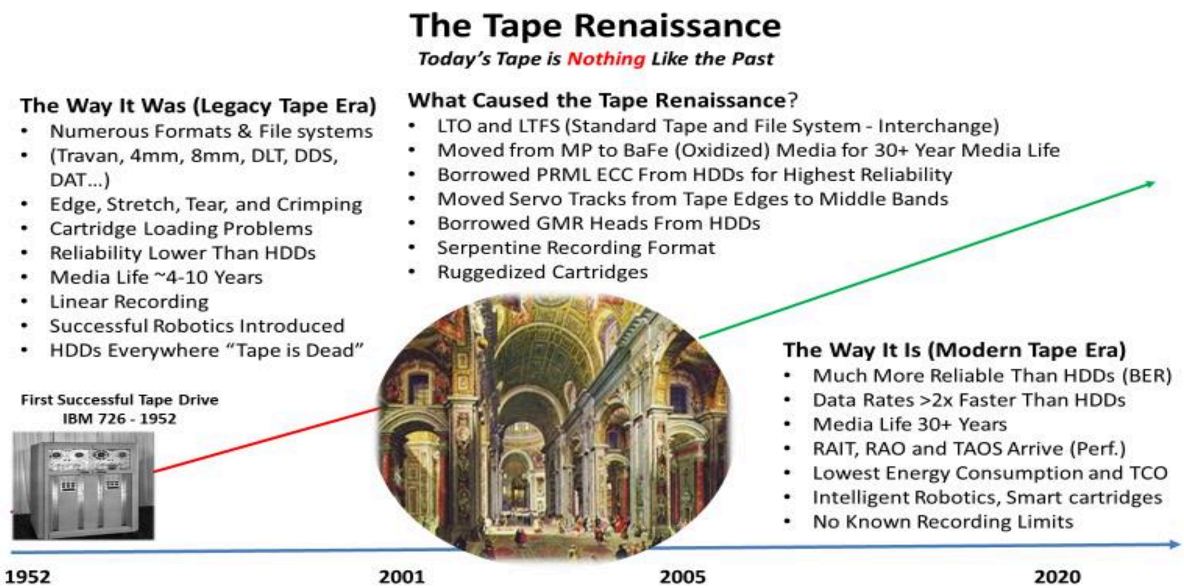
Abstract
Tape technology has experienced a resurgence as the leading strategic and low-cost storage solution for massive amounts of archival and unstructured data. The tape industry has successfully re-architected itself delivering compelling technologies and functionality including cartridge capacity increases, vastly improved bit error rates yielding the highest reliability of any storage device, a media life of 30 years or more, and faster data transfer rates than any previous tape or HDD (Hard Disk Drive) technology. Many of these innovations have resulted from technologies borrowed from the HDD industry and have been used in the development of both LTO (Linear Tape Open) and enterprise tape products. Additional tape functionality including LTFS, RAIT, RAO, TAOS, smart libraries and the Active Archive adds further value to the tape lineup. HDD technology advancement has slowed while progress for tape, SSD (Solid State Disk) and other semiconductor memories has been much greater over the past 10 years. Fortunately, today's tape technology is nothing like the tape of the past. For tape it's clearly a new game with new rules!

The Tape Renaissance Ushers in the Era of Modern Tape
Since the first tape drives appeared in the early 1950s, tape has primarily served as a backup and archive device for disk data. Troublesome tape issues of the past including edge damage, stretch, tear, loading problems, and media alignment with older (now obsolete) tape formats such as DAT, DDS, DLT, and 8MM tape were successfully addressed. By 2000, the Legacy tape Era was ending, and the tape technology *renaissance* was underway as the tape industry was building a new foundation to address many new storage intensive applications. While backup remains an active use case for tape due to its value for fast site restores and anti-cybercrime, tape's future growth opportunities lie in many new and emerging areas. With the internet, cloud, big data, compliance and IoT waves promising unprecedented data growth, the timing for advanced tape functionality couldn't be better. You may have somehow missed it, but the modern tape era has delivered the following capabilities:

- tape is cheaper ($/GB) to acquire than disk
- tape is less costly to own and operate (lower TCO) than disk
- tape is more reliable than disk by at least three orders of magnitude
- the media life for modern tape is 30 years or more for all new media
- tape drive performance (throughput and access time) improved by RAIT, RAO and TAOS
- tape libraries are delivering intelligent, faster, and more efficient robotic movement
- with LTFS tape has a standard file system with media partitions for faster "disk-like" access
- the 10-year roadmap for tape technology is well defined with few foreseeable limits



