In recent years, the general perceptions of tape have become outdated and are not current with the latest developments and significant improvements that have occurred in the tape industry. These developments include longer media life, significantly improved drive and library reliability, higher drive duty cycles and much faster data rates than any previous generation of tape technology. Tape cartridge capacities have now exceeded those of disk drives. There are two companies offering enterprise class tape drives. They are Oracle’s StorageTek T10000 and T9840 drive families and IBM's TS11x0 family. Along with the popular LTO drive family in the midrange market, these drives currently offer between 75 gigabytes (T9840D), 1 terabyte (T10000 and TS1130), and 1.5 terabytes (LTO-5) native capacities per cartridge and up to 3 terabytes compressed at 2:1. LTO has become the most popular midrange and high-end technology for open systems. LTO is now in its 5th generation with LTO-5 and another 3 generations have been defined. LTO drives, produced by Hewlett-Packard, IBM, Quantum and Tandberg, represent sales of $534.31 million, out of an overall enterprise and midrange tape industry (drives, libraries and media) that exceeded $3.1 billion in 2009. These enterprise and midrange-class product families, produced by six companies, are the most widely used tape product lines and are highlighted in this paper. Low-end and older tape product families such as DLT, 8mm, Travan and DDS continue to post sharp declines.
Tape in Its Third Era

The magnetic tape industry continues to evolve since the first successful tape drive appeared in 1952. Three eras have defined the evolution of tape technology and each era was marked by the tape industry responding to specific challenges it was facing. The first era was the era of manual tape and lasted from 1952 until 1987. By 1987, tape environments had grown to thousands of tapes and the manual media handling problems were major concerns for these enterprise companies. The second era began in 1988 and became the era of tape automation with the introduction of the industry’s first successful robotic tape library by StorageTek (acquired by Sun Microsystems in 2005 and then by Oracle in the 2010 acquisition of Sun Microsystems). Automation effectively addressed many of the human tape handling problems and the tape industry again thrived.

By 2000, the tape industry was facing the growing perception that disk had become cheaper than tape. In response to this challenge, the third era of enterprise-class tape was fully underway by 2002 and was marked by several significant improvements as the tape industry essentially was re-engineering itself. Key tape developments included much longer media life, vastly improved drive reliability, higher duty cycles and much faster data rates than any previous tape technology. Troublesome tape issues from prior generations and low-end products including stretch, edge damage, tear, and media alignment were successfully addressed.

Security features were added to tape offerings including Write-Once-Read-Many (WORM), data encryption, and various write-protect capabilities. Cartridges were ruggedized for improved portability and tape drive Mean Time Between Failure (MTBF) soared increasing from 80,000 hours to over 400,000 hours. The expected media life range for enterprise class tape was improved to 15-30 years (up from 4-8 years). Unfortunately these re-engineering efforts in the tape industry since 2002 often went unnoticed but the summation of these factors has positioned enterprise-class tape well for the exploding tier 3 storage markets that include the fixed content, compliance and archive applications as well as its continued ability to serve its long standing role as a backup and recovery solution. It’s now time to fast forward our understanding of the tape industry and the role tape plays in addressing future data storage requirements.
Tape In Its Third Era

First Era Manual Tape
1952 - 1987
- 7 to 9 tracks on a 10.5" reel
- 160 MB/reel
- 1.25 MB/sec data rate
- Primary applications include: backup/recovery, batch
- 3420 MTBF ~10,000 hours

Second Era Automated Tape
1987 - 2002
- Successful Nearline robotics appear
- Thin film heads and cartridge media replace reels.
- 100 to 200GB/cartridge with 2x compression (1985)
- 36 to 288 tracks in 5x4x1" cartridge
- 3.0 MB/sec native data rate, midpoint load
- Integrated Virtual Tape Libraries arrive for mainframes in 1998
- Primary applications: backup, recovery, archival, video, scientific
- MTBF ~ 25,000- 80,000 hours

