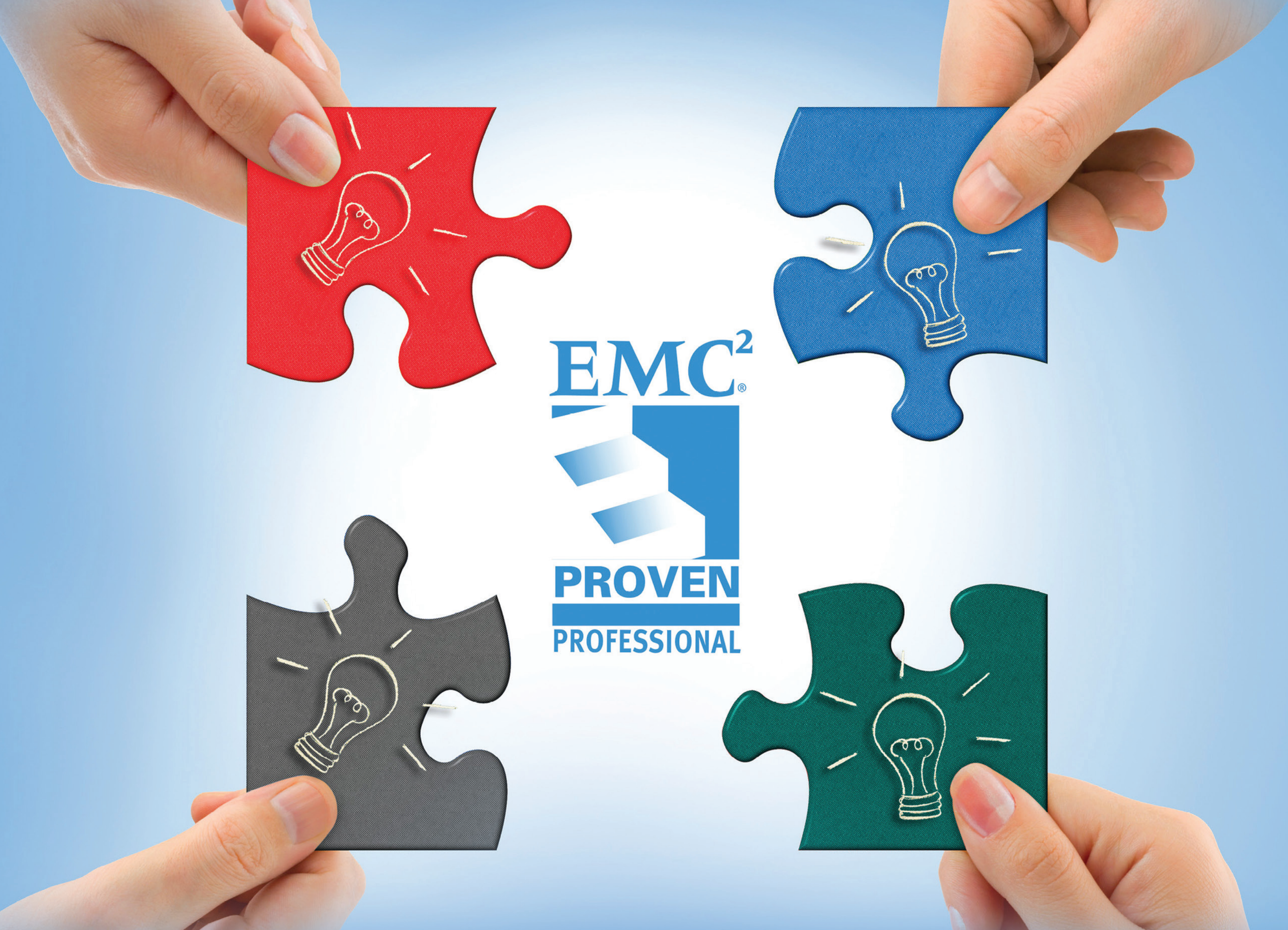

# EMERGING TRENDS IN STORAGE - EVALUATING FUTURE DIRECTIONS


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## Abstract

High capacity and fast performance have been the catchwords that characterize ever changing IT infrastructure industry over the last couple of decades. The drivers behind this evolution are the fast changing landscape of business applications and the wider technology developments resulting in a virtual data explosion. As cited often by any study on this subject, we are dealing with billions of devices which are also mobile. It won't be long before we start dealing with trillions and quadrillions of devices or IP-addressable components with the possibility of technologies like Internet of Things (IoT) becoming mainstream.