***Key point:* The tape renaissance completely re-architected the mass storage landscape and the modern tape era has arrived. It's time to bring your understanding of tape up to date and take advantage of the many benefits that tape has to offer!**

Reliability Ratings Soar for Tape

Customers have indicated for years that a key cause of tape failure was due to media and handling errors; however, these concerns are now out of date. Special prewritten servo tracks allow the tape drive head to stay aligned with data tracks on the tape to accurately read and write tape data. With the older linear tape products, servo tracks were on the edges of the tape media and dropping a cartridge could cause servo damage. Since 2000 enterprise and LTO drives have eliminated this issue by combining the pre-recorded servo tracks on the media (between the data bands) along with developing more ruggedized cartridge shells that are relatively impervious to handling damage.

Tape reliability has significantly improved due to several factors. LTO drives switched to PRML (Partial Response Maximum Likelihood) from the older RLL (Run Length Limited) error checking code. PRML is the most effective error detection scheme and is widely used in modern disk drives. PRML can correctly decode a weaker signal enabling a much higher recording density while allowing tape to surpass disk in reliability. For years MTBF (Mean Time Between Failure) was used to measure storage device reliability but this has given way to bit error rate (BER) as the de-facto standard measure of reliability. PRML made it possible for the BER specification for LTO-7 to be increased to no more than a single undetectable bit error for every 1 x 10^{19} bits transferred. Today, both LTO and enterprise tape products are more reliable than any HDD. Times have changed!

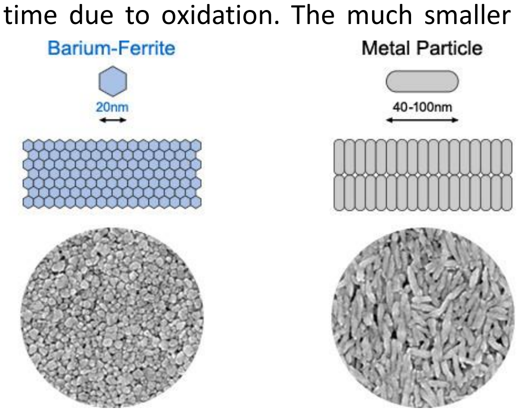
Storage Device Reliability Ratings	BER (Bit Error Rate) Bits read before permanent error
Enterprise Tape (T10000x, TS11xx, LTO-7, 8)	**1 x $10E^{19}$ bits**
LTO-5-6, SSD (NAND)	**1 x $10E^{17}$ bits**
Enterprise HDD (FC/SAS)	**1 x $10E^{16}$ bits**
Enterprise HDD (SATA)	**1 x $10E^{15}$ bits**
Desktop HDD (SATA)	**1 x $10E^{14}$ bits**

Source: Vendor's published BER

Key point:* *Tape has the highest reliability of any data storage device and even higher BER levels are expected in the future.

Barium Ferrite Arrives – A Game Changer for Tape Media

For years, Metal Particulate (MP) pigment was the primary tape media type. MP is mainly made of iron (Fe) therefore it will oxidize over time and its magnetic property will deteriorate. BaFe (Barium Ferrite) was developed by Fujifilm providing a major breakthrough for tape media. BaFe is made of an oxide and therefore it does not lose its magnetic property over time due to oxidation. The much smaller BaFe particles allows more particles-per-unit volume and therefore improves the Signal to Noise Ratio (SNR) and reliability. All generations of LTO cartridges prior to the LTO-6 arrival in 2012 have exclusively used the MP pigment. LTO-6 uses both MP and BaFe while BaFe is now standard on LTO-7 and beyond. BaFe has propelled modern tape media to a life of 30 years or more based on accelerated life tests.



Areal density refers to how many bits of information can be stored on a given surface area of a magnetic disk drive or tape media. On April 9, 2015 Fujifilm in conjunction with IBM demonstrated (not announced) a new record in areal density of 123 Gb/in^2 on linear magnetic particulate tape had been achieved. More recently Sony and IBM demonstrated 201 Gb/in^2 with potential for a 330 TB native cartridge and Fujifilm's Strontium Ferrite next-generation magnetic particle promises more than 400 TB (67 times more storage capacity than LTO-7) on a cartridge with an areal density of approximately 224 Gb/in^2