Third Era Enterprise-class Tape
2002
- T10000, LTO, TS11xx become dominant formats with rich features
- 768 to 1152 tracks replace reels. -1.25 MB/sec data rate
- 1+TB native capacity
- 100 to 200GB/cartridge with 2x primary applications include:
- RFID chips, rugged cartridges, write-protect, hub-lock, spring-loaded doors
- Virtual tape libraries emerge for non-mainframes
- High performance robotics
- WORM, encryption, VOLSAFE
- MTBF 250,000 to 400,000 hours

Major Improvements for Tape Drive Reliability

MTBF remains the standard metric used to measure tape and disk drive reliability though other measurements have been suggested such as the “number of nines 99.xxx” availability index which is often used for servers and operating systems. The MTBF for tape drives is calculated for a specific duty cycle based on the percentage of time the drive is actually reading, writing or verifying data. The duty cycle used in the calculations is critical because if the actual duty cycle is significantly different from the manufacturer's rated duty cycle the MTBF will vary. For example, if the duty cycle is lower than rated, the MTBF rating will be higher. Actual duty cycles vary widely between data centers, or even between servers within enterprises, based on application activity. Duty cycles used by manufacturers in their drive ratings can vary from 10 percent to 100 percent; however for enterprise-class tape environments a duty cycle range of 70% to 100% is commonly used. Using Fibre Channel (FC), FICON, Ultra-SCSI (Small Computer System Interface), or Serial Attached SCSI (SAS) tape drive interfaces, an enterprise class data center can deploy a highly reliable tape solution with an MTBF of 250,000 hours at a 100% duty cycle and over 400,000 hours at a 70% duty cycle.

Many new enterprise class drive and media enhancements have appeared since the third era for tape began in earnest in 2002. The bullets below summarize several of these enterprise features and availability enhancements:

- Significantly more rugged cartridge design protects data during physical transportation.
- Media reusability (read and write) is planned for at least two generations to provide investment protection.
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 can speed access to tape files, hold the cartridge’s log, and store manufacturer identification and date, cartridge type, and tape reliability statistics for media health monitoring.

- A write-protect switch that prevents writing or erasing data after activation.
- A dual-hub, fast-access cartridge for a fully enclosed tape path and higher reliability.
- Spring-loaded door protects the cartridge leader from damage and contamination.
- Hub-lock technology implemented to maintain 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.
- Non volatile caching at the drive level to reduce the impact of back-hitching caused by checkpoint and small block transfers.
- Special prewritten data tracks on the tape called servo bands are used to keep the tape heads on the correct track while reading and writing.

The chart below categorizes the drive MTBF and media shelf life ratings from round reels to the latest enterprise products. Note that 9-track round reels were always rated with lower duty cycles than their present day counterparts.

<table>
<thead>
<tr>
<th>Drive type</th>
<th>Drive Era</th>
<th>MTBF hours 70% duty cycle*</th>
<th>MTBF hours 100% duty cycle</th>
<th>Shelf Life</th>
</tr>
</thead>
<tbody>
<tr>
<td>9-track reel to reel</td>
<td>1971</td>
<td>~25,000 @ 15% duty cycle</td>
<td>9,375 @ 40% duty cycle</td>
<td>3-8 years</td>
</tr>
<tr>
<td>3480/4480 (1st cartridge drive)</td>
<td>1984</td>
<td>35,000</td>
<td>24,500</td>
<td>&lt;10 years</td>
</tr>
<tr>
<td>DLT 2000</td>
<td>1993</td>
<td>80,000</td>
<td>56,000</td>
<td>~10 years</td>
</tr>
<tr>
<td>SDLT 160/320/600</td>
<td>2002</td>
<td>250,000</td>
<td>175,000</td>
<td>15-30 years</td>
</tr>
<tr>
<td>LTO family</td>
<td>2000</td>
<td>357,000</td>
<td>250,000</td>
<td>15-30 years</td>
</tr>
<tr>
<td>T9840B-D</td>
<td>2000</td>
<td>414,000</td>
<td>290,000</td>
<td>15-30 years</td>
</tr>
<tr>
<td>T10000, TS11x0</td>
<td>2006</td>
<td>414,000</td>
<td>290,000</td>
<td>15-30 years</td>
</tr>
</tbody>
</table>

* MTBF ratings are provided by tape drive manufacturers at a specified duty cycle meeting environmental specifications.

