BY: Fred Moore President
www.horison.com

Tape.
New Game.
New Rules.

2015
Tape Technology Update Series

ABSTRACT In response to a growing "awareness" challenge as this century began, the tape industry began to re-architect itself and the renaissance is well underway. Several new and important technologies were implemented for tape yielding numerous improvements including unprecedented cartridge capacity increases, vastly improved bit error rates, much longer media life and faster data transfer rates than any previous tape or disk technology. Many of these innovations have resulted from technologies borrowed from the HDD (Hard Disk Drive) industry and have been used in the development of both LTO (Linear Tape Open) and enterprise tape products. Clearly disk technology has been advancing, but the progress in tape has been even greater over the past 10 years. Today's contemporary tape technology is nothing like the tape of the past. It's time to bring your views of tape up to date as the future for tape technology has never been brighter. *The era of modern tape is here.*

Tape Today

Have you wondered what has been happening in the tape storage industry, if anything?

Did you know:

- tape is cheaper to acquire than disk,
- tape is less costly to own and operate than disk,
- tape is more reliable than disk,
- tape now has media partitions for faster “disk-like” access,
- the capacity of a tape cartridge is higher than a disk drive’s capacity, and
- the media life for tape is 30 years or more for all new media.

If you didn’t - you are not alone – but it’s time to bring your understanding of tape up to date.

The Era of Modern Tape Arrives - Major Tape Enhancements Since 2000

By 2000, a new era of tape was underway as the tape industry was busy re-engineering itself. Key tape developments yielded higher capacities, much longer media life, vastly improved drive reliability, lower acquisition and TCO (Total Cost of Ownership) and much faster data rates than any previous tape technology. Troublesome tape issues of the past including edge damage, stretch, tear, loading problems, and media alignment from older tape formats such as DAT, DDS, DLT, Travan, and 8MM tape were successfully addressed. Coupled with the advent of Barium Ferrite media, each of these developments has helped to redefine the future of tape.

Reliability Ratings Soar for Tape

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 standard measure of reliability. Several factors have contributed to improve tape reliability. PRML (Partial Response Maximum Likelihood) is the most effective error detection scheme and is widely used in modern disk drives. Borrowing from the disk industry, LTO drives switched to PRML from RLL (Run Length Limited) encoding as PRML attempts to correctly interpret even the smallest changes in the analog signal. Because PRML can correctly decode a weaker signal, it enabled a much higher recording density while allowing tape to surpass disk in reliability. Today, both LTO and enterprise tape products are more reliable than the most reliable disk drive. Times have changed!

Technology Reliability Ratings	**BER (Bit Error Rate)**
Enterprise Tape (T10000x, TS11xx)	1 x $10E^{19}$ bits
Midrange Tape LTO-5, LTO-6	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 product specifications.

Key point:* *Tape reliability has now surpassed disk reliability.

Comparisons between disk and tape reliability have been the subject of lively debates and much of the debate is the result of past user experiences with aging tape technologies, however things are completely different with modern tape. The reliability for today's enterprise and open systems tape drives and media range from one to three orders of magnitude higher than the most reliable Fibre Channel disk drive and this trend is expected to continue to favor tape in the future.

Customers have indicated for years that their most frequently perceived cause of tape failure was due to media and handling errors and this perception has lingered. Modern tape media has made significant strides. Special prewritten data tracks on the tape called servo tracks (a track that allows the tape drive head to stay aligned with the tape) keep the tape heads on the correct track while reading and writing. With the older linear tape products, the edges of the tape media served as servo tracks. Since 2000 enterprise and LTO drives have eliminated this issue by combining the pre-recorded servo tracks on the media (away from the edge) along with developing more ruggedized cartridge shells that are relatively impervious to handling damage. Several new cartridge enhancements have also appeared since 2000 and are highlighted in the following chart.