Tape Drive and Media Specifications	Capacity (native) Compression (x:y)	Data Transfer Rate (native)	Channels/ head	Tracks	Areal Density
LTO-6 MP *and* BaFe	**2.5 TB (2:1)**	**160 MB/sec**	**16**	**2,176**	**2.2 Gb/in^2**
LTO-7 BaFe	**6.0 TB (2.5:1)**	**300 MB/sec**	**32**	**3,584**	**4.3 Gb/in^2**
LTO-8 BaFe	**12.0 TB (2.5:1)**	**360 MB/sec**	**32**	**6,656**	**8.6 Gb/in^2**
TS1140 BaFe	**4.0 TB (2.5:1)**	**250 MB/sec**	**32**	**2,560**	**3.2 Gb/in^2**
T10000D BaFe	**8.5 TB (2.5:1)**	**252 MB/sec**	**32**	**4,608**	**4.93 Gb/in^2**
TS1150 BaFe	**10.0 TB (2.5:1)**	**360 MB/sec**	**32**	**5,120**	**6.52 Gb/in^2**
TS1155 BaFe (TMR)	**15.0 TB (2.5:1)**	**360 MB/sec**	**32**	**7,680**	**9.78 Gb/in^2**
TS1160 BaFe (TMR)	**20.0 TB (3:1)**	**400 MB/sec**	**32**	**8,704**	**12.4 Gb/in^2**

Key point:* *The tape industry has pushed capacity, reliability and media life to record levels. Media demonstrations indicate continued advancements in tape technology for many years ahead.

Future Data Recording Projections

Commercially available tape areal densities have reached 12.4 Gb/in^2 while HDD areal densities are in 1,300 Gb/in^2 range, >10 times denser. Future density scenarios (see the most recent INSIC 2016 chart) project that annual HDD areal density growth rates will *fall below* their historical 35-40% values and will slow toward 16%. Tape areal density growth rates are expected to double the HDD rate averaging about 33% annually. TMR read/write heads will propel tape areal densities into the future. The surface area available to increase HDD capacity on disk platters is crowded while tape cartridges have a surface area over 200 times greater than HDD to work with.

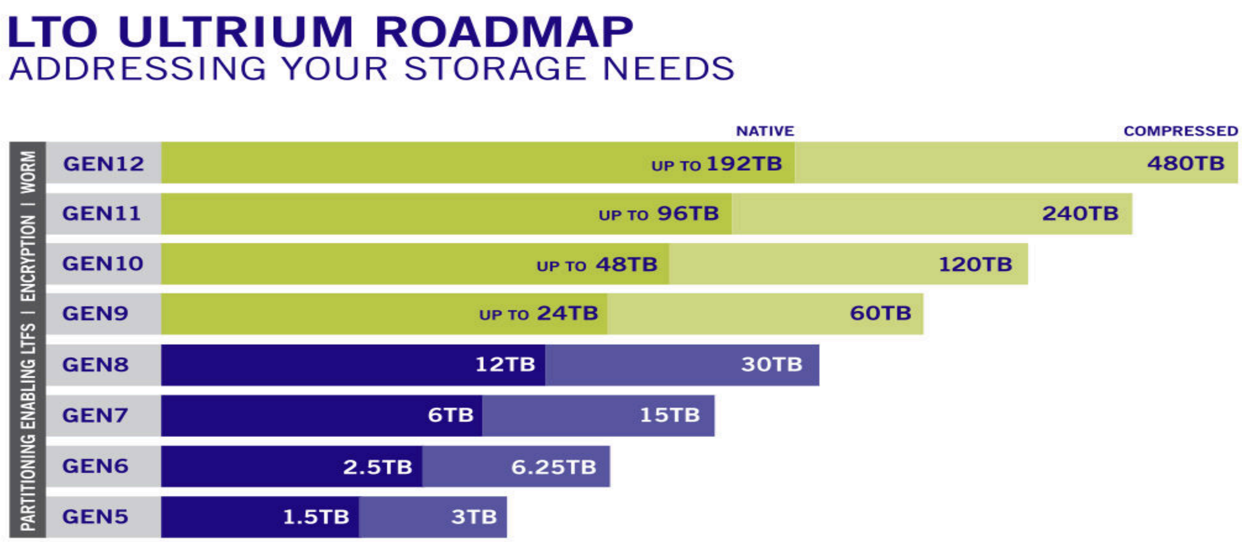
The latest enterprise TS1160 with TMR heads has a native cartridge capacity of 20 TB and 60 TB compressed (3x), yielding the highest capacity of any storage media. Disk drive capacities have reached 15 TB with 20 TB drives planned. To increase capacity, some HDDs have increased the number of platters from three to seven while using helium filled disk enclosures to reduce friction. It should be possible to continue scaling tape areal density at historical rates for at least the next decade before tape begins to face challenges related to the super-paramagnetic effect which today's HDDs are facing. The smaller the magnetic particle, the more data there is in a single bit cell. The net result of these areal density scenarios is a sustained volumetric and total capacity storage advantage for tape technology.