**Bottom line:** Beginning in 2002 as tape entered its third era, tape drive reliability has dramatically increased with MTBF improving over 5 times for drives and 3.75 times for media shelf life. The result is that the useful life of tape storage is considerably longer than a typical 4-6 year life for more IO intensive disk subsystems impacting investment decisions and the frequency of technology conversions. In the case of archive, media migration is consistently one of the top pain points for customers. Tape’s much longer useful life enables customers with long-term retention requirements to have less frequent migrations to new technology.
The Effect of Integrated Virtual Tape Library and Tiered Storage on Tape Drive Reliability

An integrated Virtual Tape Library (VTL) has become popular for mainframe systems and optimizes the integration of tier 2 backup and recovery and tier 3 archival storage solutions. Many traditional mainframe batch applications significantly benefitted from integrated Virtual Tape technology. The integrated VTL combines disk arrays that appear as tape drives as a front-end to an automated tape library. The disk storage serves as a cache or buffer providing higher performance for the more active data and files in the physical tape library. Since a high percentage, often 75% or more, of the "would be" tape accesses may come from the disk buffer, the wear and tear on the tape drive, library mechanics, and tape media may typically be reduced by 75% or more essentially improving all tape reliability measures.

As a result, an integrated VTL can improve tape reliability numbers significantly especially if Fibre Channel, SAS, or SCSI disk drives are used. Using SATA drives as a VTL or integrated VTL buffer requires that SATA drives operate at a 100% duty cycle which is well beyond their typical 30-35% duty cycle ratings. Therefore SATA disk reliability decreases from a rated 600,000 hours to approximately 219,000 hours with a 100% duty cycle. At above rated duty cycles, SATA drives can potentially have a lower MTBF than the tape subsystem they support.

NOTE: a VTL differs from an integrated VTL. A VTL is a disk array only that appears as multiple virtual tape drives and a library, but doesn’t actually integrate its disk architecture with a physical tape library or directly use tape.

In open systems, backup applications that were originally written for a tape target now support disk targets. The hierarchy of disk and tape discussed above for the mainframe is used, but the application manages the tiers and the migration across the tiers. Disk backup is common in small environments, but most enterprise data centers employ disk-to-disk-to-Tape (D-D-T) to achieve the cost benefits of tape. Open systems archive applications are written for tape targets, so what has emerged is the same disk and tape hierarchy as with VTL, but with a disk image rather than a tape image.

Bottom line: Though not effectively communicated, the integrated VTL and tiered storage with D-D-T provides a step function reliability improvement for the physical tape subsystem while reducing the number of drives, media and possibly libraries. In addition, mainframe integrated VTLs address historical cartridge capacity under-utilization levels by typically increasing tape storage usage to 80% or more of cartridge capacity.

Comparing Tape Drive to Disk Drive Reliability

Enterprise class disk subsystems have not historically served an archival role like tape as disks typically are more costly and designed to retain data against thermal decay for five years at a 100% duty cycle. However, disk drives support high performance applications that are far more I/O intensive than tape systems. Low cost SATA drives were designed for office use, not for 24x7, and carry a 25-35% duty cycle with a ~600,000 MTBF for specification ratings. The way to get a SATA disk more reliable is to 1) engineer them like FC, and SAS, which adds development cost or 2) reduce the duty cycle via drive spin down when data becomes inactive. This concept, sometimes called
green mode, is effective in theory but difficult to achieve with RAID array disks that use striping.

Specified failure rates for today's disk drives have also greatly improved from previous generation products. The magnetic disk industry experienced a 5X increase in reliability between 1990 and 1996 and these were welcomed as recovery from disk crashes was often a disaster for businesses given the criticality of data on disks. In 1990 most manufacturers specified disk drive MTBF between 100,000 and 250,000 hours at a 100% duty cycle. By 2008, disk drive MTBF specifications for FC drives had surpassed the 1.4 million hour range while SCSI/SAS drives were rated with an MTBF of 1.2 million hours and SATA drives were at ~600,000 hours. Some recent SATA announcements have indicated an MTBF ranging from 750,000 to 1,200,000 hours but duty cycles are not provided. Remember that lower duty cycles mean a higher MTBF rating.

