



## Outlook Report

# Enterprise Use Cases for Solid State Storage/Flash Memory

*An Outlook Report from Storage Strategies NOW*

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## Outlook Report

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## Outlook Report

Dear Reader,

SSG-NOW takes a look at technologies and products when confusion exists in a specific market. What is solid state storage or Flash Memory? How is it used best? What are the use cases for SSDs/Flash technologies? When should you adopt SSDs/Flash and how? This report will hopefully answer those questions about solid state/Flash-based storage and in what situations it is best used. If as a customer, you have further questions about solid state drives or Flash memory, how it is implemented and deployed and where it is best used, please feel free to contact us. We will enjoy talking to you.

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## Executive Summary

The advent of solid state storage devices that use NAND Flash technology to provide persistent data retention when systems are not powered up has made an increasing mark on the enterprise data center. In addition to higher access speeds, NAND Flash provides lower power consumption than its counterpart hard disk drive (HDD) technology.

During the last three years, enterprise consumption of solid state storage has increased to an estimated five billion dollars in the current calendar year. Storage devices include solid state drives (SSDs), which conform mechanically and with interface electronics identical to hard disk drives (HDDs). These devices can be placed in an existing disk array or server drive bay, and depending on the system, can offer immediate performance improvements. Several implementation strategies are built around PCIe cards that are placed directly in the server and utilize the performance of the server's bus to provide acceleration to applications.

In the last three years a new class of all-solid-state storage array has become available from a number of start-up companies, as well as traditional storage vendors. There is also a class of storage called a hybrid storage array. These devices use a combination of solid state storage for performance acceleration and HDDs to accommodate capacity storage.

Technology advancements in NAND Flash have followed Moore's law, decreasing cost per capacity by shrinking the size of the memory cells. The smallest cell sizes currently available are about 19 nanometers. Several array manufacturers have announced products based on this cell size, as well as a smaller 16 x 20 nanometer size, expected to be available in early 2014. Most manufacturers remain at 24/25 nanometer cell sizes using multi-level cell (MLC) technology, which stuffs two data bits in each cell. New processes from NAND Flash foundries will be able to develop three dimensional cells to add capacity without further shrinking the cell sizes. Major foundry owners SanDisk/Toshiba and Samsung have announced that they are developing three-dimensional cell technologies, which have the promise of continuing to reduce the cost per capacity of NAND Flash.

The importance of the continued development of NAND Flash capacities per area is inherent to improving a wide variety of consumer devices, such as smart phones and tablets. As has been the case in most electronics technologies, it is the high volume consumer products that are driving the cost points of products used by enterprises. The use of the consumer products is not free, however, as more exotic hardware and software strategies need to be deployed to maintain the reliability of the Flash circuits over time.

There are new technologies on the horizon that may someday provide persistent storage at costs that compete with NAND Flash. These technologies include Carbon Nanotube, Magnetic RAM, Memristor and Phase Change Memory. While these technologies will produce persistent memories that perform much faster than NAND Flash, barring an unforeseen breakthrough, however, it will be a number of years until these technologies rival Flash at a cost per capacity basis. In the meantime, the manufacturers of these new technologies will be targeting the Non-Volatile DRAM (NVRAM) applications where data persistence is achieved by adding batteries or capacitors and Flash backup to these circuits, adding additional costs and reliability concerns.

In this report we focus on the use cases where solid state storage has tremendous performance advantages and can produce reduced costs due to performance or enable applications that have been near to impossible using HDD technology.

## What is Enterprise Solid State Storage?

### Overview

Enterprise solid state storage differs from consumer-grade storage in several important ways. Some data center operators have found out the hard way by deploying SSDs designed for laptop usage in their high-use storage arrays. While things work great for awhile, without enterprise Flash management capabilities these drives will have continually degraded performance and outright failure due to the basic characteristic of NAND Flash wear. Another contributing factor to both reduction of wear and improved write speed is the use of deduplication and compression algorithms. Because NAND requires an area to be erased before it is written, the reduction of the data being written contributes to storage system performance on a positive basis.

Vendors who have been serving enterprises have developed strategies for the enablement of reliability within solid state storage devices. These include several strategies starting with basic error detection and correction technology, adding redundant capacity, analyzing usage of areas of the Flash memory that may be incurring higher wear and striping data across multiple storage devices and even systems. In addition, the ability to add scale to systems from small capacity to large capacity without replacement or downtime is extremely important in the data center.

Data center Flash users have high expectations for these expensive systems. First, the need for speed in operation is often the primary driver. In cases where the number of transactions that can be processed in a given period of time, the benefit can be easily understood. Other cases, speed is important and related to optimizing productivity of human resources. A simple example is given by a major Internet Service Provider that operates tens of thousands of servers. If a server needs to be rebooted from HDD, the technician overseeing the operation can wait upwards of five minutes to tell if the operation solved a given problem. By simply placing an SSD as a boot drive in each server, the time the technician is waiting is reduced to a matter of seconds. Due to the drop in cost of Flash, these boot drives can be obtained for less than \$80. While a critical enterprise application, a boot drive does not have the same requirements of a drive in a high use storage array. This is an important distinction and again, reinforces the importance of understanding the ultimate use case for the solid state device.

Flash storage can produce high speed operations at much lower power consumption than HDDs and in a much smaller data center footprint, reducing operating costs accordingly. When engineered and managed properly, Flash storage provides extremely high levels of reliability, especially when compared to failure rates encountered with mechanical media.

### The details

Enterprise storage architects expect a three- to five-year use-life of any system. But a consumer-grade SSD may wear out after as few as 500 total drive capacity writes. Five-hundred times is plenty for a typical laptop application, but in an enterprise environment ten to twenty drive-writes can occur in a single day. Further complicating the wear issue is that a particular area on the drive may receive an inordinate number of writes, causing that portion of the drive to become unreliable.

There are numerous wrinkles on the algorithms to distribute wear across the storage device. Commonly used is the virtualization of the physical device so that all writes become sequential, and the entire drive is written before any area is re-written. Strategies of deduplication and compression are addressed in the controller for the drive, or in the case of a hybrid or solid state array, across the entire system. This function is both important to write performance, but not all data reduction algorithms are created equal. The best are those that can handle the function in-line in real-time without impacting overall system performance. That's a tall order. The worst are those that operate after-the-fact.

Those strategies actually impair the systems wear control because the data is essentially written twice, once in bulk and again when reduced. These are important issues to address with any drive or storage system vendor. An important strategy is that of over-provisioning. SSDs storage capacities are declared on a net basis. A 400GB drive has an actual capacity of 512GB. The difference is used to backfill areas that are wearing rapidly. Each Flash cell may have a different wear characteristic, so the best systems monitor the health at a cell basis.

High availability (HA) is an expectation of the enterprise data center, meaning that no single component failure can cause any system data to become unavailable. This feature requires redundant controllers on a given system, or redundant nodes in a clustered architecture. Other redundant components involve power supplies, fans and even backup power

strategies if a large amount of volatile DRAM is involved in the controllers to improve performance. No one ever said enterprise storage systems were easy to pull off. Error detection and correction algorithms are also critical to system reliability. While an individual SSD or Flash module may have a controller doing this on a local basis, hybrid and all-Flash storage systems implement features that extend detection and correction across multiple SSDs, modules, storage nodes and even, clustered system components. Each vendor should be able to explain their approach in understandable terms and backup their claims with real-world data. Some systems have hot-swap capabilities and upgrade processes that do not involve downtime. These are difficult to implement and will ultimately contribute to the overall system cost. In all cases, the buyer must be aware of the trade-offs.

### Why it matters

Enterprises have expectations that their data is reliably stored and will be available in the long haul. The most important component of stored data is that which is needed the most frequently and at the highest need, the so-called Tier 0 of storage. Solid state storage is becoming the gold standard for this type of data. Despite the technology issues related to wear-leveling, HA and data reliability, the enterprise data center can obtain these systems from multiple sources. Many buyers will stick with their long-term storage vendors, at a price, while others will go with younger companies with newer technology and lower price tags.

In any event, enterprises should evaluate companies based on technology, reliability, reputation and staying power. Technology is also an important dimension because often it can be the difference between a cost-justifiable implementation and a system that just isn't worth the money and effort.



## History

### Overview

Solid state storage has long been the solution for data center operations that have an overriding need to accelerate applications. The earliest applications used all kinds of metal oxide semiconductors (MOS) that were invented at Bell Labs in the mid 1960's.

Data centers began using these systems because of their speed and simplicity when compared to the rotating media of the era. But magnetic disk media advancements, particularly the Winchester drive, rapidly rendered solid state memories to niche applications.

### The details

There were three kinds of MOS large-scale integrated circuits. PMOS used all positive charged gates, NMOS used all negative charged gates and CMOS, or complementary MOS, paired an equal number of positive and negative gates, a much more complex circuit. CMOS had a number of distinct advantages despite the higher cost of design and manufacture. The circuits, which used less than a tenth of the energy of PMOS and NMOS, were efficient at high and low temperatures, and critically, the data was persistent regardless of the availability of a power source. CMOS was deployed in exotic applications, such as satellites and warheads, and more mundane applications, such as portable computers for inventory control and utility meter reading.

Later improvements in memory technology, driven by the need for high speed processor memory in minicomputers and the later x86 machines drove the development of dynamic random access memories (DRAM). DRAM was relatively inexpensive and extremely fast, but had the disadvantage of volatility.

### Why it matters

Later improvements in memory technology, driven by the need for high speed processor memory in minicomputers and the later x86 machines, drove the development of dynamic random access memories (DRAM). DRAM was relatively inexpensive and extremely fast, but had the disadvantage of volatility. The memory needs power to continually refresh each bit.