NAND flash memory has set the standard for storage performance, stability, efficiency, and low-power consumption. With no moving parts, flash SSDs are excellent for use in devices and for applications that require high performance and reliability. Hard drives have access latencies in milliseconds, while SSDs operate in hundreds of microseconds. Flash SSDs have surpassed HDD technology in areal density with announcements of 2,770 Gb/in^2. With the transition from single layer to 3D-flash with 64-96 layers – and potentially more - now complete, the SSD industry continues to apply pressure to the HDD industry. 3D XPoint is poised to follow 3D Flash into the high-performance SSD market.

Tape Roadmaps - LTO Roadmap Defined to Generation 12

The LTO Consortium publishes a well-defined roadmap (see below) and in Oct. 2017 extended the LTO family to LTO-12. With each successive LTO generation scheduled to arrive in approximately two- and one-half-year intervals, steadily improving the acquisition price, capacity and performance over previous models. The LTO-7 format expanded the "history buffer" in the compression engine, giving it a 2.5:1 compression ratio, up from 2:1 on previous LTO drives while the enterprise TS1160 drive offers a 3x compression ratio. To push the innovation and capacity boundaries of LTO going forward, the current LTO format required a recording technology transition that supports the high cartridge capacity growth for future LTO generations. As a result, the LTO-8 specification is only backwards compatible with the former generation LTO-7 rather than two prior versions. The 12 TB native LTO-8 cartridges can hold 7,140,000 photos, 8,000 movies or 2,880,000 songs.

Fujifilm and Sony are the manufacturers of LTO media and presently remain in litigation over LTO-8 media halting LTO-8 media shipments. Not to be deterred by the litigation, the tape industry has been delivering **LTO-7 Type M media** to address steadily increasing capacity requirements. LTO-8 drives can initialize new unused LTO-7 cartridges, yielding the LTO-7 Type M media, increasing native capacity 50% to 9 TB and 22.5 TB compressed compared to 6 TB and 15 TB in a standard LTO-7 cartridge. The new LTO-7 Type M is manufactured and logoed as LTO Ultrium 7 media but labelled with a barcode label ending with the last 2 characters "M8". The new 9 TB LTO-8 cartridge can hold 1,071,000 photos, 12,000 movies or 4,320,000 songs. The Type M data rate is the same as LTO-7 at 300 MB/sec.



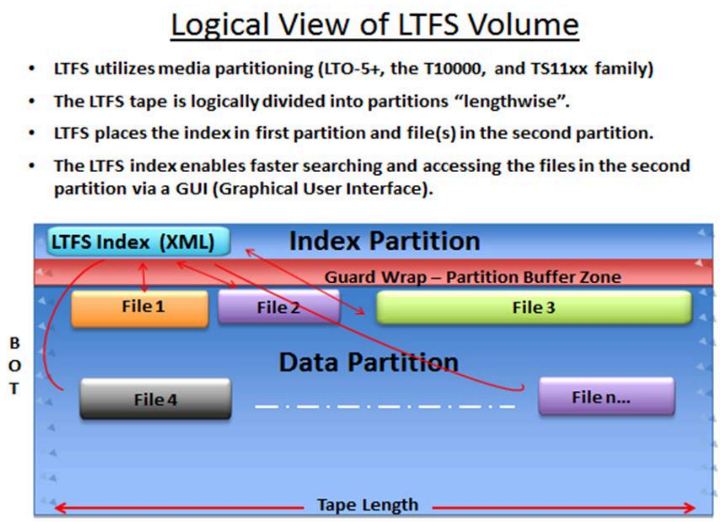
NOTE: Compressed capacity for generation 5 assumes 2:1 compression. Compressed capacities for generations 6-12 assume 2.5:1 compression (achieved with larger compression history buffer).
SOURCE: The LTO Program. The LTO Ultrium roadmap is subject to change without notice and represents goals and objectives only. Linear Tape-Open, LTO, the LTO logo, Ultrium, and the Ultrium logo are registered trademarks of Hewlett Packard Enterprise, IBM and Quantum in the US and other countries.

***Key Point:* The progress of future LTO tape systems is well defined, highly attainable, and is expected to support several more years of technology advancements. Expect similar improvements and steady progress for enterprise tape.**

LTFS Enables Faster Data Access for Files and Objects

Tape is improving file access times and data rate (throughput) with Active Archive, RAIT, RAO, TAOS and LTFS while offering the storage industry's fastest data rates. LTFS (Linear Tape File System – aka Spectrum Archive) continues to gain momentum and now has 36 companies as licensed implementers. Developed by IBM and introduced in 2010 with LTO-5, LTFS (Linear Tape File System) provides an easier and faster way to access and archive data to tape.