Cartridge Feature	Reliability Description
Cartridge design	Significantly more rugged cartridge design protects data during physical transportation and handling
Tape path reliability	Fully enclosed tape path provides for higher reliability
Contamination protection	Spring-loaded doors protect the cartridge leader from damage and contamination
Media tension control	Hub-lock technology maintains the correct tension on the media inside the cartridge preventing media rotation, reducing read errors and preventing the hub from hitting the inside of the cartridge during handling
Smart cartridges	Use of a radio frequency identification (RFID) non-volatile memory chip mounted inside the tape cartridge shell that can be accessed via an RFID interface providing a direct connection to the tape drive's on-board processors. These hold the cartridge's log, and store manufacturer identification and date, cartridge type, and tape reliability statistics for improved media health monitoring

Security and Media Life

Security features are included on LTO and enterprise tape offerings to address countless compliance and legal requirements including Write-Once-Read-Many (WORM), data encryption to protect data at rest, and various write-protect capabilities. Since tape is removable media, physical cartridges can be easily transported to another location in the case of extended power outages which have become all too common in recent years. Given the number of natural disasters forcing data centers to go without electricity, media portability remains the last line of defense for data protection. As a result, the traditional "truck access method" hasn't lost its value. In addition, the media life for all new LTO and enterprise class tape now reaches 30 years or more making tape a highly secure, long-term storage and archive medium.

Tape Media Considerations

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. In order to slow down the oxidation process, the outer layer of MP is intentionally oxidized from the beginning. All generations of LTO cartridges prior to LTO-6 have used the MP pigment. Along with magnetic material advances, tape media have increased substrate dimensional stability with reduced thickness, much smoother surfaces, lower defect densities, and increased edge slitting precision. Tape media must be highly reliable, portable and rugged enough to be moved without impacting reliability, and must have a high capacity and very long-life for archival applications. Recent barium ferrite developments have enabled these requirements to become reality.

Barium Ferrite Arrives – A Game Changer for Tape

In January, 2010, scientists at IBM Research in Zurich demonstrated recording data onto a new, advanced prototype barium ferrite (BaFe) tape media developed by Fujifilm Corporation at a density of 29.5 billion bits per in^2 potentially yielding a native (uncompressed) capacity of 35 TB on a single cartridge. As a result of this joint R&D effort, several new tape technologies were also developed including improved precision control of read-write head positioning, more than a 25-fold increase in the number of tracks, new detection methods to improve read accuracy, and a new low friction read-write head.

In May, 2014, Fujifilm and IBM jointly announced that another record density of 85.9 billion bits per in^2 on linear magnetic particulate tape had been achieved using Fujifilm's proprietary NANOCUBIC and BaFe particle technologies. This achievement is potentially capable of storing 154 TB native capacity on a single cartridge. Getting to the projected 154 TB cartridge capacities will still take some time as the current maximum native cartridge capacity is 10 TB with IBM's enterprise TS1150 tape drives. These enhancements represent the most significant step yet toward achieving tape areal densities of 100 billion bits per in^2 and beyond while further improving tape reliability.

BaFe is made of an oxide and therefore it does not lose its magnetic property due to oxidation. The smaller BaFe particles are one of the main advantages for using BaFe as it allows more particles-per-unit volume and therefore improves the Signal to Noise Ratio (SNR) and reliability.