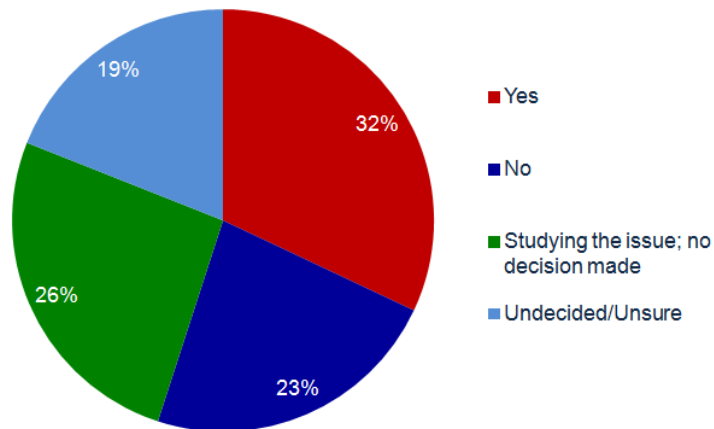
In later sections of this report we discuss these technologies in detail because they all remain relevant in enterprise storage applications.

## IT Professionals Adoption Survey of SSDs/Flash

Storage Strategies NOW and ITIC conducted a survey of IT professionals on SSD/Flash adoption and deployment. Among more than 550 respondents, the results were balanced across the enterprise. Twenty-nine percent of respondents were from SMBs, 44% from mid-size and SME environments and 27% represented large enterprises. As many as 47 vertical market segments were surveyed.

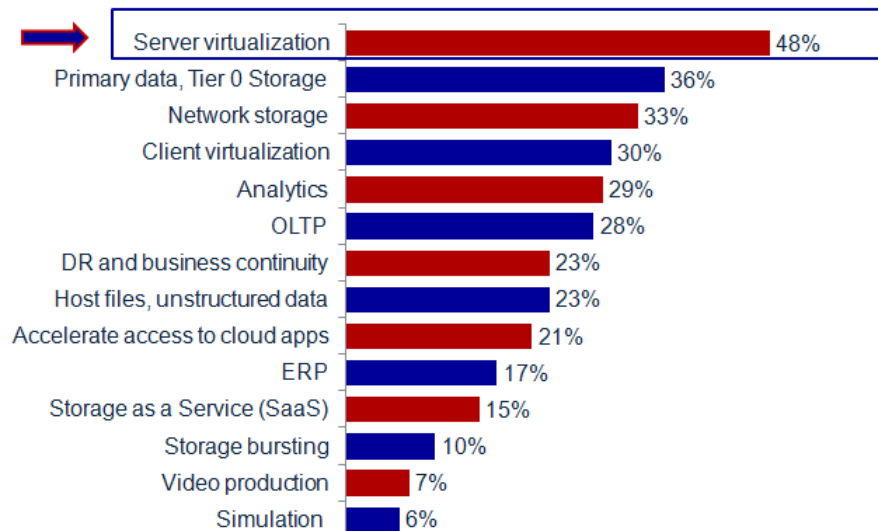
Of the results, 32% of the respondents currently use or have definitive plans to deploy SSD/Flash technologies.

**Does your firm currently use or have definitive plans to deploy Flash/SSDs?**



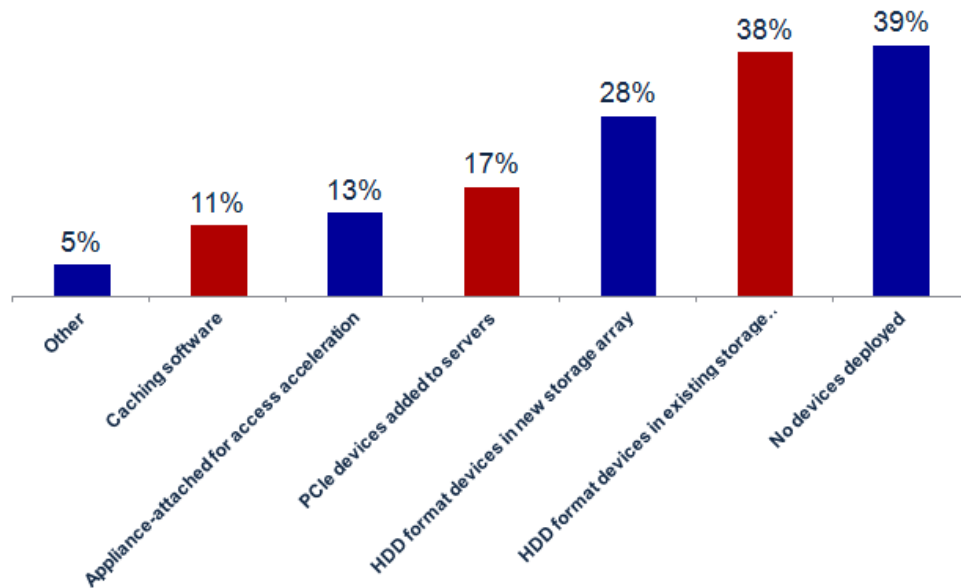
Forty-eight percent of the respondents will use SSDs/Flash for server virtualization; 30% for desktop virtualization; 29% for analytics and 28% for OLTP.

**If your firm currently uses/has definitive plans to deploy Flash/SSDs, how will it use it?**



The survey also showed that by a large percentage (38%) will use SSDs/Flash instantiated in existing storage devices. The remainder will purchase new SSD-based storage (28%), add PCIe adapters to servers (17%) or use appliances to accelerate performance (13%). Eleven percent will use caching software to accelerate performance.

**What type of solid state drives or high speed memory storage devices has your firm deployed or definitively plan to deploy?  
(Select ALL that apply)**



## Solid State Storage Fundamentals

### Flash Memory

#### Overview

NAND Flash memories have been in use in mobile devices for about twenty years. The primary advantage of Flash is that the data written to it is persistent. Unlike dynamic random access memories (DRAM), data is retained after the circuit has no power provided. The primary disadvantage is that the memory needs to be written in pages and an entire page needs to be written even if only one bit has changed. Pages vary in size, ranging from 1K bytes to 32K bytes. Once the entire memory is written, each page needs to be erased before new data can be written. This is referred to as a 'program-erase' (PE) cycle, which takes time. But, that is only the beginning of the problem. Each PE cycle causes wear and tear on the memory and the memory will eventually wear out. For this reason, Flash memories need to have careful care and feeding algorithms. These include processes referred to as 'wear leveling,' which distribute writes across pages so very active areas do not wear out quickly. Most wear-leveling processes start by treating the entire memory as a sequential device, writing pages until the memory has been completely written and then 'rewinding' to start over again. This requires an index of virtual pages to physical pages.

Moore's Law states that we should expect silicon device capacities to double every two years, as the companies that manufacture the devices continue to shrink the internal circuits using ever-smaller unit densities, driven primarily by demand for consumer-class Flash memories. In fact, we have seen this in the last four years, as Flash lithography has dropped from 40 nanometer (nm) units, to 30nm units, to 25nm/24nm, to 20nm/19nm units and this year 16nm units are coming on-line. Each reduction allows higher capacity devices at similar production costs. However, smaller cells also require more error correction technology.

A recent round of industry consolidation and partnering has created a situation where the vast majority of Flash memories are manufactured by only three consortiums: SanDisk-Toshiba who operate a gigantic facility in Japan, Samsung who operates similar facilities in Korea (Samsung recently sold its HDD manufacturing operation to Seagate) and Intel-Micron who operate facilities in Utah and Singapore. Business is good for these 'foundry' owners. Demand for smart phones and tablet computers have gobbled Flash memories at astonishing rates. These consumer devices create the volume production necessary to support the rapid expansion of enterprise SSDs.

Flash memories come in two basic flavors, single-level cell memories (SLC), which have a single data bit in each cell, and multi-level cell (MLC), which has two or more bits in each cell. While MLC components are available with three and four bits per cell, enterprise class SSDs currently only use SLC and two-bit per cell MLC.

Flash memories provide persistent storage with resilience during the loss of system power and speed of access that provides data in microseconds, a rate that is more than 100 times faster than that available from HDDs. Other advantages include lower overall power consumption and the ability deliver high quality of service levels for a variety of applications. However, Flash memories are more expensive per capacity than the lowest cost HDDs and, while an HDD has virtually unlimited ability to process data writes, Flash memories are subject to wear that must be handled at both an individual Flash device and on an overall system basis.

Flash memories provide rapid performance for data reads but are slower for data writing due to a characteristic that requires the erasure of a physical page of data on the Flash module before it can be written. This slows down the write process unless other system functions can mitigate this step. The performance of all storage systems relies on the use of high speed volatile memories known as DRAM.

## The details

### *SLC vs. MLC*

SLC devices are faster than MLC and support more PE cycles per page. An analogy is the capacity of a hotel. If every room has two people instead of one, twice as many people can stay in the hotel. However, access to each person will be slower because you need to go to the room and ask for person A or B and the wear and tear on the entire hotel will be much higher. MLC has another 'feature.' It is possible to accidentally 'disturb' the other tenant in the cell when reading or writing a bit, so the control algorithms must take this into account. Nevertheless, due to its cost (at the foundry) of about half of SLC for a given capacity, MLC devices are going into enterprise drives at an increasing rate.

### *eMLC*

There has been significant discussion of 'enterprise MLC.' Indeed, foundry operators have many grades of MLC devices at the same lithography size and bits per cell. This not only relates to testing, or screening of the finished devices, but also has to do with the manufacturing process and even the area of the silicon wafer from which a given die, or chip, is cut. Most 'enterprise MLC' chips offer variable timings and voltages that trade endurance for reliability. Consider hammering a nail into a wall. If it is driven all the way into the wall, it will leave a large hole but stay in place very well. If the nail is only hit once or twice, it will damage the wall less, but it will fall out easier. To offer both endurance and reliability, 'enterprise MLC' SSDs have the equivalent of 'hammers' tapping all the 'nails' (data pages) periodically. Intel calls the MLC they put into their own SSDs 'compute class' NAND and is very frank that they take the cream of the crop for the devices that they sell under the Intel brand. As competition increases for the enterprise business, controller technology advances will continue to make MLC devices better and better for many enterprise applications. As lithography sizes shrink into the teens of nanometers or smaller, there is one big problem. Electrons, tiny as they are, stay the same size and are the basic unit for detecting the state (zero or one) of the bit. This creates challenges for designers of MLC circuits and represents a real brick wall for Moore's Law and flash memories.