LTFS has implemented tape partitioning, one partition holds the index and the other contains the content, allowing the tape to be self-describing. The metadata of each cartridge, once mounted, is cached in server memory. Metadata operations, such as browsing directory tree structures and file-name searching using familiar drag and drop techniques are performed more quickly in server memory and do not require physical tape movement.



On July 5, 2017 LTFS announced a connection with OpenStack Swift to enable easier movement of cold (archive) data from object storage to more economical tape storage for long-term retention. LTFS now provides a back-end connector for open source SwiftHLM (Swift High Latency Media), a high-latency storage back end that makes it easier for users to perform bulk operations using tape within a Swift data ring. LTFS has made archiving and retrieving data easier than ever before for tape applications.

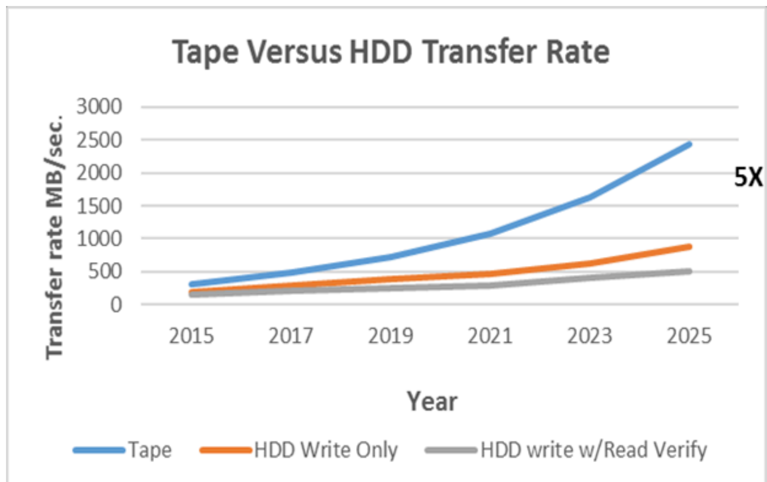
***Key point:* Expect LTFS partitioning and its future iterations to provide even greater access capabilities for tape and attract more ISVs (Independent Software Vendors) to exploit its capabilities.**

The Tape Air Gap Provides Security and Cybercrime Prevention

Security features are included on LTO and enterprise tape drives to address countless compliance and legal requirements including data encryption to protect data at rest, Write-Once-Read-Many (WORM), and various write-protect capabilities that prevent data overrides. The LTO-3 and later tape drives include the WORM feature and the LTO-4 and later tape drives can encrypt data. Since tape is removable media, physical cartridges can be easily transported to another location in the case of extended power outages or natural disasters which have become more common and costly in recent years. Given the number of causes that could potentially force data centers to go without electricity, media portability remains a final, but vital line of defense for data protection and transport. As a result, the traditional "truck access method" has considerable – and renewed - value for data resiliency.

The tape air gap, inherent with tape technology, has ignited and renewed interest in backing up data on tape. The "tape air gap" means that there is no electronic connection to the data on the removeable tape cartridge therefore preventing a malware attack. Disk systems remaining online 7x24x365 are always vulnerable to a cybercrime attack. About 70 percent of ransomware attacks in 2018 targeted small businesses, with an average ransom demand of $116,000, according to a recent report from Beazley Breach Response Services. Beazley researchers analyzed 3,300 ransomware attacks against their clients in 2018 and found the highest ransom demand was $8.5 million and the highest demand paid was $935,000. Ransomware attacks increased 11 percent from 2017, with 206.4 million attacks, according to recent SonicWall research. In Sept. 2017, The Wall Street Journal published an article highlighting tape's unique new role in cybersecurity.

Tape Data Rates Soar



The INSIC 2015-2027 International Magnetic Tape Storage Roadmap projects tape data rates to increase at 22.5% annually and are expected to be as much as five times faster than HDDs by 2025. This is great news for businesses needing to move or recover large amounts of data the fastest way possible. Data from the IoT, big data analytics, content from higher density images and streaming video, hybrid cloud workloads and traditional DR and hot site applications will benefit from the higher data rates. The faster data rates will significantly increase the benefits and value of RAIT, which allows multiple tape drives to transfer data in parallel providing a data rate multiplier. If the fastest data transfer rate (throughput) is needed, tape is the best solution available.