Comparisons between disk and tape reliability are often debated. Disk has a higher MTBF than tape, but for a much shorter lifetime. Tape drives typically have a useful life at least twice as long as disk drives, with the help of backward read-compatibility, while tape media can last 4-5 times or longer compared to disk drives. Tape is designed for tier 3 long-term storage applications and combined with disk buffers in an integrated VTL, also becomes an effective tier 2 backup solution. Disk drives store the world's mission critical applications and perform most of the IO intensive transactions. For most data, it becomes less active as it ages and more effectively suited for a lower total cost and longer lifetime tier of storage. Today, tape is the total cost of ownership for tier 3 applications. Remember that disk and tape are basically designed to address different sets of application requirements and reliability comparisons should account for these differences.

**Bottom line:** Tape drives and tape media have a longer useful life than disk products making them better suited for the long-term data retention requirements demanded by fixed content, compliance and archive applications.

**Tape Media Reliability Improvements**

Customers have indicated for years that their most frequent perceived cause of tape failure was due to media and handling errors and changing this perception has been difficult even as tape media has made significant strides. Tape damage from environmental contamination also ranked very high along with tape media problems as the major contributor to the basically out-of-date perception regarding tape reliability. Media errors are usually the result from contamination or damage to the physical media within the tape cartridges, rather than a result of defects on the media. Tape media damage typically occurs because of incorrect tape handling procedures and the most common problem in the past was edge damage. If a tape cartridge is mishandled or dropped, the edges of the media could get crimped.

With the older linear tape products, the edges of the tape media served as servo tracks (a track that allows the tape drive head to stay aligned with the tape.) Therefore it was possible that media errors occurred because the head could no longer stay on track causing costly read or write errors. Enterprise class and LTO drives have basically eliminated this issue in the late 1990s by using a series of pre-recorded servo tracks on
the media along with ruggedized cartridge shells that are relatively impervious to handling damage.

Tape media advances are closely linked with the ongoing progress of tape drive development. The most popular enterprise class tape cartridge format uses a half-inch wide media and high performance metal particle (MP), metal evaporated (ME) and Barium Ferrite tape materials. Smaller width form factor tape media exist, but are being squeezed out in the market by half-inch tape media and disk and flash memory products. Along with magnetic material advances, tape media have increased substrate dimensional stability with reduced thickness, smoother surfaces, lower defect densities, and increased edge slitting precision. With these advancements, shelf life for all new enterprise class tape media is rated between 15 and 30 years.

**Bottom line:** Tape media management has historically been viewed as the single biggest operational challenge for tape administrators. Since 2002, tape media has significantly improved in reliability, ruggedness, and media life compared to its predecessors, making many commonly held perceptions of tape media reliability outdated.

**Tape Library Architecture Improvements**

The introduction of Nearline® automated tape libraries by StorageTek in 1987 successfully heralded the second era of the tape industry and led a tape revival as robotics eliminated many of the historical tape handling activities and problems. What appeared to be a shrinking tape industry began to grow again for both backup and archival applications. Optical disc was attempting to become a viable data center backup/recovery technology at this time but failed and has never reappeared as an effective data center technology. As a result, disk was beginning to increase its presence in the backup market - albeit slowly as the price was viewed as too high.

The new tape libraries were often referred to as ‘silos’ given their shape and circular (non-rail) robotics. Twenty years later, tape automation has become a primary component for enterprise class tiered storage implementations and represents the architectural foundation for many tier 3 applications of the future. Tape libraries have proven to be the ultimate long-life storage technology as the robotic library outlasts the attached tape drives and tape media. In 2004 the popular 9310 PowderHorn library was finally replaced by the Oracle’s StorageTek SL8500 library, heralding the beginning of the end of an unprecedented 16-year reign for a single storage product. No other storage product can boast such a long useful product life.