### *Three Bits per Cell and Four Bits per Cell*

Rather than relying on shrinking lithography for higher density chips, processes that create three-bits-per cell, often referred to as 'TLC' as in 'Three Level Cell'. This is erroneous because these components actually have eight voltage levels, with two required for each bit. Likewise four-bits-per cell requires sixteen voltage levels. With all of those voltage levels flying around, the components become complex from a control and reliability standpoint. So far these components have not had successful deployment in anything but throw-away consumer devices, such as USB thumb drives.

### *Three Dimensional Flash*

Having recognized the challenges involved in continually shrinking lithography, Flash foundry owners have been preparing new processes that build components into the vertical dimension by stacking whole circuits on top of each other as a way to increase the density of each chip and doubling the capacity available from a silicon wafer. This makes sense if the processes become reliable and do not add a lot of cost. The first components of this type are expected in late 2014. SanDisk-Toshiba and Samsung have announced new foundry expansions to incorporate the 3D processes.

## Why it matters

Flash memory remains the most viable technology for persistent storage. With tremendous demand for consumer products driving foundry capacities and supporting research and development into technologies and processes that benefit enterprise users, Flash memory will certainly be the primary technology for the balance of this decade. We can expect continued reduction in cost per capacity with improved technologies driving speed of performance and reducing operating costs due to density increases and decreases in power consumption.

## Memory Technologies other than Flash

### **DRAM**

Dynamic Random Access Memories (DRAM) are the fastest and easiest to manage. They are the basic computer processor memories used in all devices ranging from a cell phone to a multicore server. Moore's Law is alive and well with DRAM technology and indeed, these devices continue to get faster and cheaper but do not have the same density, per

area, as Flash. DRAM, while close to a cost per GB of Flash, needs a larger area and more power. Just like Flash, DRAM memories have the same electron size problem, so a brick wall exists for this critical system component. Since they are dynamic, which means they need to be refreshed frequently, DRAMs need a power source at all times otherwise they forget their contents.

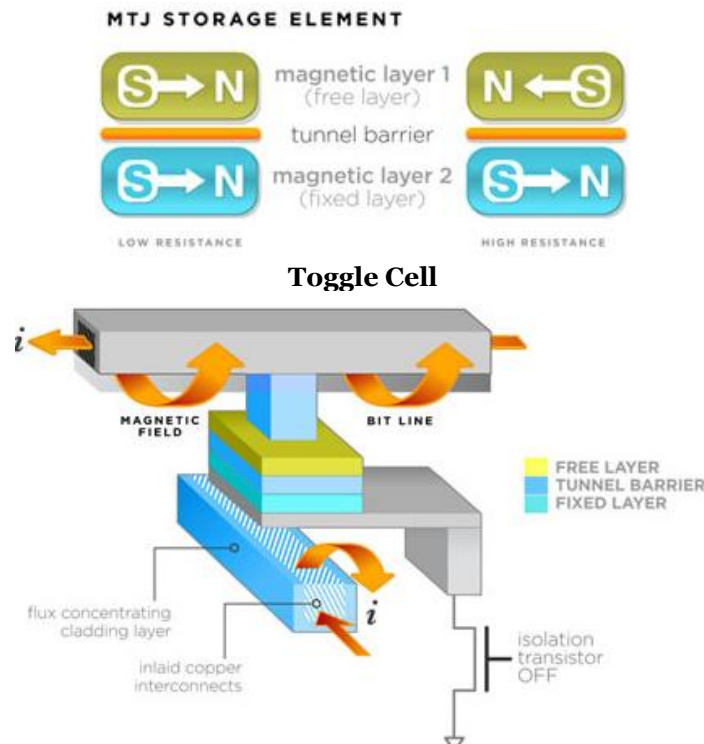
Despite these issues, DRAM usage continues to expand in high-performance computing environments, with acceleration appliances and even entire databases held within rack-mount devices. Since they have no real management issues, such as wear-leveling and program-erase latency, applications requiring speed at any cost will use DRAM. Backup batteries are deployed to keep the appliances from losing their contents in applications where data loss due to power failure is not acceptable. New generations of hybrid non-volatile DRAM systems are being deployed using super-capacitors, coupled with a Flash memory circuit to save the contents of the DRAM to Flash in the event of a power failure.

## NVRAM

Non-volatile random access memory (NVRAM) combines DRAM with additional circuitry in order to make DRAM memory persistent through a power failure. Depending on the amount of DRAM that needs to be protected, additional circuitry can involve capacitors, batteries, Flash memory or combinations, such as a capacitor tied to a Flash module. In any event, NVRAM is expensive because circuitry and components need to be added to the already expensive DRAM.

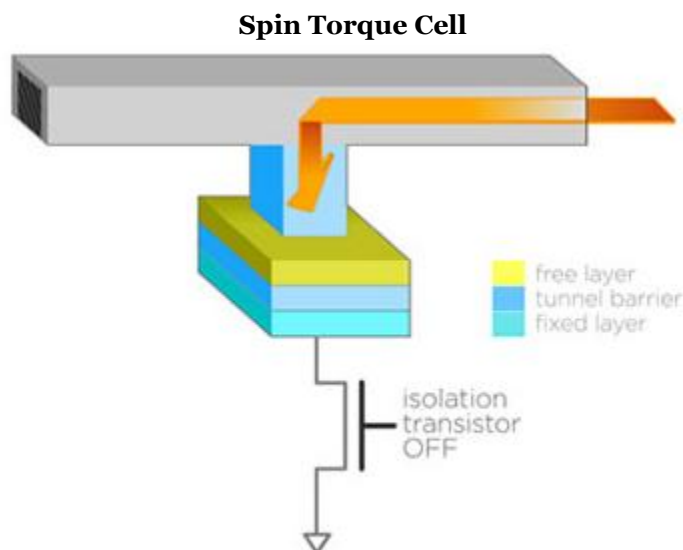
## MRAM and Spin-Torque

Everspin announced that its shipments of magnetic random access memory (MRAM) have increased substantially in the last two years. MRAM combines complementary metal oxide semiconductor (CMOS) technology with magnetic cells inserted between metal layers to create a very fast memory that can retain its state for years without power supplied to it. A simple transistor per cell detects the amount of resistance in order to determine the state of the bit. This technology is referred to as memory tunnel junction (MTJ) because the areas of charge are separated by a tunnel. One wire is used to charge the magnetic cell to a zero or one state, and another wire is used as a constant magnetic field, in a setup referred to as a toggle cell design.



While at present, at a fairly large geometry (around 100nm), the advantages of the high-speed memories for processor memories and caching are already creating high-volume demand that will allow the continued development of the technology. Currently, major customers in the aerospace, energy and automotive fields are utilizing the low latency (<50ns) and wide operating temperature (-40C to +125C) of MRAM in applications that require memories to withstand power failures and, unlike Flash memories, have unlimited read-write cycles and can retain data for more than 25 years.

Everspin has 64Mbit DDR3 compatible components and its product roadmap is clearly headed towards Gigabit densities that will allow MRAM to compete effectively with nonvolatile DRAM in applications that at present require an expensive battery back-up or super capacitor combined with Flash memory to provide data persistence after a power failure. The key to shrinking the size of the lithography to 40nm and even <30nm is going from the double-wired MTJ 'toggle' set-up to what is called spin-torque. Spin torque allows a bit to be programmed directly without the double wire setup. The MTJ still remains paired with a transistor to sense the status of the bit. Since the MTJ requires less current as its lithography shrinks, the transistor can likewise be shrunk. Everspin sees 8Gb and 16Gb parts appearing around 2015. While not intending to price attack the Flash and phase-change memories (PCM) that should be appearing in that time frame, the needs of applications such as the high-speed non-volatile processor workspace and non-volatile write caches should account for about one-third of the total dollars spent for DDR, Flash and non-volatile solid state memories.



Everspin came from Motorola's Freescale business unit in 2008 and is a privately held company. It holds over 600 patents and filings with over 175 already granted covering the MRAM, and spin-torque technologies. The production steps involve receiving a CMOS wafer from one of the generic foundries and applying the MTJ cells and final packaging at the Everspin Chandler, Ariz., facility. As demand and applications for the technology increase, Everspin expects to license to process to one or more of the major memory fab owners.

## Carbon Nanotube

Nantero is promoting an emerging memory technology built from Carbon Nanotubes (CNT) that it calls NRAM. Nantero has been developing the technology since 2001 and has a patent portfolio of 165 issued and another 200 patents pending. Rather than developing foundries to produce the components, Nantero has focused on licensing the intellectual property and providing technology support to foundry owners and fab-less silicon producers. Complementary metal oxide semiconductor (CMOS) fabs are currently capable of producing the parts with recipes provided by Nantero and its supply chain partners.

CNT works like a mechanical switch, when the carbon tubes touch, the switch (bit) is set and when they are separated the switch is reset. This provides an extremely robust data persistence that has been tested for retention for



decades at temperatures in excess of 300°C. Further good news is the very low current necessary to set and reset the circuit. The devices under development by Nantero's licensee's have already produced 4Mb sample parts that operate faster than DRAM, have no endurance issues like flash and operate at 100 times the speed of flash. The processes to bake the parts in the foundry are straight-forward and materials used in the nanotubes are available from the typical fab supply chain. Not that this has always been the case. The initial materials used to create nanotubes had too high a concentration of contaminating metals, which can destroy a CMOS fab. Several years of incremental refinement have produced the materials and the cost per capacity profile of NRAM is less than competing technologies of magnetic RAMs (MRAMs) and phase change memories (PCMs).