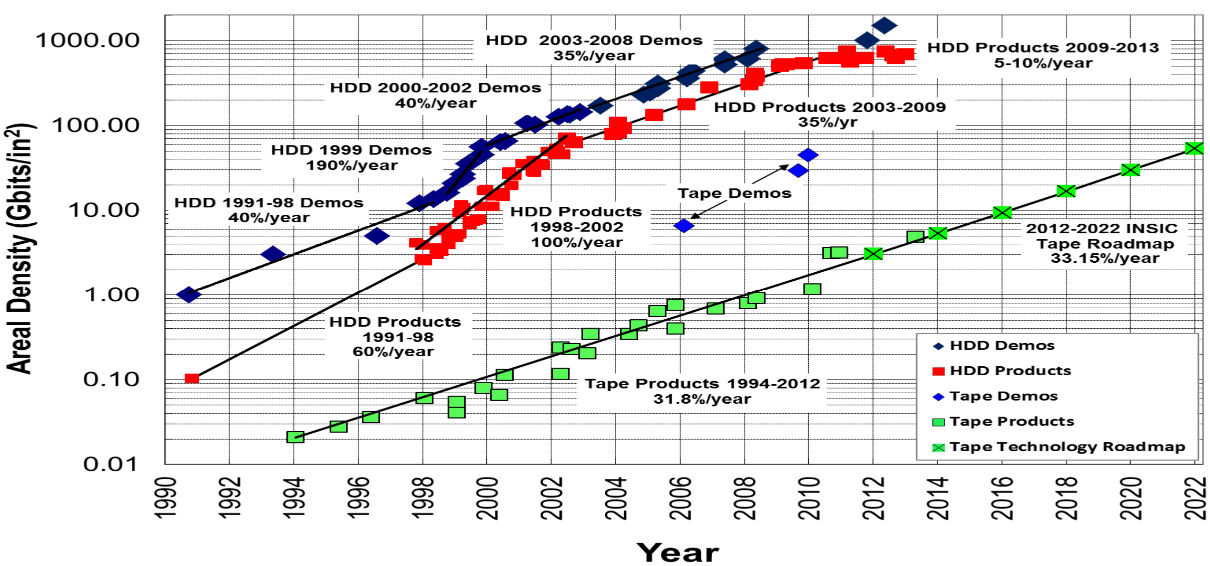
Drive Type and Media	Capacity (native)	Data Transfer Rate	Channels/ head	Tracks	Areal Density
LTO-5 MP	1.5 TB	140 MB/sec	16	1,280	1.2 Gb/in^2
LTO-6 MP, BaFe	2.5 TB	160 MB/sec	16	2,176	2.2 Gb/in^2
TS1140 BaFe	4.0 TB	250 MB/sec	32	2,560	3.2 Gb/in^2
T10000D BaFe	8.5 TB	252 MB/sec	32	4,608	4.93 Gb/in^2
TS1150 BaFe	10 TB	360 MB/sec	32	5,120	6.4 Gb/in^2

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

Future Data Recording Projections

Future density scenarios (see chart below) suggest that the projected annual tape areal density growth rates will be either maintained at traditional 30% values or exceed traditional growth rates. These scenarios also suggest that annual HDD areal density growth rates will not maintain their traditional 40% values using vertical recording and will likely slow toward 10% values. Specifically, the tape bit cell is currently 300x to 500x larger than the HDD bit cells. Thus the surface area available to increase HDD capacity is getting crowded and HDD areal density growth is slowing while tape cartridges have a much larger area to work with. The smaller the particle, the more data there is in one bit cell. The net result of these areal density scenarios is a sustained volumetric and total capacity storage advantage for tape technology. Tape cartridge native capacities using BaFe exceeding 150 TB are within reach given these strides in areal density. This also signals a lower total cost per gigabyte and reduced floor space requirements for tape over HDD technologies for the foreseeable future.

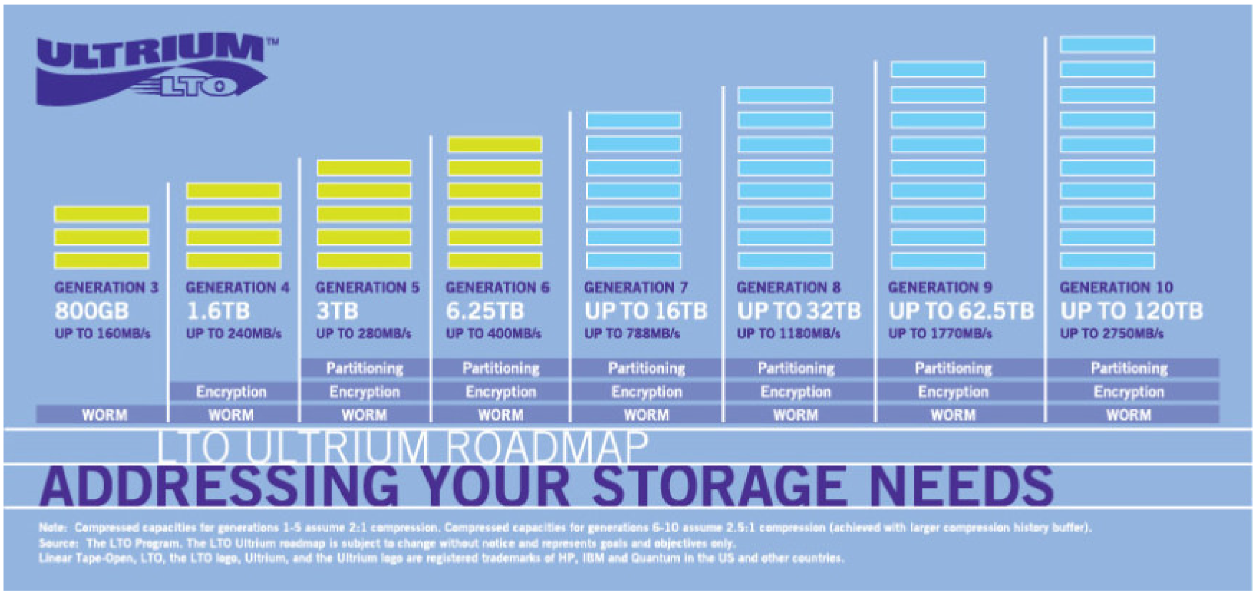
Areal Density of Hard Disk and Tape - Laboratory Demonstrations and Products