<table>
<thead>
<tr>
<th>Library type</th>
<th>MEBF hours</th>
<th>MTTR</th>
<th>Exchanges/hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>1988-2004 PowderHorn</td>
<td>7,900,000 Single robotic arm, two hands</td>
<td>&lt;30 minutes</td>
<td>90-450</td>
</tr>
<tr>
<td>2005-present SL8500</td>
<td>2,000,000/handbot (4 to 8 handbots)</td>
<td>&lt;30 minutes</td>
<td>&gt;1000</td>
</tr>
</tbody>
</table>
Reliability measurements for tape libraries have always been relatively high. Today Mean Exchanges Between Failures (MEBF) is the commonly used metric for robotic libraries in addition to the traditional MTBF. Exchanges/hour is the number of tape mounts and dismounts that can be completed in an hour and is the primary measure of tape library performance. Oracle’s newer StorageTek SL8500 tape library used a different design and offers either 4 or 8 handbots or small robots operating in parallel for improved performance and availability compared to the single robotic arm with two hands in the earlier StorageTek PowderHorn library. MEBF for the SL8500 is rated at 2,000,000 exchanges per handbot. Automated tape library reliability benefited from several other architectural enhancements and serviceability features that were introduced in this timeframe.

These include:

- Redundant power supplies and AC power feeds
- Control-path and data-path automatic fail-over hot-swappable and fully redundant components, including multiple robots, designed to help keep the library system up and running
- Capability to add slots and tape drives easily without scheduling downtime
- N+1 power for tape drives are now a standard feature
- Microcode, robotics and library electronics that can be replaced on the fly while the library is operating for non-disruptive serviceability, yielding higher uptime
- Dynamic throughput scalability to add drives and slots non-disruptively
- New software controls that can configure a physical library into multiple virtual libraries (partitions)

Note: Not all features are offered by all vendors.

**Bottom line:** Tape libraries have been successfully re-architected delivering higher performance, non-disruptive upgrades, and higher availability through redundancy and fault-tolerance designs.

**Data Security Solutions Expand Tape’s Role for Archival Storage**

The enterprise class tape solution providers are positioning tape for its emerging role as the digital archive and compliance solution of choice by providing encryption and Write-Once-Read-Many (WORM) capabilities. Encryption and WORM capabilities are commonly used to ensure that data which is regulated for compliance reasons cannot be read if lost or modified after initial creation. Ensuring that e-mails, health care records, and financial transactions for example cannot be tampered with or read by unauthorized parties for the duration of their required life-cycle is a major compliance requirement. In 2000, the WORM tape media feature was first introduced by StorageTek as a feature by the name of VolSafe. Most enterprise class drives now offer encryption and WORM capabilities to ensure the data could not be altered or read if it is lost, stolen or misplaced. Designed to further enhance the integrity of tape data, WORM provides a non-erasable, non-rewritable, tape-based storage solution. After information is written to tape, information can be read or added as often as needed, but never changed, moved, or deleted.
In 2006, and encouraged by countless compliance regulations, both Sun/StorageTek and IBM announced encryption built directly into their enterprise class tape drives allowing users to protect data on tapes in case they were lost or stolen. Because the encryption capability is built into the drive itself, backup servers and networks didn’t have to experience any performance degradation or overhead. Also in 2006 the LTO Consortium, an LTO focused tape vendor-operated group, followed suit announcing that encryption would be added to its LTO-4 tape drive specification thus addressing regulatory data protection requirements for non-mainframe markets.

**Bottom line:** Encryption doesn’t help in the event of device failures, worms or viruses that corrupt data. It does help in instances of intrusion, data theft, lost media, or stolen PCs as the time has come to encrypt all portable data. Accessing encrypted data is meaningless unless it can be successfully decrypted. Decrypting encrypted tape media is basically impossible. Expect implementation of encryption for digital data to become a standard feature for nearly all tape drives and eventually for selected disk drives and personal appliances using hardware-based Application Specific Integrated Circuits (ASICs) designed into the drives or control units or possibly software encryption. The time has arrived for all mobile and portable data to be encrypted due to the variety of security, legal and life-cycle retention requirements and most businesses have now started to implement their comprehensive encryption strategies.