Given this larger context, how are we going to achieve balance between high-capacity, high-performance on one side and affordability, scalability on the other? We believe the current hype around flash and SSDs being the ultimate solution for high capacity and high performance is not going to last as these technologies are yet to mature to be comparable to that of HDDs in terms of price per GB or TB. While disruptive technologies tend to bring about paradigm shifts and create new categories of products and services along the way, the fundamental logic of why businesses exist will not change, i.e. greater profitability. Affordable technologies which can offer near comparable outcomes will always have the upper-hand vis-à-vis their expensive latest fashion counterparts. This article attempts to do a comprehensive analysis of the latest developments in the field of magnetic storage as well as flash and SSDs and how we may have to arrive at a judicious mix of these technologies in order to deliver the best value proposition to the business.

## Introduction

Information storage is the fundamental building block of the modern information technology industry. The revolutionary technological breakthrough which enabled information storage to become a viable enterprise was magnetic recording of data. Danish engineer Valdemar Poulsen first demonstrated magnetic recording of sound publicly in the year 1900.

Computer memory is generally classified in to two categories; Volatile and Non-Volatile based on whether the storage is persistent or temporary. Examples of volatile memory include RAM, DRAM, SRAM, etc. Meanwhile, Magnetic Tape Cartridges, Magnetic Disk Drives, Optical Disk Drives, and Solid Stage Drives like Flash Storage and MRAM are grouped under non-volatile memory. Both types have their own specific applications in the field of data storage and computing depending on the business situations. The following computer memory hierarchy illustrates the different contexts in which each of the memory types are used.