### Phase Change Memory

A new type of device that solves the electron size problem in DRAM and Flash memories is becoming a reality. Phase Change Memory (PCM) uses heat to change the conductance of an area on the circuit. Since conductance, rather than electronic charge, is used to determine the state of a bit, the lithography is not limited by electron size. This allows a memory that can be directly written without a page PE cycle. These heat cycles are very quick and the wear caused by a cycle is small, each bit can be written a billion times. While small, the wear is enough, in terms of enterprise computing, to require a wear-leveling process. The technology belongs to foundry owner Micron as the result of Micron buying Intel out of a joint venture called Numonyx. The status of Moore's Law, in terms of capacity and cost per bit, is lagging Flash by years, as Flash continues to be developed with solutions that will keep it viable for many years.

Development of PCM devices is currently in the domain of research labs. San Diego State University's Computer Science and Engineering department has taken encouraging steps for commercial viability within the a few years. The product of the research is a PCIe test platform called 'Moneta' from the Latin for the goddess of memory. While fairly anemic in terms of capacity (64GB of PCM capacity due to available lithography size), Moneta shows surprising performance when compared to the current crop of PCIe Flash products. Significant engineering effort was applied to Moneta, no doubt with help from Micron, but the work by SDSU is very impressive: 368,534 4KB random read IOPs and 389,859 4KB random write IOPs. The Moneta prototypes look remarkably like commercial devices rather than lab-built experiments. The Moneta prototypes will provide a test bed for improvements in PCM control techniques and a baseline as the PCM technology begins to mature and approaches Flash in density and cost.

### Memristor

Memristor is a promising technology that can use resistance levels as the representation of bits. The technology is still in the research labs of major organizations including HP, IBM and Samsung. The devices remain to be commercialized.



## Interfaces

### Overview

Solid state storage uses many form factors and interfaces, but the most prominent is the familiar hard disk drive (HDD) form factor. These easily slip into server drive slots and storage arrays. These products are typically interfaced using Serial ATA (SATA), Serial Attached SCSI (SAS) or Fibre Channel. SSDs in PCIe form factor typically are accessed as a block device with a driver provided by the manufacturer. Rack or tower format appliances can be built up from HDD form factor SSDs or have Flash modules directly built on memory array circuit boards. These appliances can support Fibre Channel, iSCSI and even the high- performance computing InfiniBand connectivity. In all of these cases, the SSDs are accessed as block devices.

### The details

#### *Parallel versus Serial*

The fastest way to push data is in a parallel-fashion by sending 8, 16, 32 or 64 bits of data simultaneously over a computer bus or cable. The disadvantage is that the cables become fat (each bit needs its own wire) and the distance that signals can be pushed in a simultaneous fashion becomes a big problem. Keeping all of those signals simultaneously screaming along that cable becomes impossible after a short distance.

Serial devices send one bit at a time, require simpler cables and connectors, can support more complicated addressing schemes and longer distances, but require more complex electronics to speed things along. Development of serial electronics has bumped the speeds of these interfaces to levels that were inconceivable when many parallel standards were initially developed.

#### *SCSI*

The Small Computer Systems Interface (SCSI) is a set of standards for physically connecting and transferring data between computers and peripheral devices, initially developed for disk and tape drives, but applicable to many computer peripherals. The granddaddy of open drive interface specifications, its name goes back to when Shugart Associates (later Adaptec) contributed intellectual property to the ANSI committee to create an open standard in 1982. Originally called SASI (Shugart Associates System Interface), the ANSI committee balked at naming a standard after a company, or a person in this case – Al Shugart. SCSI was originally pronounced ‘sexy’, but the pruders of the day prevailed with the common pronunciation of ‘scuzzy,’ which achieved full ANSI standardization in 1986. The parallel interface had the advantage of speed but was large and expensive and did not take hold in the explosion of the PC market. The IDE and later ATA interfaces (discussed below) prevailed. SCSI has been primarily used in high-end workstations and servers. The specification was updated in 2003 with the release of the SAS specification (discussed below) and iSCSI, which uses the protocol over Ethernet and bumped supported speeds to 640MB per second, but retained the 16 SCSI device limit.

#### *ATA*

ATA was an evolution of the Western Digital Integrated Device Electronics (IDE) interface in order to support the IBM PC/AT and its 16-bit wide bus (prior PC bus width had been only 8 bits). A wide (40-pin) ribbon cable attached the drives to the PC bus because of the parallel nature of the interface. The interface has effectively been replaced with the SATA interface, approved as a standard in 2003. ATA drives have not been produced for several years. But the protocol of ATA lives on in one company’s product line. Coraid uses the ATA protocol over Ethernet. It provides a very fast and lightweight protocol when compared to iSCSI, which has protocol overhead in the Internet Protocol used.

#### *SATA*

Serial ATA was developed as a way to reduce cable costs and take advantage of faster electronics which offset the speed advantage of the ATA parallel interface. SATA is the gold standard for low cost, client-side and large storage arrays that can live with lower speeds. SATA devices are addressed by a physical port attachment and are not universally addressable as SAS devices. The latest SATA specifications support up to 6Gbps and cable lengths of 1 meter.

## **SAS**

Serial Attached SCSI, in addition to providing lower cost serial cable and connector systems, has advantages of a more involved addressing scheme which allows drives to be addressed by a globally unique domain identifier (like an Ethernet MAC address) that is assigned by the manufacturer. Theoretically, a SAS device, therefore, can communicate to any other SAS device in the world. The addressing scheme also allows simultaneous reading and writing, which is a huge advantage for solid state drives, which, unlike hard disk drives, can actually execute reads and writes at the same time. The SCSI Trade Association maintains the standard and provides roadmaps that include future speed advancements and updates to transport media, connectors and power provision. The current specification supports speeds up to 6Gbps and future products at 12Gbps and 24Gbps. Since SAS also supports SATA devices (but not vice-versa), enterprise storage systems, be they direct attached, or implemented in a shared storage area network, are all moving towards SAS as a high-speed interface that has cost advantages over other interface topologies.

## **Fibre Channel**

Fibre Channel was developed as a high speed, fiber optic-based topology for Storage Area Network (SAN) and server to storage controller connectivity. The standard is administered by the Fibre Channel Industry Association (FCIA), which maintains a multi-year product roadmap that includes speed increases and any updates to transport media, connectors or protocols. While the numbers of HDDs and SSDs that use this topology is decreasing on a market share basis, it is important to note that the server to storage controller connectivity is extremely viable and will continue to be a critical topology for many years into the future. While Fibre Channel can be used in a point-to-point or ring topology, most implementations are deployed as a fabric with many-to-many switching rather than a hierarchical topology. Current Fibre Channel standards support speeds of 8Gbps, with planned future steps to 16Gbps and 32Gbps. Developed as an alternative to metal wired cabling, Fibre Channel (note the spelling) takes advantage of fiber-optic cables as a way to overcome speed and distance limitations inherent in metal cables. Used in SANs, where data is accessed by block number rather than file name, Fibre Channel has been the gold standard for SANs for about a decade. But due to its speed and wide availability of switches, Fibre Channel is also used as a data center fabric, connecting servers and storage networks alike. While the spelling has helped us differentiate this interface from fiber-optic wide area network cabling, it was adopted by the standards committee as an expectation of faster adoption by non-USA organizations. More expensive in the electronic interface and physical cable, these devices are getting heavy competition from SAS devices in future systems. Fibre Channel devices have recently been enhanced by an alternative and lower cost wiring scheme called FCoE (Fibre Channel over Ethernet).

## **InfiniBand**

Similar to Fibre Channel, InfiniBand is primarily used in many-to-many fabric implementations. Developed specifically for high-performance computing and enterprise data center applications, InfiniBand offers higher speeds and lower latencies albeit at higher costs. The InfiniBand Trade Association manages the specification and future roadmap. InfiniBand was created as a standard in 1999 when two competing consortiums consisting of the Future I/O (Compaq, IBM and HP) and Next Generation I/O (NGIO) consisting of Intel, Microsoft and Sun Microsystems merged specifications. Now InfiniBand is heavily used in the TOP500 supercomputers. Texas Memory Systems and Violin Memory Systems have InfiniBand options for connecting their SSD appliances to shared storage systems. Current InfiniBand implementations support port speeds of up to 40Gbps.

## **Ethernet**

Ethernet has become an increasingly important SAN connection topology with the advent of the iSCSI protocol, which uses the internet TCP/IP protocol to communicate with block storage devices. This communication method provides a low-cost and ubiquitous interface method in which the same hardware and cabling can be used for both SAN storage (iSCSI) and Network Attached Storage (NAS) file servers.

Ethernet deployment is further enhanced by the continued development of high speed switching and fabric controllers that can be scaled to support thousands of network connections and allow the same protocol to be used within a data center and across wide area networks.

The Ethernet standard is managed by the IEEE 802.x committees. Current data speeds support 1Gb and 10Gb per second connections. Roadmaps are in place for 20Gb and 40Gb per second.



## Outlook Report

### ***ATA over Ethernet (AoE)***

A block protocol that uses the lightweight ATA protocol over standard Ethernet connections is gaining traction as a method for supporting high speed block storage access within a data center without the expense of the TCP/IP protocol. This makes a lot of sense, since TCP/IP was developed for network traffic rather than storage traffic. Coraid is a manufacturer of storage systems that employs AoE.

### ***Other interfaces***

USB 3.0 SSD devices are promising to become a common removable resource due to speed and rugged reliability.

Memory Channel Technology is a way to interface persistent storage directly to the CPU without traversing the entire storage interface stack.

## Deployment issues

### Over-provisioning

Ever since the late 1980's, HDD capacity has been stated in terms of decimal GBs, rather than the higher binary equivalent. That's because a KB is really 1,024 bytes. A binary GB is  $1024^3$  (1,073,741,824). A decimal GB is 1,000,000,000 bytes, a difference of nearly 74MB, or 7.4%. Where do the lost bytes go? They are used for error correction, housekeeping data and bad blocks that are the result of tolerances in the manufacturing process. They are used internally by the drive controller, but are not available for storage of data or metadata. With Flash memories and the wear factor of multiple writes and, to a lesser degree, multiple reads, even more of the raw capacity of the memories are reserved for controller use. These uses include error correction coding of 128 bits, 256 bits or even more for every page, which is typically around 4 kilobytes. Some file systems add information to the blocks and a problem related to the alignment of blocks on the physical Flash pages can cause wasted space. But in addition, as blocks become weaker they get put in a garbage can. This can be detected by a use map coupled with increased error correction activity. RAID-like striping of data across multiple Flash dies (chips) increases reliability and error recovery, but adds cost in useable space.