***Key point:* Honestly, did you realize magnetic tape has such a recording density, media life and data rate advantage over HDDs?**

RAIT Provides Much Higher Transfer Rates and Access Times Improve

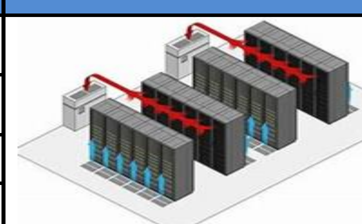
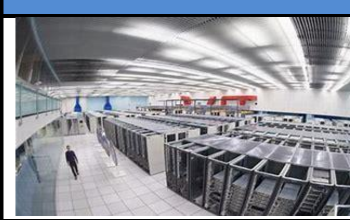
RAIT (Redundant Arrays of Inexpensive Tape) is available with HPSS (High Performance Storage System) and aggregates bandwidth across multiple tape drives in parallel significantly increasing data transfer rate (throughput). RAIT uses multiple tapes loaded in parallel for writing and reading data and provides parity for data reconstruction like RAID does for HDDs. Interest in RAIT is increasing as it takes advantage of significantly higher future tape transfer rates which are projected to yield tape data rates 5x faster than HDDs by 2025. The much higher transfer rates position RAIT for the HPC, hyperscale, cloud and enterprise markets. See INSIC data rate projection chart for tape and HDDs (above).

The tape industry has stepped up its focus on **access time** to a tape file by delivering two exciting capabilities, RAO (Recommended Access Order) for enterprise tape and TAOS (Time-based Access Order System) for LTO. These features create an optimally ordered list of files on a cartridge which reduces file access times as much as 50% while significantly reducing physical tape movement and wear. This capability becomes more important as tape capacities increase and the probability that the number of concurrently accessed files on a cartridge increase. To complement these features, **robotic tape libraries** have gotten smarter and faster adding features that minimize robotic movement times to optimally locate a tape cartridge while adding the benefit of improving library reliability.

Energy Consumption - Tape Means Green Storage

A commonly stated objective for many data center managers today is that *"if data isn't used, it shouldn't consume energy".* In response to this directive, the movement of archival data from HDD to much more energy efficient and more cost-effective tape storage is actively underway. Unlike storage providers, energy providers have shown little interest in lowering their rates (price per unit) and average data-center energy costs often grow at 10-20% per year or more per unit consumed.

Best practices for using less energy in the data center focus on the two highest areas of energy consumption – servers and disk storage. Tape cartridges spend most of their life in a library slot or on a shelf and consume no energy when not mounted in a tape drive. Energy costs for tape capacity are significantly less than the equivalent amount of disk capacity and this gives tape a significant TCO advantage. The limits of power distribution in many data centers are being approached, forcing organizations to explore new cooling techniques such as water-cooled racks, outdoor and mobile cooling, or in some cases, building another data center. Building another data center is normally a last resort and is extremely expensive mandating that energy consumption be properly managed. Average IT electrical consumption rates for data centers are summarized in the chart below.

Average Electrical Power Usage for Data Centers		
Chillers, cooling, pumps, air-conditioning	**24%**	
Uninterruptible power supply	**8%**	
Air movement, circulation, fans etc.	**10%**	
Misc. lighting, security, perimeter surveillance	**3%**	
Total infrastructure – external consumption	**45%**	
Servers	**30%**	
Disk drives, control units	**14%**	
Tape drives, robotic tape libraries	**3%**	
Network gear, SAN switches and other devices…	**8%**	
Total IT equipment – internal consumption	**55%**	

Source: Horison, Inc. and estimates/averages from various industry sources.

Utility companies can restrict the amount of power data centers can use at certain times of the day making data center energy management strategy more critical. Hyperscale data centers such as Amazon, Apple, Facebook, Google and Microsoft face enormous energy management challenges which encourage using tape for storing enormous quantities of less active data. AI and machine learning algorithms enable supervised control over cooling, gradually making changes to allow for the most effective usage of power.

***Key point:* Shifting less-active, archival and inactive data from disk to tape storage and virtualizing servers are the most significant ways of reducing energy consumption in the data center.**

The Active Archive Emerges to Improve Performance.
Tape's favorable economics for storing archival data are fueling increased interest in Active Archive solutions. An active archive is a combined solution providing users an automated means to store and manage all their archive data by integrating HDDs, SSDs, and tape in the data center or cloud. The active archive greatly improves tape access time by using HDD or SSD as a cache buffer for a tape library. The active archive enables a high percentage of accesses to more active data in the physical tape subsystem to be satisfied from SSD or HDDs (cache hit ratio) improving access time to first byte of data.