Key point: ***Honestly, did you realize a tape cartridge has a higher capacity than a HDD?***

Tape Roadmaps Show Continued Progress

The tape industry has delivered numerous enhancements in the past 15 years with significant improvements in drive reliability, media life, and data rate and cartridge capacity. Expect more breakthroughs to follow. The LTO Consortium publishes a well defined roadmap with each successive LTO generation arriving in approximately two year intervals. The LTO roadmap indicates that future LTO tape drive models will improve the acquisition price, capacity and performance, and will reduce cost of ownership over previous models. LTO's stated direction is that "an LTO Ultrium drive is expected to **read** data from a cartridge in its own generation and at least the two prior generations. An Ultrium drive is expected to **write** data to a cartridge in its own generation and to a cartridge from the immediate prior generation in the prior generation format." This eases customer conversion efforts by extending the life of the older media while newer LTO tape drives replace prior versions. In addition, the most recent LTO-6 format has expanded the "history buffer" in the compression engine, giving it a 2.5:1 compression ratio, up from 2:1, yielding an average of 6.25 TB per cartridge capacity.



***Key Point:* The progress of future LTO tape systems is fully expected to support several years of technology advancements. Expect similar improvements and progress for enterprise tape.**

The Storage Landscape is Shifting as Disk Challenges Mount

Technology roadmaps and the approaching technology limits indicate HDD storage is entering a squeeze play in the data center. HDDs are increasing in capacity -but *not* in performance - as the IOPS (I/Os per Second) for HDDs have basically leveled off. Therefore, as HDDs increase in capacity, their ability to deliver the same level of performance per GB of capacity declines. The potential for more concurrently active data sets increases as HDD capacity grows and the increased contention for the single actuator arm causes response time delays. HDDs also have a much higher TCO and use considerably more energy than tape - or SSD. Excessive RAID rebuild times are becoming a concern and it now can take several days to rebuild a failed HDD. This means that the disk subsystem will run in degraded mode during the lengthy rebuild period impacting performance. As HDD capacities continue to increase, the amount of time required for the rebuild process will become unacceptable for many IT organizations and higher capacity HDDs could force a replacement for traditional RAID architecture implementations.

A notable shift in the storage landscape is underway as high performance data finds its way onto flash SSD while lower activity and archive data migrate to modern tape. For the foreseeable future, HDDs will remain the home for primary storage, mission-critical data, OLTP, the highest availability applications and databases. HDD shipments will continue to grow *but* shipment growth rates will slow. High performance data migrates from HDDs to faster SSDs and low-activity and archival data moves to more economical tape facilitating a “storage squeeze play” as HDD’s are caught in the middle.

