Config: 192GB DDR4 + x2 375GB DC P4800X (each on 3 worker nodes). Performance results are based on testing as of July 31, 2018 and may not reflect all publicly available security updates. See configuration disclosure for details. Tests document performance of components on a particular test, in specific systems.

[7] Power, cooling, and consolidation. Based on HDD: 7.2K revolutions per minute (rpm) 4-TB HDD, annualized failure rate (AFR) of 2.00 percent and 7.7 W active power; 24 drives in 2U (1,971 W total power). SSD: 22 W active power, 0.44 percent AFR, 32 drives in 1U (704 W total power). Cooling cost based on deployment term of five years with kWh cost of $0.158 and number of watts to cool 1 watt 1.20. Based on 3.5-inch HDD, 2U, 24 drives, and EDSFF 1U long-1U, 32 drives. Hybrid storage based off using Intel® TLC SSD for cache.

[8] Drive replacement. Calculation: HDD 2 percent AFR x 256 drives x 5 years = 25.6 replacements in 5 years; SSD: 0.44 percent AFR x 32 drives x 5 years = 0.7 replacements in 5 years.

[9] Supermicro. "The systems support front hot-swap accessibility to 32 EDSFF drives for up to 1PB of fast low-latency NVMe storage in 1U". Source: "Supermicro Opens New Era of Petascale Computing with a Family of All-Flash NVMe 1U Systems Scalable up to a Petabyte of High Performance Storage." August 2018. https://www.supermicro.com/newsroom/pressreleases/2018/press180807_Petabyte_NVMe_1U.cfm. Referencing SuperStorage SSG-136R-NR32JBF: https://www.supermicro.com/products/system/1U/136/SSG-136R-NR32JBF.cfm