Consider the current crop of SSDs that come in 100GB, 200GB and 400GB capacities. The raw capacities of these devices, in binary, are 137,438,953,472 bytes, 274,877,906,944 bytes and 549,755,813,888 bytes respectively. So instead of just a 7.4% per GB over-provisioning that has become the norm in the HDD business, over-provisioning in the SSD business can be as high as 37% per GB or more. We explore the use of this space below in the discussion of write endurance and wear leveling.

Over-provisioning is a necessary evil with Flash devices. The amount of extra space has a negative effect on the cost per GB, but a positive effect on the long-term use life of the product. To some controller strategies, the knowledge of a large expanse of extra space makes controller development easier. In others, particularly as competition increases, the luxury of oceans of extra pages will demand improved controller strategies and improved Flash memory components. The reporting of raw capacity versus useable capacity has improved in recent years, but it remains an important question to ask the purveyor of any Flash-based product. Again, over-provisioning doesn't apply to DRAMs where the raw capacity is equal to the useable capacity.

### Wear-leveling

The first thing we learned in the mobile device field when we started using Flash was that software could break hardware. If you continue to erase and re-program the same page, the page will wear out. I remember a near painful product recall that dealt with this feature of Flash memory. Fortunately we found the problem during beta testing and were able to fix it with software upgrades. It did delay the product launch, however, because we had to implement a more intelligent file system on the product.

In the modern SSD world, wear-leveling has become a science and all vendors continue to improve their algorithms in close formation with strategies for correction of errors and studying of use maps. The obvious first step is to create a physical to virtual map of the drive in order to ensure that regardless of what the operating or file system is trying to do with the drive, all pages get used once before they get used again. Further discussion of this is covered on the subject of write amplification.

In addition to the physical to virtual mapping, another type of mapping is used. The number of times a page has been written is usually maintained and due to disturbance of adjacent data, the number of reads is also maintained as a way to determine the health of a page. Since some circuits are stronger than others, a pure count is usually not enough to assure the health of a page, hence advanced forward error correction techniques, that can be used to correct an error after detection and background processing called 'patrol reads' are all deployed as part of a wear-leveling algorithm.

### Write endurance

Write endurance in Flash memories, that is, how long a page can remember every bit, will vary greatly with the technology (SLC vs. MLC) and the number of times the page has been erased and re-programmed and even the number of times the page has been read. This is because, over time, the electronic charge of a given bit can degrade to the point of

unreadability. We have discussed the strategies to minimize the effects of degrading write endurance. First, a wear-leveling strategy must be deployed that evenly spreads the write activity across the entire number of pages on the device. Second, an error correction coding, involving advanced error correction and a large size, or strength of correcting codes included in each block of data. A RAID-like algorithm that stripes data across multiple Flash circuits is deployed in many devices. While this increases the over-provisioning, it also makes recovery from serious errors possible.

## Write amplification

Write amplification is a 'feature' of Flash memories that impedes random write performance. The basic problem is this: whether you are updating a single bit or more, an entire multi-page block needs to be erased and completely re-written. This takes time, or latency, which can negate the very reason the for the price premium paid for an SSD. Blocks in high-end Flash chips are 256 KB or 512 KB. Another feature of this issue is that brand new drives will operate much faster until the entire space of the drive is written. Then the problem rears its head, unless some serious rocket science is applied. Since erase-program cycles wear out the chip over time, this is a critical issue when developing enterprise controller technology. There are multiple strategies to deal with this and the very bright engineers and scientists working in the field are continually improving these processes and running to the patent office to protect their intellectual property.

The very first thing we learned in the mobile field, where Flash memories have been deployed for nearly two decades, is that you treat the entire memory like a sequential tape. You write every page before you 'rewind' to the front of the tape and start erasing and programming. This is really a case of 'the more things change the more they stay the same.' Many of the algorithms for sequential writing of SSDs originated in such obscure devices as the Digital Equipment 'DecTape' drives which could be randomly read and written. They were fun to watch (but not so fun to wait for) while they moved forward and backwards to access a file. A similar issue occurs with a highly fragmented hard drive, hence, the venerable Windows de-fragmentation utility. Basically, whether you are writing a bit or many bytes, the next free page is written and indices are updated to reflect the real data location.

Clearly, if writing Flash is a bottleneck, a good strategy is to reduce the amount of data to be written. Here we have significant compression and de-duplication technology to utilize, even at the chip level, to reduce the amount of data that is written. As any compression and de-dupe guru will tell you, the in-line, primary storage compression algorithms are limited to the data stream being received, unlike the original backup and recovery applications, there is still significant reduction available, but the results can vary widely based on the type of input data. For example, MPEG and JPEG files are already heavily compressed and therefore, trying to reduce them will just burn CPU cycles. The only real way to reduce them is to uncompress them and recompress them using a better algorithm. By the time you do that, you would have been better off just writing the pages. But controllers that do not attempt to compress and de-dupe in-line will suffer performance issues for typical files like PowerPoint's, Word, database and executables.

Another important strategy involves background processing. Once the disk is full, known obsolete pages can be erased and ready for programming again by a background process. There are other advantages to these background processes in managing Flash that include 'patrol reads,' which can determine if the wear issues are impacting certain pages and other housekeeping important to the health of an SSD.

Benchmark developers have addressed write amplification in performance evaluation of various manufacturers' SSDs by recommending that first the entire drive needs to be written. Other strategies involve writing a mix of compressible and incompressible data. One freeware benchmark only writes incompressible data, causing certain manufacturers to add disclaimers to their data sheets and providing provisos in their datasheets for compressible and incompressible files.

Whether the Flash memory is in an HDD form factor, or on a PCIe card, or in a purpose-built appliance, write amplification management needs to be addressed in the software driver, controller or a combination of both. How write amplification is addressed has significant performance and use life ramifications and needs to be evaluated for enterprise applications.

## IOPs – Read/write performance

The primary reason to use solid state memories is to increase the performance of a given computer function. Measurements of performance are touted as features of a given product. There are two important metrics used when

measuring performance: Input-Outputs per second (IOPs) and bandwidth, expressed in bytes per second (Bps). Since read performance and write performance can vary greatly for reasons of write amplification and program-erase cycles, IOPs must be taken in context with type of operation, be it read or write or a combined workload and the size of the data being exchanged. We try to get the manufacturers to indicate this whenever stating IOPs in a specification. Typically, IOPs are specified for random reads of 4KB and random writes of 4KB. Bandwidth is usually specified as sequential reads MB/sec and sequential writes MB/sec.

## Latency

Latency refers to the total amount of time it takes to complete an operation, so just because you have a fast device, it does not mean that you can take full advantage of its speed. This is especially true of SSDs. Generally speaking, the farther from the CPU accessing the device, the more latency exists. Thus, DRAM that makes up the CPU's main memory has less latency than sitting on a PCIe card, which has less latency than an SSD sitting on a shared storage network. HDDs have lots of latency doing random reads, because of the time it takes to move the read head to a new spot. But HDDs have less latency during a long sequential write as long as the data being written can keep up with the rotation of the drive. While SSDs will generally improve performance, how much improvement often depends on the application's use of the data and other overheads associated with its access.



## Implementations

### HDD Form Factor Flash SSD Drive

HDD form-factor SSDs represent the highest volume devices in the market because they are deployed in both enterprise data center applications as well as in client devices. While an SSD may be installed in a server, it does not necessarily need to be of an enterprise-class drive. A good example is the boot drive.

Far beyond boot drives, the major deployments for enterprise products are in SANs, network attached storage (NAS) and direct attached storage (DAS) systems. As a bet, we vote for foundry owners taking more and more of the market through both direct technology development and acquisitions.

The drive format products have a great advantage of being able to plug and play into an existing array. This does come at a cost over other implementations. Drive format products need to pretend that they are really a disk drive. This means that an industry standard interface, be it Fibre Channel, Serial ATA or Serial Attached SCSI needs to be built into each drive. Besides being able to plug-and-play into a number of existing products (drive bays, JBODs, storage area networks), the drive format products provide reliability benefits in terms of no single point of failure and compatibility with in-use protection and self-healing strategies.

Foundry owners continue to use their unit cost advantages to compete with other market entrants. There has been considerable consolidation in the HDD form factor market. HDD manufacturing giant Western Digital, while not a foundry owner, certainly has the purchasing clout to keep the foundries competing with each other. WD has purchased SSD maker sTec and caching software maker VeloBit this year. Prior SSD investment by WD include its acquisition of Hitachi GST. Foundry owner SanDisk has added SSD maker Smart Storage to its portfolio this year along with making strategic investments in several startups.

### PCIe Format Flash SSD

While taking advantage of the full bandwidth of the CPU bus, PCIe format SSD products have some interesting trade-offs. Once the exclusive domain of Fusion-io, PCIe products are supplied by a large number of vendors, including foundry owners Micron, Samsung, SanDisk and Toshiba. These devices provide extreme performance at premium price points. They certainly keep to the rule of taking the highest speed devices closest to the server CPU. In many situations this direct-attach deployment makes perfect sense. However, as in all things storage, there are tradeoffs. A big one, especially when you are dedicating a single piece of expensive hardware (these PCIe devices can run to tens of thousands of dollars) to another expensive device (a high-end server), lots of concerns about the expense of redundancy and the potential for single points of failure taking very costly components offline are associated with these devices.