Key Factors That Are Changing the Rules for Tape	
Tape Reliability Better Than Disk Reliability *Note: BER (Bit Error Rate) Hard Read Errors per Bits Read*	T10000x Enterprise 1 x $10E^{19}$ bits **Tape drive BER** TS11xx Enterprise 1 x $10E^{19}$ bits LTO-5,6 Open Systems 1 x $10E^{17}$ bits Enterprise HDD FC/SAS 1 x $10E^{16}$ bits **Disk drive BER** Enterprise HDD SATA 1 x $10E^{15}$ bits Desktop HDD SATA 1 x $10E^{14}$ bits
Capacity	The increasingly popular LTO tape drive family is now in its 6th generation with LTO-6 and two future generations are now defined in the LTO roadmap. LTO-6 media has a native capacity of 2.5 terabytes (6.25 terabytes compressed @2.5:1). The Oracle StorageTek T10000D cartridge currently has the industry’s largest media capacity at 8.5 TB native.
Data Rate Max.	252 MB/sec for tape – 175 MB/sec for disk.
Device performance trends	Faster data rates and improved access time with LTFS lie ahead for tape. Few performance gains left for HDD.
Capacity growth trends	Roadmaps favor tape over disk as 154 TB capabilities have been demonstrated by Fujifilm and IBM using barium ferrite materials. Increasing HDD capacity increases RAID rebuild times.
Security features	LTO and enterprise tape drives offer both WORM and encryption for higher levels of security.
Long life media (Shelf life)	The shelf life for all new LTO and enterprise tape media is rated at 30 years or more making it ideal for long-term archival storage. Disk drives typically have a 3-4 year lifespan before replacement or failure.
Improve tape file search and access time performance (LTFS)	LTFS arrived with LTO-5 the tape cartridge implementing two distinct, individually addressable, unequal partitions with the first quick read partition containing descriptive metadata that enables the quick search capability (random-like) of the data contained in the second partition.
Energy efficiency heavily favors tape ***(green initiatives)***	This is becoming a goal for most data centers for archival data - “If data isn’t being used, it shouldn’t consume energy”. The 5 year HDD energy cost is approximately 25x higher than that of tape for equivalent capacity subsystems.
Acquisition price	Tape has a lower purchase price ($/GB) than disk.
Management Capability	Typical tape administrator can manage PBs ($1x10^{15}$) of automated tape. Typical disk administrator can manage TBs ($1x10^{12}$) of data.
Tape TCO Better Than Disk	5-year TCO for disk is 2-4x times higher for backup and 15x higher for archive storage than tape.

Source: Horison, Inc.

***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.**

Total Cost of Ownership Favors Tape over Disk

A comprehensive TCO study by ESG (Enterprise Strategies Group) [1] comparing an LTO-5 tape library system with a low-cost SATA disk system for backup using de-duplication (best TCO case for disk) shows that disk deduplication has a 2-4x higher TCO than the tape system for backup in several use cases over a 5 year period. The study also concluded that disk has a TCO of 15x higher than tape for long-term data archiving. The TCO advantage for tape is expected to become even more compelling with future technology developments. See [1] A Comparative TCO Study: VTLs and Physical Tape, by ESG.

Emerging Applications are Driving Future Tape Growth

Tape has been expanding its historical role as a backup solution to a much broader set of requirements including data archives and disaster recovery services. Digital archives consisting of unstructured data, digital images, multi-media, video, social networks, compliance data are the fastest growing data category experiencing a CAGR (Compounded Annual Growth Rate) of >60% annually. [Note: the archive level of storage is commonly referred to as tier 3 storage]. Just ten years ago, large businesses generated roughly 90% of the world's digital data. Today an estimated 75-80% of all digital data is generated by individuals - not by large businesses – however the majority of this data will eventually wind up back in a large business or service provider's data center necessitating unprecedented archival requirements and much of this will be destined for tape.

The Big Data Era is here and the value of the digital archive is increasing as the benefits of analyzing and working with very large datasets enable analysts to project new business trends, prevent diseases, and improve security and national defense, and much more. Presenting an ever-moving target, the limits of digital archives are now on the order of petascale ($1x10^{15}$), exascale ($1x10^{18}$) and will approach zettascale ($1x10^{21}$) capacity levels in the foreseeable future. Meeting these storage requirements only with disk will become financially prohibitive for most businesses.

***Key point:* Tape has a TCO of 1/15th of disk for archival storage, and with reliability having surpassed HDDs, the pendulum has shifted to tape to address much of the exploding tier 3 demand.**

LTFS Enables Faster Data Access and Interchange Improvements

To improve the access and interchange capabilities of tape, a new, long awaited file system specification for LTO called LTFS (Linear Tape File System) became available with LTO-5 in 2010 which improves tape access. Originally developed by IBM, LTFS provides an easier way to archive data to tape without the need for other backup software. With the new dual partitioning functionality of LTFS, 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 browse directory tree structures and file-name search, are performed more quickly and do not require physical tape movement. The faster file access capability provided by LTFS becomes more important as BaFe pushes tape capacities to much higher levels and the number of files per tape steadily increases. LTFS makes archiving and restoring data easier than ever before for tape drive and library applications.