**Capacity Increases for Enterprise Tape Outpace Disk**

From the beginning of the storage industry until late 2001, it took several tape cartridges to back up the contents of a single disk. Since then the reverse has been true as a single tape cartridge now contains the contents of several disks. This is especially true for non-mainframe systems where the average disk utilization remains in the 30-45% range. By 2002, magnetic tape technology was experiencing the most significant technological improvement curve in its 50-year history. Since then, tape cartridges with 2x compression gives tape a total tape cartridge capacity higher than disk-drive capacity. This is particularly significant because disk recording densities had been increasing on an average of 60 percent annually since the early 1990s but have slowed somewhat as the cutover to perpendicular recording and smaller form factors slowed areal density growth. Tape data transfer rates have increased 7 times since 2002 dramatically improving performance for throughput intensive applications. When the capacity of magnetic tape cartridge surpassed the capacity of the largest disk drive for the first time ever, the rules of the game for magnetic tape changed regarding acquisition cost, operating cost, and volumetric storage density.

A new step forward for using tape as an archival tier 3 solution is the LTFS (Linear Tape File System) which is included with the LTO-5 tape announcement in 2010. LTO-5 media, with a native capacity of 1.5 terabytes and a data rate of 140 MB/sec, can be natively partitioned into two segments. LTFS uses the first partition to store a self-contained hierarchical file system index for the contents of the tape on the second partition. LTFS becomes valuable in environments requiring active archiving of large amounts of unstructured data, such as medical imaging, media and entertainment, and some compliance applications. IBM also plans for the mainframe to support LTFS for enhanced archival capabilities at a future date.
### Year Disk Actuator Capacity Tape Cartridge Capacity and Data Rate

<table>
<thead>
<tr>
<th>Year</th>
<th>Disk Actuator Capacity</th>
<th>Tape Cartridge Capacity and Data Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1975</td>
<td>317.5 MB</td>
<td>180 MB (round reel) 1.25 MB/sec</td>
</tr>
<tr>
<td>1980</td>
<td>630 MB</td>
<td>180 MB (cartridge) 3.0 MB/sec</td>
</tr>
<tr>
<td>1985</td>
<td>1.26 GB</td>
<td>200 MB native to 1.6 GB</td>
</tr>
<tr>
<td>1990</td>
<td>1.89 GB</td>
<td>800 MB native to 1.6 GB (now with 2x compression*) 6.0 MB/sec</td>
</tr>
<tr>
<td>1998</td>
<td>47 GB</td>
<td>20-40 GB 10-30 MB/sec</td>
</tr>
<tr>
<td>2001-2002</td>
<td>72 GB</td>
<td>100-200 GB (LTO) 20-40 MB/sec</td>
</tr>
<tr>
<td>2003</td>
<td>300 GB</td>
<td>200-400 GB (LTO) 40-80 MB/sec</td>
</tr>
<tr>
<td>2004</td>
<td>500 GB</td>
<td>400-800 GB 80-160 MB/sec</td>
</tr>
<tr>
<td>2007</td>
<td>750-1TB</td>
<td>750GB-1.5 TB 120-240 MB/sec</td>
</tr>
<tr>
<td>2008</td>
<td>1.5 TB</td>
<td>1-2 TB 120-240 MB/sec</td>
</tr>
<tr>
<td>2009</td>
<td>2.0 TB</td>
<td>1-2 TB 120-240 MB/sec</td>
</tr>
<tr>
<td>2010</td>
<td>2.0 TB</td>
<td>1.5 – 3 TB 140-280 MB/sec</td>
</tr>
</tbody>
</table>

* Tape data compression first arrived on the IBM 3490 drive in 1986. Note: a 2x compression factor is the norm for open environments. IBM uses 3x for their mainframe data and Oracle uses 4x for its mainframe data. A conservative 2x compression factor is used in this report.