### All Flash Appliance/Array

Storage appliances, sometimes called storage arrays, are purpose-built devices, usually in rack mount form factors, which act as either a shared block device or a network attached storage file system. These devices can be built-up from available HDD format SSDs, DRAM memories, custom Flash modules or combinations.

Appliance interface options typically include Fibre Channel, InfiniBand, and Ethernet physical connections. For storage area network (SAN) block-oriented connections, Fibre Channel Protocol over Fibre Channel, SCSI Remote Protocol (SRP) over InfiniBand, iSCSI over Ethernet and recently ATA over Ethernet (AoE) are popular options. Network attached storage (NAS) options typically include Network File System (NFS), Common Internet File System (CIFS), or Server Message Block (SMB) protocols running over Ethernet. Devices range in size and capacity from a single rack unit (1.75" tall, 1U) to an entire rack supporting hundreds of TBs of solid state memory.

Advantages of these devices include their shareable nature, wide bandwidth and scalability. Disadvantages include high centralized costs and single points of failure for many designs. The best uses generally involve applications where an entire dataset can be contained in an appliance or appliance pair and shared across a fabric to a number of servers.

## Hybrid HDD and Flash Array

Hybrid arrays incorporate both Flash devices and conventional HDDs. The combination allows a lower cost per capacity by using the HDD for data that is accessed less frequently and using the Flash components for hotter data. Hybrid arrays incorporate advanced software algorithms for tier management, caching, data reduction and data reliability by using the higher capacity HDDs for mirroring and data striping to avoid data loss due to a single component failure.

## Fabric Connected PCIe Flash

Using PCIe-based Flash memories to accelerate server operations has become a regular practice within data centers of all sizes. Initially the use was no different than direct attached storage (DAS), just a lot faster than using a hard disk drive (HDD). This worked as long as the capacity of the data set could be kept on the Flash card. But to handle larger data sets, typically due to virtualized environments, larger capacities of Flash cards were needed at increasing cost, creating an expensive single source of failure.

The use of write-through caching algorithms became a partial solution to the capacity issue. By keeping hot data on the Flash card and going to shared storage for everything else has become a standard practice. We call this server-based caching version 1.0. While this implementation works well within a single physical server, when a virtual workload is moved to another physical server, the cache is unavailable to the moved workload and the hot data must be re-created, causing a period of impaired performance until the hot data is created on the second physical machine's cache. This behavior can drive an administrator, trying to load-balance a cluster of servers, to the brink of insanity. Another challenge with 1.0 caching is the ability to support clustered applications. Lastly, administrators need to mess around with configurations and scripts to make sure that data among multiple physical servers does not get corrupted accidentally.

## Why IT matters

The variety and capabilities of solid state storage devices is a tremendous advantage to the modern enterprise data center. With all of these products available from both major vendors as well as a new crop of start-up companies, the data center operators have the capability to choose the right product mix for their data use.



## Best Practices and Recommendations

### Understand the Input-Output bottlenecks

While it seems intuitive that slapping an expensive solid state memory device in place of rotating media will always improve performance, the amount of performance improvement may not be dramatic or justify the costs. Conversely, solid state memory devices should not be measured against rotating media on strictly a cost per GB basis. The cost per IO is more important to many applications which are not storage bound, but are performance bound.

Running virtualized workloads is often the culprit in creating IO bottlenecks. Even workloads that have been optimized for sequential IO performance get their IO requests all scrambled up with other virtual machines running on a server. This is called the 'IO Blender' effect.

Increased access time, or operation latency, occurs the farther the memory is away from the CPU core. Devices attached to the CPU bus have less latency than devices accessed over networks. This is why several vendors we have discussed in this report and others still operating in stealth, are working on what we refer to as 'server-centric' acceleration, where PCIe or direct attached SSD is used as a cache to accelerate access to other file or block storage systems. These solutions can often off-load an overcommitted storage system and avoid a costly replacement or upgrade cycle.

### Understand the technologies

You don't need to be a storage administrator or rocket scientist to understand the basics behind the access protocols, device implementations and solid state device technology. Like all things in our industry, there are multiple dimensions to price, performance, use life and reliability that must be viewed in context with the application. Make the vendor explain the price performance advantage of their technical approach. If they can't that is a huge red flag.

Data reduction techniques of compression and de-duplication provide advantages in capacity used, improving speeds of write processes and limiting wear and tear on the flash. These techniques do have an impact on the storage control speed, however. Be certain to understand the effects on system performance in addition to write speed and capacity used. While much of this report has focused on NAND flash devices, DRAM remains the highest performing technology that does not wear out. But it is not persistent, meaning that when power goes off the device, the data goes with it. This means battery backup systems may need to be deployed, *which wear out over time*. For many users, SLC NAND flash is the best deal, in terms of performance and longevity, but costs are double or more per GB over MLC flash. Fibre Channel (FC) and Serial Attached SCSI (SAS) devices have a faster full-duplex interface than Serial ATA (SATA) devices, which typically cost less. Finally, caching and tiering, while providing improvements in performance in hybrid (both SSD and HDD) applications, will never be as fast as all-solid state devices.

### Don't use a consumer-class device in an enterprise application

Stories of arrays crashing because the SSDs have worn out at the wrong time abound. The important words here are caveat emptor. Know the technology and warranty of the devices being deployed.

Premium SSD pricing is often used by major systems vendors who charge a premium for SSDs but offer 'one throat to choke' and free replacement of components under warranty or support policies. Again, caveat emptor. Know what the premium is. This usually can be checked by interrogating online SSD vendors like NEWEGG.COM. All enterprise SSD vendors represent warranties in terms of years and 'full drive writes per day,' meaning the capacity of the drive can be written x many times per day for the warranty period.

### Go for the low-hanging fruit

Organizations need to evaluate the time that their personnel spend waiting for operations to complete. The productivity of a workforce can be improved by adding SSDs as boot drives in servers and in storage drives in user workstations and laptops for knowledge workers.

AOL uses SSDs as boot drives in all of its some 50,000 servers. This really makes sense. Keep in mind that boot drives can be set up as nearly read-only devices. That limits the wear and tear factor dramatically. With HDD boot times on the order of magnitude of five minutes and SSD boot times of about ten seconds, the payback is extremely quick. High priced network engineers don't need to sit for five minutes before they find out if a reboot has fixed a server or VM crash.

Foundry owner and SSD manufacturer Intel has deployed SSDs in all of its employee laptops, practicing what it preaches and justifying the capital expenditure on improved employee productivity.

If a server is having problems accessing shared storage, the use of new, server-centric caching products can provide an instant payback and reduce stress on the shared storage.

Server-side caching can greatly increase the number of VMs that can operate on a given physical machine which reduces license fees and operating expenses.

### **Evaluate Multiple Offerings and Negotiate features and pricing**

There are number of storage system offerings that have Flash memory deployed to increase speed of operation. If possible, get the vendors to compete on an apples-to-apples basis. An understanding of the technologies and underlying costs, as outlined in the beginning of this report, will avoid getting 'blinded by science.'

By understanding the effect of Moore's Law in the next few generations and planning storage upgrades to synchronize with the availability of the next wave of lithography size can save enterprises millions of dollars in capital expenditure. While Flash cannot compete on a cost per capacity basis with rotating memory, the operational costs are not represented by this metric.

SSDs don't have to spin up and spin down to save power. They operate at a much lower power per IO than rotating media. A quick look at the first wave of Storage Performance Council energy benchmarks shows that SSD enabled products dramatically lower the annual electric bill in a data center or server closet.

Whenever discussing SSDs we focus on the wear-and-tear associated with program-erase cycles. But when properly engineered into a fault tolerant control process, SSDs are incredibly reliable when compared to rotating media. That factor is shown in the early adoption of SSDs in military and rugged applications. SSDs are not affected by drop shock that would destroy a rotating device and harmonic minimization (necessary in large HDD arrays) is not a factor.

## Enterprise Use Cases

### Overview

The use of solid state storage can be generalized by benefit. The primary benefit of speed can be applied in many use cases. The most common involve virtualization of servers and workstations. Speeding up a complex operation, such as database analysis is another speed benefit. Operational costs are reduced because solid state devices use less energy per transaction. Productivity of personnel is improved because functions complete faster.

### The details

While generic to virtualization, online transaction processing and high performance computing, in this section we analyze use cases within vertical applications spaces where solid state storage is used in ways to increase productivity and speed processes.

#### Academic Research

Academia is deploying virtualization at both the server and workstation level. One University found that the reduced IT support time was so beneficial that it could provide the virtual desktop infrastructure (VDI) to replace a conventional PC workstation and save the using department hundreds in operational usage fees. The trick with VDI is to keep the shared storage costs low while providing a user experience that is the same or better than desk top computing. Flash arrays provide the shared storage speed to support implementation. Flash storage is utilized throughout the high performance computer systems utilized in academic institutions.

Reduced run-time in analytical operations and database management are use cases that benefit the Academic environment. Processor and data heavy operations are improved by the speed of indices and meta data access available from solid state storage.

#### Archive

Archived information does not have the rapid access demands that top tier data requires, but the speed of Flash storage is highly beneficial to the processing of data for archive. Systems that compress and de-duplicate archive data use the speed of Flash storage to reduce data ingestion time.

#### Big Data

The importance of high speed storage to Big Data is the ingestion processing and metadata creation and access. Object Stores have the ability to keep metadata separate from data stores and can place metadata that has high future access priority in solid state media.

#### Biosciences and Pharma

The Biosciences and Pharma applications require large data sets that require analysis to determine if an expected outcome occurred and to retain these large datasets over time on an ever-increasing basis. While it is not currently practical to maintain these data sets on solid state devices, the use of server-side caching algorithms can greatly speed the completion time of these processes. Similar to Big Data analytics, the metadata involving these large file and database elements can greatly speed the analytic processes when stored on high speed memory.