***Key point:* The active archive is a disk-like cache buffer for tape libraries providing faster access times for backup files and more active archival data.**

Hyperscale and Cloud Data Centers Take Off
A tremendous shift towards hyperscale and cloud computing technologies across various industries and global geographies is fueling the demand for highly scalable data centers. The global hyperscale data center market size is forecast to reach $1.47 trillion by 2025 and was $583 billion in 2017. The growing demand of cloud computing technologies is anticipated to grow the hyperscale market annually at 12.1% during the forecast period. Started by few hyperscale and cloud providers in the United States, new hyperscale providers have now spread across the globe to meet the new data requirements.

Three major challenges could hinder the global hyperscale data center market and include - the need of huge capital investments, high power consumption and increasing carbon emissions. Hyperscalers have been constantly trying different methods to improve the power efficiency are implementing new equipment designs and cooling systems using AI. According to the Cisco Global Cloud Index report, the hyperscale data centers are poised to grow from 338 in 2016 to 628 by 2021 representing 53 percent of all the data center servers by 2021. The single major influence on the hyperscale market growth has been the advent of cloud computing.

Tape Playing an Increasing Role for the Hyperscale and Cloud
Tape's role in the cloud provider market is expanding as tape is being recognized as the optimal solution for archival storage to address and reduce the higher HDD cost issues. Using HDDs for archival storage is a strategy – just not a very cost-effective one - and the cloud providers now understand this as their

storage requirements soar. Since tape media is portable, using tape for cloud storage becomes highly advantageous if the cloud provider shuts down or should you want to quickly move your entire archive set to another cloud provider. Moving large amounts of archival data using available network bandwidth can take days or even weeks and can become cost prohibitive compared to moving tape via truck or airplane. Hyperscale/cloud environments are large public cloud providers offering services that require an infrastructure that has lower cost. Cloud providers may not advertise the fact, but even the largest ones are increasingly using tape for economical archival and cold data storage.

Internet of Things and Emerging Applications Accelerate Future Tape Growth

With the IoT now taking off, much of the data generated by a projected 25 billion or more connected sensors and devices by 2025 will be fulfilled by hyperscale data centers. The introduction of 5G, the next-generation of wireless mobile networks, will enable the IoT to further fuel the hyperscale market in the coming years. The IoT, which refers to multiple data input sources at the edge of a physical domain such as a home, office, factory, or even a smart city, will require tape storage to store the vast volumes of edge sensor data that will eventually be used to analyze, report, and manage data to increase information efficiency.

Emerging technologies such as autonomous cars, virtual reality (VR), augmented reality (AR) and video, which is projected to be as much as 82% of all IP traffic by 2022, should benefit significantly from 5G and will also have a large influence on the hyperscale data center market. The rapid growth of Artificial Intelligence (AI) software across many industry vertical markets are boosting the demand for high performance computing hardware and vast amounts of data for cloud and on-premise data centers to deal with.

The Big Data Era has firmly established itself, and the value of the digital archive is increasing as the benefits of mining and analyzing very large datasets enable analysts to project new business trends, prevent diseases, improve security, address cybercrime, and strengthen national defense, and much more. Presenting an ever-moving target, the boundaries of digital archives now reach petascale ($1x10^{15}$) or exascale ($1x10^{18}$) and will approach zettascale ($1x10^{21}$) capacity levels in the foreseeable future.

Tape has been expanding its historical role as a backup solution to address a much broader set of requirements including data archives and disaster recovery services. Traditional digital archives consisting of unstructured data, digital images, multi-media, video, social networks, compliance and surveillance data are the fastest growing data category experiencing a CAGR (Compounded Annual Growth Rate) in the range of 60% annually. Meeting these storage requirements only with disk and/or SSD will become financially prohibitive - much of this data will ultimately be destined for tape until needed for analysis.

***Key point:* Cloud providers are deploying tape for their lowest-cost, most secure, long-term archival storage offerings. Storing archival data in the cloud represents a significant future growth opportunity for tape storage providers and a much lower cost solution for cloud providers.**

Total Cost of Ownership Favors Tape over Disk

Tape's significant cost per gigabyte and Total Cost of Ownership (TCO) advantage compared with other storage mediums clearly makes it the most cost-effective technology for long-term, secure data retention. Keep in mind that tape capacity can scale without adding more drives – this is not the case with HDDs where each capacity increase requires another drive, along with more energy and cooling. RAID requires, by definition, more disk space and mirroring can double disk costs. Additionally, disk storage requires much more work to clean up, and it is usually enough of a hindrance that many users overbuy capacity to accommodate their needs all adding to HDD costs. Some excellent TCO studies are publicly available and show the TCO for HDDs typically ranges from 6 to 15 times higher than for the equivalent capacity tape systems. See TCO reports and the easy to use TCO calculator from Brad Johns Consulting.