Computer Memory Hierarchy

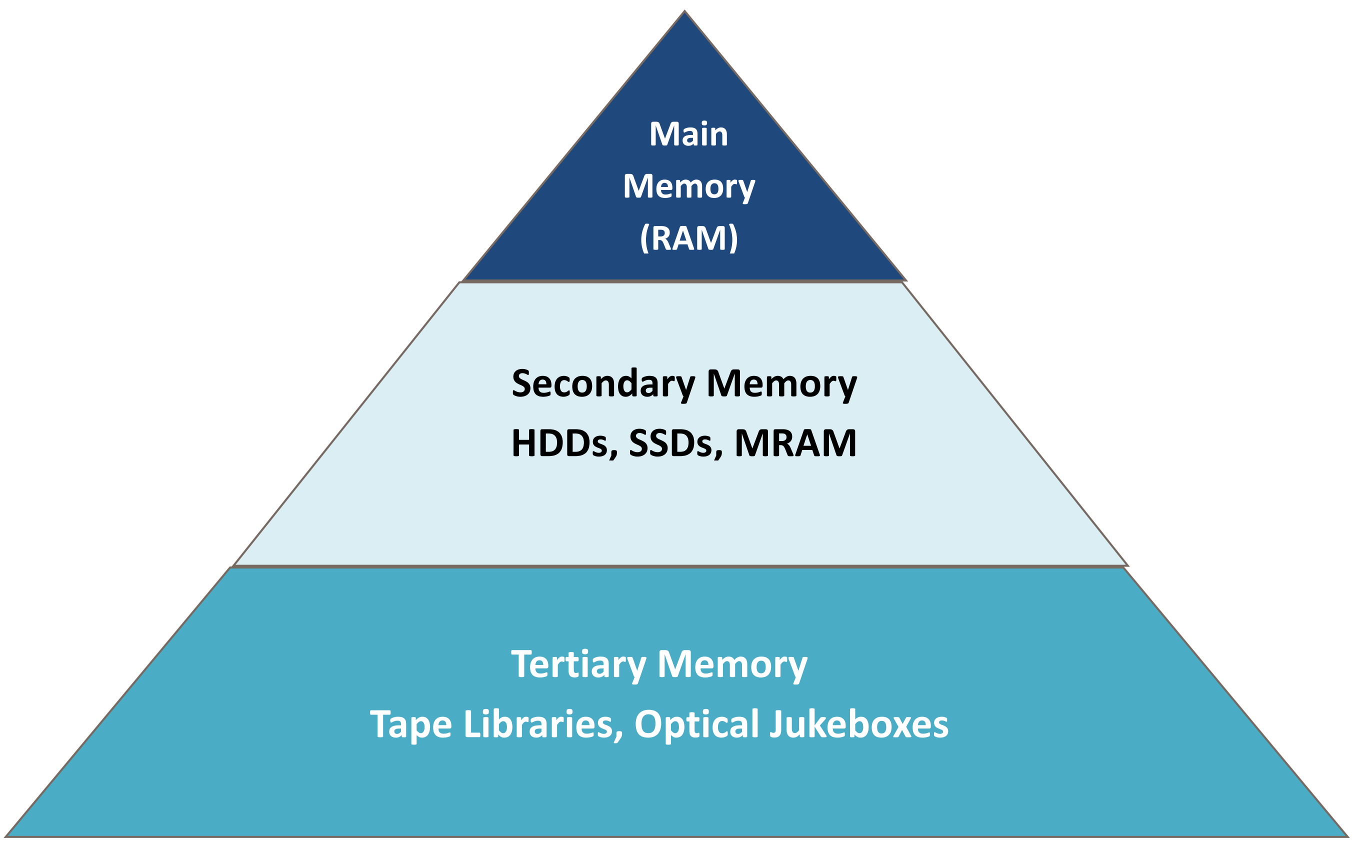


**Figure 1: Computer Memory Hierarchy**

We will briefly discuss each of the major storage types before getting into detailed sections on emerging trends in magnetic storage and flash storage.

**Magnetic Tape Cartridges**

This is the cheapest way to store data. Typically used for backup and archival data and forms a key component of disaster recovery for data storage. Infrequently accessed data are generally stored using magnetic tape libraries. Areal density of bits is used as a measurement for determining the storage capacity of a tape which is normally packaged in the form of cassettes.

**Solid State Drives**

Historically, semiconductors are referred to as the solid state devices. They provide much faster access to data compared to magnetic tape libraries. Traditionally, semiconductor as a storage option has been much more expensive compared to magnetic tape solution.

**Hard Disk Drives**

The advent of hard drives in the 1960s revolutionized the world of data storage and computing and has been the backbone of secondary storage needs for over five decades. This consist of spinning magnetic platters with read and write head.

## Evolution of Hard Disk Drives

It was clear from the early days of data storage research that magnetic tape storage will be much cheaper than semiconductor-based memory options. There was a need for a magnetic storage-based solution that performs better than magnetic tapes. That pretty much sums up the motivation for development of hard drives as captured in the quote below.

> "Magnetic disk drives have been developed as gap fillers between semiconductor memories and tape recorders. They provide faster access to data than tape recorders and at a considerably lower cost than semiconductor memory". [Kanu G. Ashar]

The first Hard Disk Drive was made by IBM in 1956 with a capacity of 5 MB and 1200 RPM. The first HDD consisted of fifty 24-inch disks with an areal density of 2 Kbits/square inch. In 2015, a 3.5 inch HDD from HGST, a subsidiary of Western Digital, came out with a storage capacity of 10 TB. Going by the cost for making the 5 MB IBM RAMAC HDD in 1956, the cost of 1 GB would have been 10 million dollars. In 2016, the dollar per GB for HDD is around USD 0.06, i.e. six cents. These facts and figures provide a fair sense of the evolution that the magnetic hard disk drive industry has gone through over the last six decades.

> "Increasing capacity and decreasing cost in disk drives are achieved by increasing bit areal densities, expressed in bits per square inch. The progress in technology is measured by the rate of improvement in this parameter. Areal density is a function of bit density on a track and track density on a disk surface. Progress in bit density depends on making the distance between the writing/reading head and disk as short as possible". [Kanu G. Ashar]

The following graph illustrates the bit areal density growth over the last six decades.