#### Cloud Compute and Storage

The prime drivers that create enterprise demand for cloud services are driving increased usage of Flash storage in the major cloud service providers. More and more service providers are finding differentiation and revenue opportunities by allowing users to provision workloads with a given quality of service in terms of input-output operations per second (IOPs). If a using organization has workloads that require a given service level, they are going to gravitate to the service providers that can allow provisioning of systems that will support the enhanced performance of SSDs.

Major cloud service providers in the Infrastructure-as-a-Service (IaaS) field are allowing customers to provision bare-metal configurations that include server-side SSDs as well as shared storage that includes a varying amount of SSDs.

On-ramp providers utilize solid state storage to provide a buffer between a customers' data center and the remote cloud site.

**Finance**

Financial services are the epitome of the time-is-money adage. Transactions per second (TPS) is the metric that ties directly to the financial performance of an institution in many applications. Server-side cache and all solid-state arrays are deployed in these applications that can change the economic picture of an organization, and financial services firms have been the early adopters of Flash storage for more than a decade.

Large-scale analytic simulations are the domain of these firms and the speed of outcome of a given simulation is an important component to the feedback loop that dominates organizations of all sizes.

**Government**

Military and Intelligence operations require high speed analysis of vast quantities of information. Ingestion of three dimensional graphical data from a wide variety of sources is a critical use case where solid state storage is used extensively.

**Internet Content**

Streaming applications are perfect for Flash because they are read intensive. Examples are video-on-demand and edge-servers delivering promotional content. Web-scale organizations use Flash in servers and direct attached storage for rapid boot and caching, as well as application acceleration and higher virtual machine to physical machine ratios.

**Manufacturing**

Enterprise resource planning (ERP) is the critical application for manufacturers and whether operating SAP, Oracle or another software suite ERP performance is greatly enhanced by Flash storage at the server and shared storage level. In fact, major ERP supplier Oracle provides storage systems that are performance tuned to the application and utilize Flash storage in the server, storage controller and storage array.

Workstation virtualization is deployed in manufacturing application because many of these systems are task-worker oriented and have a very thin workspace profile, particularly suited to solid state storage.

Online transaction processing, particularly order entry, is deployed in most ERP systems and customers become increasingly impatient if the order entry process is slow. Workstations used for Computer Aided Design are excellent targets for SSDs because of the productivity improvement allowed for expensive design engineering resources.

Manufacturing data needs to be retained for years and retrieved quickly in the case of a recall or quality problem. This is an ideal use case for tiered storage with the most recent data retained in solid state storage and older data descending in priority to lower cost storage.

**Media and Entertainment**

Production and post-production applications are enhanced by the use of solid state storage because they involve expensive labor resources applied to very large data sets. Most labor intensive operations in production are short-lived but the data is retained for the long term for re-purposing.

Streaming data, similar to web content, is a perfect application because it involves multiple random reads after a single sequential write, very well suited to Flash storage.

**Oil and Gas**

Analytics that operate against a four-dimensional database (time included) is standard procedure for determining the location of oil and gas resources. These operations are enhanced by server-side cache and solid state tiered data. The demand for these analytics has been increased substantially by the use of hydro-fracking processes which increase the output of oil and gas from a given formation.

The current boom in US production of oil and gas has been enabled by these analytics which, prior to solid-state storage, often took days to run and now are completed in a few hours.

Other applications include the typical ERP coupled with process control for refiners. As refining resources become more committed due to supply and demand changes, the use of high speed storage is increasing.

There is a large component of the modern oil and gas industry which includes distribution management and retail. These applications have the same time-is-money calculation and are enhanced by the use of high speed solid state storage.

**Retail**

Major applications in retail that benefit from solid state storage include point-of-sale (POS), inventory management, seasonal workload variance and analytics.

POS systems increasingly are becoming virtualized server-based computing workloads, because the centralized management simplifies many aspects of what are becoming increasingly complex applications. The check-out process in brick-and mortar retail is the single most revenue-throttling factor and is exacerbated by fluctuations in seasonal workloads. Inventory management has long been a function of portable computers that use Flash for program and data storage and WiFi and Bluetooth radios for communications.

Seasonal variance, as the result of holidays and changes in inventory for a particular season, create stress for the core processing systems which have to be built to handle peak loads. Again, Flash storage provides a method to serve these peak loads.

Retailers are increasingly using Big Data analytics to determine seasonal trends and optimal inventory composition. Often the analytics need to deliver the answer within hours if they are to have any business value. Flash storage is increasingly used for storage of the metadata necessary to support this information base.

Web-based retail has all of these characteristics with the addition of online transaction processing stress with customer satisfaction directly related to the speed that orders can be placed, questions serviced and delivery status information available. Tiered storage and server-side caching provide the functionality necessary to provide essential customer satisfaction.

### **Surveillance**

Ingestion of data from multiple high speed resources is enhanced by processing that uses Flash storage for staging of data.

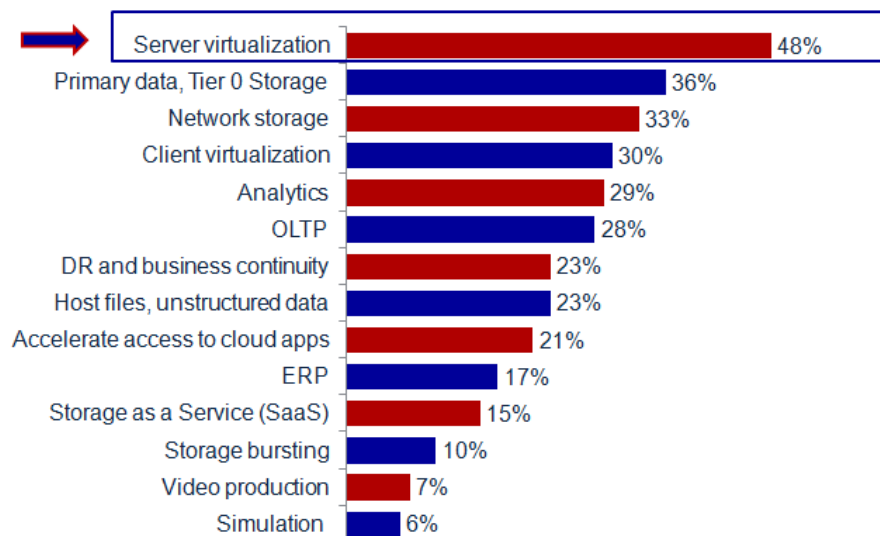
### **Why it matters**

Persistent high speed storage is being deployed by organizations of all sizes because time is money in nearly every human endeavor. Reduction of process time, increased employee productivity and reduced operating costs for a given function are the benefits accrued to many use cases.

## Application-specific Use Cases

The ITIC/Storage Strategies NOW Survey queried IT professionals on their use of Flash/SSDs for various application scenarios.

### If your firm currently uses/has definitive plans to deploy Flash/SSDs, how will it use it?



Three scenarios, among the most common for SSD adoption, follow:

### Server Virtualization

Server virtualization ranks as the application use case most requiring the use of SSDs/Flash memory. With nearly half of the servers deployed each year for virtualization purposes, data required by applications in virtualized environments must be easily and quickly retrieved from the storage subsystems servicing the applications and users. Incorporating SSDs into virtualized servers via PCIe form factor adapters or attached SSD appliances allows the hypervisor to utilize very fast and powerful flash memory to service more virtual machines much more responsively than traditional storage.

With SSDs, the number of virtual machines supported by a single virtualized server can substantially increase. IO performance and a lower latency to all VMs can improve.

### Transaction processing/analytics

If ever there is a case where time is money, it is in online transaction processing, or OLTP. In fact, there are entire workloads developed to simulate OLTP so that systems can be benchmarked and rated on the number of transactions per second per dollar of cost. Whether it is in support of securities or commodity trading, internet sales, funds transfer, claims processing, transportation reservations or simple queries of retail locations, the amount of time it takes to complete a transaction directly affects an organization's ability to make or save money.

OLTP is a perfect example of an application that will benefit from caching and tiered storage strategies discussed later in this report. That is because the information needed during an OLTP session ages very rapidly. The contents of an



Electronic shopping cart will be accessed frequently until the transaction is completed. The transaction details will be accessed frequently until the goods are shipped and may be accessed again in case of a return. After that the transaction data can be migrated to very low cost storage, because the frequency of access will decline to a minimum.

Historically, the management of the transaction data and its related storage has been the job of the application. But as file and storage systems become smarter, the motion of the data to a lower cost (and lower speed) tier of memory has become the responsibility of the system rather than the application.

## Virtual Desktop Infrastructure

The promise of low cost ultra-thin client workstations coupled with lower costs of management of user data has been the reason many organizations set out to virtualize their desktops beginning about five years ago. In many mobile applications, such as acute health care, going to a thin client saved a lot of money and time as related to battery acquisition and recharging logistics. In college labs, customer service operations in financial and technical organizations, telemarketing and general office automation, it really makes sense to move the data from the workstations to the data center.

But early adopters ran into a big problem. They found that they were trading consumer class drives that cost a few a few hundred dollars per TB for shared enterprise class Fibre Channel drives that cost several thousand dollars per TB. In addition, the math of the IOPs just didn't work out. A desktop or laptop consumes between 20 and 40 IOPs. But even an enterprise 15K RPM drive can only deliver about 200 IOPs. When planning for several thousand virtual desktops, the cost of the storage quickly swamped the budgets and VDI remained solidly on the wrong side of the proverbial chasm. This is a perfect application for a high-speed shared memory appliance.

For instance, a financial institution used an SSD/Flash appliance for their VDI rollout. The company had been plagued by slow response time from an existing storage area network (SAN). To overcome IO throughput and budgetary issues, the company installed the appliance after considering several options, including solutions that combined a solid-state cache with traditional disk arrays and 'man in the middle' caching solutions that relieve the pressure on the underlying disk.