***Key point:* The TCO of tape over disk is most compelling for archival storage. With reliability and security having surpassed HDDs, tape is well positioned to capture the exploding demand for long-term storage requirements.**

Disk Challenges are Mounting - The Storage Squeeze Play Has HDD's Caught in the Middle

HDDs are increasing in capacity - but *not* in performance - as the IOPS (I/O's per Second) for HDDs have basically leveled off. The potential for more concurrently active data sets increases as HDD capacity grows and the increased contention for the single actuator arm causes further response time delays. Excessive RAID rebuild times have become another major concern and it can take several days to rebuild a failed high-capacity HDD impacting subsystem performance. As HDD capacities continue to increase, total time required for the RAID rebuild process will become prohibitive for many IT organizations. Higher capacity HDDs could force a replacement for the traditional RAID architecture with such features as Erasure Coding. A notable shift in the storage landscape is underway as high-performance data moves from HDD onto flash and other memory technologies, while lower activity and archive data migrate from HDD to modern tape. Worldwide HDD shipments have declined over 40% since its highpoint in 2013 as the squeeze play is underway and disk is caught in the middle.

Functionality	Tape	Disk
TCO	Favors tape for archive as much as 6-15x over disk and cloud	Much higher TCO, more frequent conversions and upgrades
Long-life media	30 years or more on all new enterprise and LTO media favoring archive requirements	~4-5 years for most HDDs before upgrade or replacement, 7-8 years or more is typical for tape drives
Reliability	Tape BER (Bit Error Rate) @ $1x10^{19}$ versus $1x10^{16}$ for disk	Disk BER falling behind - not improving as fast as tape

Inactive data does not consume energy	Yes, this is becoming a goal for most data centers. "If the data isn't being used, it shouldn't consume energy"	Rarely for disk; potentially in the case of "spin-up spin-down" disks *Note: data striping in arrays often negates the spin-down function*
Provide the highest security levels – encryption, WORM	Encryption and WORM available on all LTO and enterprise tape. The tape "air gap" prevents hacking	Becoming available but seldom used on selected disk products, PCs and personal appliances.
Capacity growth rates	Roadmaps favor tape over disk for foreseeable future – a native 200+ TB cartridge has been demonstrated	Slowing capacity growth as roadmaps project disk capacity to lag tape for foreseeable future
Scale capacity	Tape scales by adding cartridges	Disk scales by adding more drives
Data access Time	LTFS, the Active Archive, TAOS and RAO improve tape access time	Disk is much faster (ms) than tape (secs) for initial access and random-access apps
Data transfer rate	400 MB/sec for TS1160, 360 MB/sec for LTO-8, RAIT multiplies tape data rates	Approx. 160-220 MB/sec for typical HDD
Portability - Move media for DR with or without electricity	Yes, tape media is completely removable and easily transported in absence of data center electricity	Disks are difficult to physically remove and to safely transport
Cloud Storage	Tape Improves Cloud Reliability and Security, Lowers Archival Storage Costs, Unlimited Capacity Scaling	HDDs Become Very Expensive as Cloud Providers and Hyperscale data centers grow

***Key point:* HDDs are caught in the middle as storage administrators strive to optimize their storage infrastructure to address high performance applications with SSD and archival demands with tape.**

Summary

The magnetic tape industry has made significant progress in many areas over the past 10 years. Clearly the continued role for disk is well established but disk is facing growing technological and cost challenges making capacity increases and any additional disk performance gains difficult. Tape will not replace HDDs or SSDs, but it has expanded its position as a highly cost-effective complement to SSD and HDD for the foreseeable future due to its lower TCO, high reliability, higher capacities, faster data rates, and significantly lower energy costs. Because of this progress, the tape industry is quickly re-positioning itself to address many new high capacity, long-term archival and big data storage repositories which now represent more than 60% of the world's total stored digital data. The rich technology improvements in the tape industry suggest that tape will continue to be the most cost-effective storage solution for the enormous challenges that lie ahead, whether on-site, at a remote location, or in the cloud.

***Bottom-line:* The tape renaissance has positioned tape for the data intensive world that lies ahead. For tape it's clearly a new game with new rules!**