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**Magnetic Mass Data Storage Futures Roadmap - Tape**

<table>
<thead>
<tr>
<th>Year</th>
<th>Unit</th>
<th>2007</th>
<th>2009</th>
<th>2011</th>
<th>2017</th>
<th>2019</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Form Factor</td>
<td>inch</td>
<td>5.25FH</td>
<td>5.25HH</td>
<td>5.25FH</td>
<td>5.25HH</td>
</tr>
<tr>
<td></td>
<td>Volumetric Density</td>
<td>GB/in³</td>
<td>100</td>
<td>200</td>
<td>400</td>
<td>2,000</td>
</tr>
<tr>
<td></td>
<td>Cartridge capacity (native)</td>
<td>GB/TB</td>
<td>800 GB</td>
<td>1,200-1,600GB</td>
<td>3-4 TB</td>
<td>12-16 TB</td>
</tr>
<tr>
<td></td>
<td>Areal Density</td>
<td>Gb/in²</td>
<td>1.2</td>
<td>2.0</td>
<td>3.0-3.5</td>
<td>10-14</td>
</tr>
<tr>
<td></td>
<td>Data Rate</td>
<td>MB/s/drive</td>
<td>120</td>
<td>160-180</td>
<td>200-280</td>
<td>400-800</td>
</tr>
<tr>
<td></td>
<td>Tape Speed (for data)</td>
<td>meters/sec</td>
<td>6-8</td>
<td>8-10</td>
<td>10-12</td>
<td>12-15</td>
</tr>
</tbody>
</table>

*Source: Bi-annual INEMI Mass Storage Report for 2008*

**Bottom line:** By 2002, and for the first time ever, the native capacity of a tape cartridge surpassed the capacity of the biggest disk drive signaling a fundamental and lasting change in the $/GB pricing model of tape libraries compared to disk subsystems. Cartridge capacities have since exceeded 1 terabyte native and 3 terabytes or more.
compressed. Native capacities are predicted to approach 60 terabytes (compared to 50 terabytes for magnetic disk) over the next ten years yielding over a 120 TB compressed capacity per cartridge and serves as a strong indicator that the continued price per gigabyte/petabyte advantage of automated tape over disk will continue.

Summary
The magnetic tape industry has progressed into its third era since the first successful tape drive appeared in 1952. Each era had its 'golden period' and so will era 3. The growth opportunity that lies ahead for tape storage solutions is increasing and is being fueled by the following advancements in tape technology:
● Cartridge tape capacities will continue on an unprecedented growth pace and are expected to approach 60 terabytes by 2019.
● Tiered storage systems that include tape will proliferate to the non-mainframe and midrange markets. Some of these will present a disk image for integration with archive applications.
● Tape WORM and the growing requirement for encryption will address data protection for the compliance and archival markets.
● The average price per gigabyte for automated tape library storage is expected to remain below that of magnetic disk storage for at least the next 10 years.
● The operating expense (opex) for automated tape systems should remain significantly below that of online storage as people, facilities and energy costs rise. The average tape library administrator manages from 40TB to more than 1PB (varies based on capacity of a single library) of data. Today’s storage administrator currently manages an average nearly 30 TB for non-mainframe disk and over 100 TB for mainframe disk storage.
● The promise that network bandwidth would be cost-effective to replace physical transport for moving large amounts of data has yet to materialize. The growth of the data that needs to be backed up continues to exceed the rate of growth of affordable bandwidth. This gives tape a financial advantage over disk as an off-site backup technology along with the lower energy cost of tape versus disk over the lifetime of the stored data.
● Tape has a much longer storage life than disk, eliminating the need to move data to new media as frequently during its lifetime.

The economics of tape for many applications are compelling from an acquisition cost and more importantly a cost of ownership perspective. At the same time, the reliability of tape products has significantly improved in the third era though many businesses remain unaware of these enhancements. The technological ingredients for tape’s success and its sustainability are now evident, its time to fast forward and raise the industry’s overall awareness of these important tape capabilities.