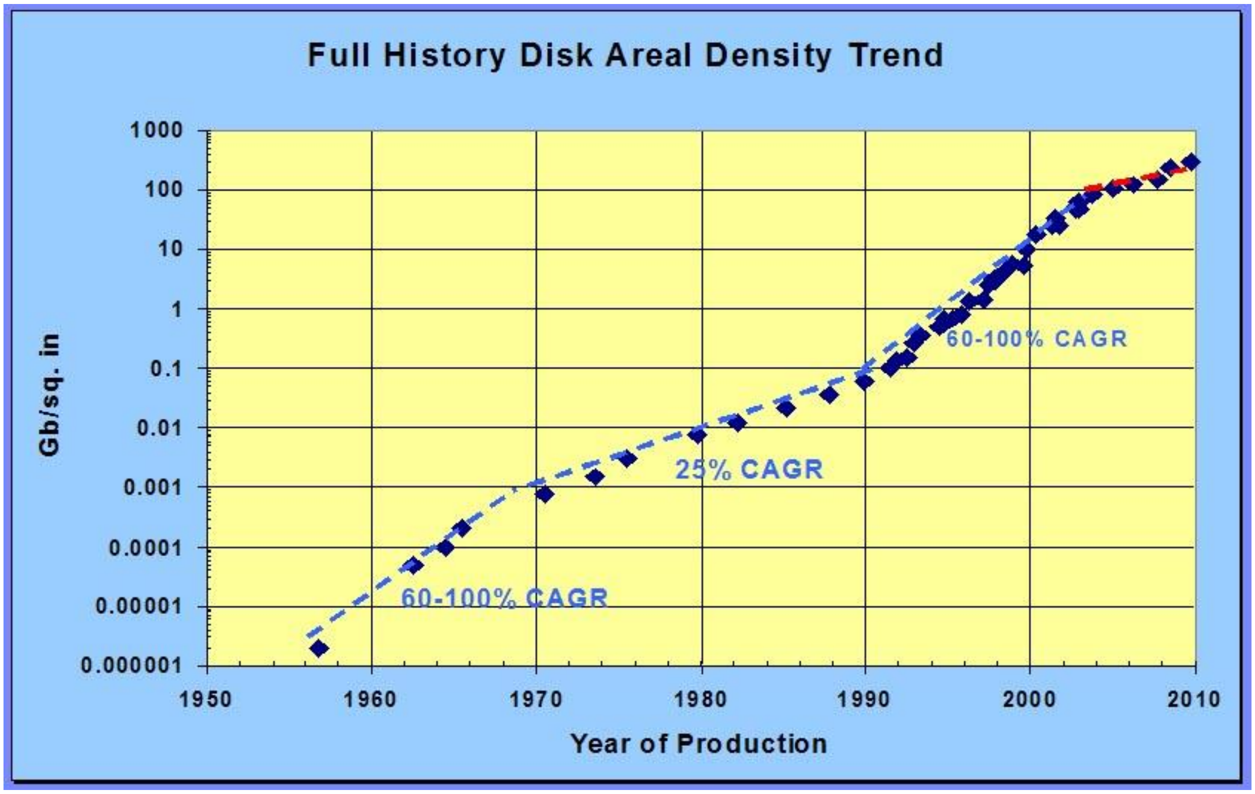


**Figure 2: Bit Areal Density Historical Trend**

*Source credit :*

*Disk drive evolution – "Technological impact of magnetic hard disk drives on storage systems", Grochowski & Halem, IBM Systems Journal Vol 42, number 2, 2003*

Exploiting the discovery made by Peter Gruenberg and Albert Fert, the speed at which the capacity of HDDs grew after GMR heads were introduced is in the order of 65% CAGR from 1990s defying Moore's Law and sustaining the longevity of magnetic drives.

## SSD and Flash Disruption

Solid State Storage (SSD) technologies have been around the last six decades. The technology had its origins in the 1950s when IBM pioneered the first computing systems. SSDs refer to the use of semiconductors for memory storage. Though the technology has been around as long as magnetic storage, it could not enter main stream data storage market until the late 90s and early 2000s. A number of players were trying to introduce semiconductor-based storage technologies since the 1970s. However, the industry was beset with a number of false starts and dead ends. Electrically Alterable Read Only Memory (EAROM) made out of silicon nitrides were around in the 1970s and were soon replaced by CMOS RAMs due to durability issues. Companies like Dataram and Micro Memory tried to introduce semiconductor-based storage drives without much success.

One of the major developments in SSD evolution was brought about by Storage Technology Corporation also known as StorageTek or STK who released a solid state disk in 1978 with an initial capacity of 45 MB at the rate of $8800 per MB. That would make the cost of 1 GB $8.8 million. The technology evolved gradually in the 1980s and achieved a level of maturity in the 1990s starting to be used alongside mainstream magnetic storage technologies.

By 2001, we saw the emergence of SCSI flash SSDs with 14 GB capacity closely followed by NAS flash SSDs in 2002. With the maturity of the technology evolving, server-based SAS SSDs emerged and SSDs achieved the status of being one of the key data storage and computing technologies of modern data centres. SSDs achieved capacities similar to hard drives by 2010 with availability of flash disks with terabytes of capacity. Dynamic RAM-based technologies popularly known as DRAMs and Static RAM-based technologies popularly known as SRAMs are volatile in nature but are in extensive use currently. But new technologies such as Magnetoresistive RAM and Ferrroelectric RAM – known as MRAM and FRAM respectively – are breaking new grounds. They are flash technologies which are non-Volatile.