'When looking at how we could increase performance with our existing SAN, the only option was to add way more storage capacity than we actually needed, just to get the spindle count necessary to achieve the IO required,'

'Things that would typically be immediately noticeable to our VDI users, such as cloning operations occurring on the same LUN they were working on, boot storms, AV rollouts and so on disappeared immediately. We were able to watch an HD video on a VDI desktop whilst provisioning a desktop pool on the same LUN and rebooting about 50 others at the same time. Our viewing was uninterrupted and throughout disk latency was pretty much zero. Its performance on IOPS (especially write IOPS) was dramatic.'

In the recent survey, respondents from organizations that are currently using SSDs/Flash or have definitive plans to deploy SSDs or Flash, that 30% are using the SSDs for analytics applications.

## Vendor/Product Profile

### Vendor Name: QLogic

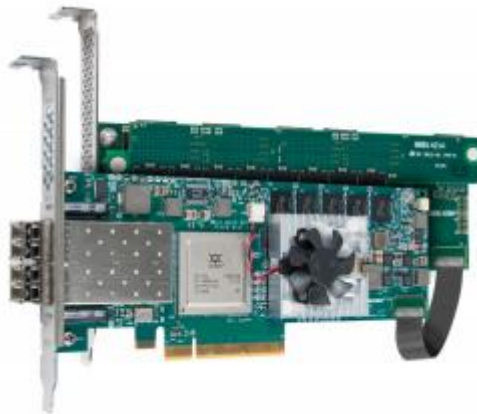
Product Name: FabricCache™ QLE10000 8Gb Fibre Channel adapter

Product Type(s): Fabric Connected PCIe Flash

Link to website: [www.qlogic.com](http://www.qlogic.com)

Link to Data Sheet: [http://www.qlogic.com/Resources/Documents/DataSheets/Adapters/DataSheet\\_10000Series.pdf](http://www.qlogic.com/Resources/Documents/DataSheets/Adapters/DataSheet_10000Series.pdf)

The FabricCache™ QLE10000 caching SAN adapter implements as flash memory on a PCIe card attached to the Fibre Channel (FC) host bus adapter (HBA). The read and write-through cache algorithm is offloaded to, and managed by a System-on-Chip (SOC) on the HBA. The SOC is responsible for finding a given block for read operations and will get it from flash if it exists on the local flash card *or any other FabricCache card in the fabric*. Because the FC fabric has the bandwidth, and the SOC has the brainpower, reads from the storage area network (SAN) only occur if the block does not exist in any of the attached flash memory. This solves the problem of moving virtualized workloads between physical machines, because the workload has access to its original cache no matter to where the VM is moved.



The FabricCache QLE10000 solution uses two PCIe slots, which is the same as a separate Fibre Channel adapter and a PCIe flash card approach. The first slot houses the adapter which includes the SOC and is connected to a second PCIe board with a cable that operates as a PCIe interface and contains either 200GB or 400GB of enterprise-grade single level cell (SLC) flash memory. The second slot provides **only** power to the flash board. The use of SLC makes the system operate faster and minimizes the effect of wear on the flash cells. Since the flash memory is a shared resource among all of the servers in a cluster, the aggregate capacity of the flash becomes a substantial and scalable resource available to all FabricCache adapters. No modifications need to be made to the SAN or any other switching or cabled infrastructure. The adapter provides an 8Gbps, dual-port FC connection and a caching engine that operates on a four core SOC.

Control parameters are offered via intuitive standard QLogic graphical user interface (GUI) as well as a command line interface. A plug-in is available for VMware. There are no changes necessary as FabricCache uses the standard QLogic adapter driver stack, which is supported across a broad range of operating systems including Windows Server and Linux. FabricCache adapters are ordered under a single SKU for HBA and PCIe flash card.

QLogic measured performance of FabricCache using a TPC-E like workload. The hardware configuration used Dell PowerEdge 720 servers with 32GB of DDR memory and 24 cores running Windows Server 2008. The SAN used was an HP EVA6300 with 24 10K RPM hard drives configured with seven 100GB LUNs. The HBA was the FabricCache QLE10542 with 400GB of flash capacity. The first measurements used a single server and a 250-user workload. Without caching, the system produced 74 Transactions per Second (TPS). With caching enabled, the system produced 544 TPS, a seven-fold increase.

The second set of measurements used four servers and a 250-user workload. Without caching, the system produced 87 TPS. With caching enabled, the system produced 1,925 TPS, a twenty two-fold increase.



The third set of measurements evaluated the performance in the shared cache environment, using two servers and a 250-user workload with the cache configured as local and SAN (available over the fabric on the other server). The SAN cache was only slightly slower, yielding 500 TPS when compared to 544 TPS for the local cache, maxing out at about an 8% difference. In either case, the latency for a local or SAN cache hit is less than 1ms. That's not bad, when you consider that included both the fabric latency and PCIe latency for the SAN cache. This demonstrates that the fabric has plenty of bandwidth for sharing the SAN cache between physical servers.

Most datacenters have deployed numerous scripts of management of the SANs within the environment. Server-based caching 1.0 implies the need to modify many of the scripts regarding data placement and load balancing. QLogic's FabricCache requires no additional software to be added to the host, and is therefore totally transparent to existing configuration management. This means that workloads can be dramatically accelerated without disruption to existing operations. Just install the HBAs into the cluster and then turn the cache on. The load on the SAN will be greatly reduced, extending the use-life of existing systems and allowing them to be configured for capacity using lower cost, higher capacity hard drives.

#### Specifications:

- Two card solution: Fibre Channel HBA and PCIe flash card
- PCI Express Base Specification, rev. 2.0, PCI Express
- 8Gbps Fibre Channel full-duplex line rate per port (maximum)
- 8, 4 and 2Gbps Fibre Channel auto-negotiation
- SLC NAND Flash 200GB or 400GB capacities

QLogic has entered the server-based flash cache market in a unique way that is likely to cause many OEMs and data center managers to rethink the deployment model. The ease of installation and support of the FabricCache solution is a major advantage over other methods, which involve deploying products from at least two and sometimes three vendors to achieve a less capable implementation. QLogic provides FabricCache at a price point that competes well with the combined pricing of HBA, flash card and cache software from other vendors.

## Enterprise Use Cases

| Company Name | Product Name          | Direct | OEM | Reseller | Integrator | Other (Specify) | Organization: Business | Organization: Government | Organization: Education | Organization Medical | Organization: Other (specify) | If Business: Financial | If Business: Manufacturing | If Business: Web | If Business: Oil/Gas | If Business: Entertainment | If Business: Cloud Ser. Prov. | If Business: Pharma | If Business: Other (Specify) |
|--------------|-----------------------|--------|-----|----------|------------|-----------------|------------------------|--------------------------|-------------------------|----------------------|-------------------------------|------------------------|----------------------------|------------------|----------------------|----------------------------|-------------------------------|---------------------|------------------------------|
| QLogic       | QLE10522 and QLE10542 |        |     | X        |            |                 | X                      |                          |                         |                      |                               | X                      |                            |                  |                      |                            |                               |                     |                              |

## Enterprise Use Cases: Table 2

| Company Name | Product Name          | ERP | OLTP | Analytics | Simulation | Other (Specify) | Structured data | Unstructured data | I | II | III | IV | V | VIII |
|--------------|-----------------------|-----|------|-----------|------------|-----------------|-----------------|-------------------|---|----|-----|----|---|------|
| QLogic       | QLE10522 and QLE10542 | X   | X    |           |            |                 | X               |                   |   |    |     |    |   |      |

## Enterprise Use Cases: OS Support, Capacities

| Company Name | Product Name          | Windows | Linux | UNIX | Mac | Other (Specify) | ESX | Hyper-V | XEN | KVM | Other (Specify) | DRAM/NVRAM Capacity (GB) | Flash Capacity (net) (TB) | Total Capacity (TB) |
|--------------|-----------------------|---------|-------|------|-----|-----------------|-----|---------|-----|-----|-----------------|--------------------------|---------------------------|---------------------|
| QLogic       | QLE10522 and QLE10542 | X       | X     | X    |     |                 | X   | X       | X   |     |                 | 4GB                      | 200, 400GB                |                     |

## Features Validation Tables

### Fabric Connected PCIe Flash

| Company Name | Product Name | Lithography: 25/24nm | Lithography: 20/19nm | Lithography: Other (Specify) | SLC | MLC (2bpc) | Other (Specify) | Full size | Half Height | Half Width | Other (Specify) | GbE | 10GbE | 8GbFC | 40Gb InfiniBand | SAS Driver | FC Driver | IB Driver | Other Driver (Specify) |
|--------------|--------------|----------------------|----------------------|------------------------------|-----|------------|-----------------|-----------|-------------|------------|-----------------|-----|-------|-------|-----------------|------------|-----------|-----------|------------------------|
| QLogic       | QLE10522     | X                    |                      |                              | X   |            |                 |           | X           | X          |                 |     |       | X     |                 |            | X         |           |                        |
| QLogic       | QLE10542     | X                    |                      |                              | X   |            | X               |           | X           | X          |                 |     |       | X     |                 |            | X         |           |                        |

### Fabric Connected PCIe Flash: OS support, Performance

| Company Name | Product Name | OS Support: Windows | OS Support: Linux | OS Support: UNIX | OS Support: Mac | OS Support: Other (Specify) | Capacity (net) GB | 4KB Read IOPs | 4KB Write IOPs | Read Bandwidth | Write Bandwidth | MSRP                                  |
|--------------|--------------|---------------------|-------------------|------------------|-----------------|-----------------------------|-------------------|---------------|----------------|----------------|-----------------|---------------------------------------|
| QLogic       | QLE10522     | X                   | X                 | X                |                 | VMware ESXi                 | 200GB             |               |                |                |                 | N/A, pricing set by reseller partners |
| QLogic       | QLE10542     | X                   | X                 | X                |                 | VMware ESXi                 | 400GB             |               |                |                |                 | N/A, pricing set by reseller partners |

## About Storage Strategies NOW™

Storage Strategies NOW™ (SSG-NOW) is an industry analyst firm focused on storage, server, cloud and virtualization technologies. Our goal is to convey the business value of adopting these technologies to corporate stakeholders in a concise and easy-to-understand manner.

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