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

Energy Consumption - Tape Means Green Storage

A commonly stated objective for many CIOs 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 more reliable, much more energy efficient, and more cost-effective tape storage is actively underway at the other end of the storage hierarchy. Unlike storage providers, energy providers have shown little interest in lowering their prices and average data-center energy costs are growing at 10-20% per year or more per unit consumed. Compounding this dynamic is the fact that power density is going up for most IT equipment at a rate of 20% to 30% per year. This has the following domino effects; 1) more power needs to be supplied to each square foot of a data center 2) more power is required to cool hotter equipment and 3) more heat extraction equipment is needed to support each square foot of a data center.

The maximum heat density that can be air-cooled in a data center is approximately 10,000 watts/sq ft, yet many data centers have been designed for power densities of less than 1,000 watts/sq ft. The limits of power distribution in many data centers is being approached, which is 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 support infrastructure – external consumption	**45%**
Servers	30%
Disk drives, control units	12%
Tape drives, robotic tape libraries	3%
Network gear, SAN switches and other devices…	10%
Total IT gear – internal consumption	**55%**

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

Heat is the enemy of all IT technology as it impacts reliability and makes managing recommended environmental requirements a critical factor. Various utility companies are restricting the amount of power some businesses can use at certain times of the day making data center energy management more critical. Clearly, exceeding the power limits a utility company can deliver to a given facility should be avoided as moving to a new facility can be cost prohibitive.

***Key point:* Shifting less-active, inactive and archival data to tape storage is the most significant way of reducing energy consumption in the data center.**

What about Tape in the Cloud?

The inherent consolidation of unstructured data into large-scale archive repositories in the cloud suggests that another category of storage is emerging –*Tape in the Cloud* – which will further expand the economic market for tape as the preferred archiving technology. Cloud storage users (private and public) currently rank security and service levels as their top cloud concerns. By definition, cloud users must be willing to have their data reside side by side with that of a possible competitor, which is why encryption and security mechanisms can become more important.

Tape's role in the cloud is significant. From a practical point of view, a copy of all or most data stored in the cloud on disk is typically migrated to tape, if only to address incidents that put data stored exclusively on disk at risk of loss. Tape is now being used in cloud archival storage environments to address the higher HDD cloud provider cost issues, as tape is much less costly than disk in terms of both initial capital expenditure and ongoing operating expenditures. Using HDDs for archival storage is a strategy – just not a very cost-effective one.

When disks are used for cloud storage, disk arrays use RAID to break up and spread data from several users at the block level across multiple disks for data resiliency. Additional software is required to ensure that any given customer's data is securely isolated from every other user on a given disk or array. When tape is used for cloud storage however, each tape cartridge is a separate object. The customer or cloud provider has control over what's on each cartridge.

Encryption and WORM capabilities may be mandated by government regulations and provide additional security for data at rest. These are fundamental requirements for delivering a secure archive strategy. If just one bit is in error, encrypted data cannot be de-crypted and the data is rendered useless. 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 archive set to another cloud provider. Moving large amounts of archival data on available network bandwidth can become excessive taking days or weeks. Using a truck or airplane to move portable tape media can be much faster!

***Key point:* Cloud providers should look to tape for the lowest-cost, most secure, long-term archival storage offering. Storing archival data in the cloud represents a significant future growth opportunity for tape vendors and a much lower cost solution for cloud providers.**

Summary

Today's reality is that the magnetic tape industry has made considerable progress in the past 10 years surpassing disk in many categories. The continued role for disk is well established, but tape has expanded its position as an effective complement to disk for the foreseeable future due to its lower TCO, improved reliability, higher capacities, faster data rates, and significantly lower energy costs. As a result of this progress, the tape industry is aggressively re-positioning itself to address many new high capacity storage opportunities which now represent more than 65% of the world's total stored digital data. The latest technology improvements in the tape industry suggest tape will for the foreseeable future continue to be more cost-effectively suited for the enormous archival opportunities that lie ahead, whether on-site, at a remote location, or in the cloud.

For tape it's definitely a new game with new rules.

End of report