The main advantages offered by flash technologies over hard drive are their performance factors. Typically, SSDs use NAND-based flash memory which is a non-Volatile storage technology. Unlike hard drives they do not have any mechanical moving parts. This makes the process of data writing and retrieving much more efficient compared to hard drives. A typical random access operation may take 0.1 ms in an SSD and may take from 2.9 to 12 ms in an HDD. When it comes to data transfer rate also, SSDs can transfer in terms of gigabytes per second whereas HDDs can transfer about 140 MB per second. However, the performance of SSDs can degrade over time faster due to usage than compared to HDDs. But the main disadvantage for SSDs over HDDs is the price factor. Though the cost multiplier for similar HDD to SSD capacity configuration has come down from 40X some years back to almost 6X to 10X now, it is still coming in at a considerable premium compared to hard drives. Achieving price parity with hard drives may still be some time away with new developments happening in the field of magnetic storage which may bring back the days of 60%-100% CAGR growth in storage capacity.

## Emerging Trends in Magnetic Storage: A Fight to Stay Relevant

Both the magnetic tape industry and the hard disk drive industry are breaking new ground in their respective domains. In the world of ever increasing content libraries in the magnitude of zetabytes, their strength lies in offering extraordinarily large storage capacity at affordable cost.

### Magnetic Tape Development

Sony announced in 2014 that they have developed a new method of storing data in tapes that allows areal density up to 148 GB per inch. This would allow development of tape disks with 185 TB storage capacities which will leapfrog the storage capabilities of tape storage medium thereby breathing in a fresh lease on life.

### SMR: Shingled Magnetic Recording

Shingled magnetic recording is an alternative to the widely used Perpendicular magnetic recording in order to increase the platter density or tracks per inch. While this method vastly improves drive capacity, it introduces new challenges such as the need to enforce sequential writes by means of an additional management layer.

### TDMR: Two-Dimensional Magnetic Recording

As track density increases, it introduces a new problem of generating more inter-track noise that could interfere with a signal when read heads are picking up signals. To keep the signal-to-noise ratio at acceptable levels, TDMR technique proposes having multiple read heads either in-series or in-parallel to address this issue.

### EAMR: Energy Assisted Magnetic Recording

To dramatically improve areal densities of HDDs 1.5 TB per square inch and beyond, researchers are exploring a new approach called energy assisted magnetic recording. Here, the methodology is to use energy to reduce the grain size of media surface where bits are stored. Achieving the balance between smaller grain size and stability of data storage is the key technological breakthrough promised by this approach. Heat-assisted magnetic recording and Microwave-assisted magnetic recording are two of the most promising technologies based on this approach.

**HAMR: Heat Assisted Magnetic Recording**

Laser beam is used here to heat the surface of media so that the magnetic coercivity is altered to avoid superparamagnetic effect caused by perpendicular magnetic recording. This allows us to write on a much smaller area leading to very high bit density on the order of 1.5 TB per square inch. Companies like Seagate have announced successful prototypes with commercialization leading to market availability expected between 2016 and 2018.

A lot of researches in the field of advanced magnetic materials are being driven by the needs of magnetic storage industry. For example, till now hard disks have been generally made of magnetic cobalt-chromium or cobalt-platinum alloys. Either longitudinal or perpendicular magnetic recording method is used to create these storage media. But new approaches include considering other alloys like Fe-Pt (Iron-Platinum) whose magnetic properties would allow higher bit areal density as elaborated below.

> "Each bit is stored on a tiny area with a magnetic field pointing in one of two opposite directions, denoting a binary digit 1 or 0. The smaller these magnetized areas are, the higher the density of the disk. When the areas get down to 25 nanometers to a square side (corresponding to 1 terabit per square inch), they become unstable, meaning that a small amount of heat can make them flip their magnetic field direction. More-stable magnetic materials, such as iron-platinum alloys, are available, says Mark Kryder, an electrical and computer engineering professor at Carnegie Mellon University and previous CTO of Seagate. However, to write on them requires magnetic fields much larger than those conventional recording heads can produce. If, however, you heat the material, smaller magnetic fields will work. So heat-assisted recording involves heating iron-platinum disks with a short laser pulse when the head applies a magnetic field to write data." [MIT Technology Review]

**MAMR: Microwave Assisted Magnetic Recording**

In this approach of energy-assisted magnetic recording, microwaves are used instead of laser beam to negate the magnetic effects that prevent data being written into grains of smaller sizes.

**Helium Filled HDDs from HGST**

HGST which is a subsidiary of Western Digital – one of the world's three largest storage vendors – has come up with a unique innovation in HDD using helium as quoted in the Gizmag report below:

> "We first caught wind of HGST's high capacity hard drives in 2012, when the company claimed it could boost storage capacities by 40 percent by replacing regular old air inside the drive enclosure with helium. The Western Digital subsidiary stayed the course, producing a helium-based 6 TB HDD in 2013 and 8 TB model in 2014, and has now continued the upward trend with the world's first 10 TB hard drive. HGST calls its version of this HelioSeal and has combined it with shingled magnetic recording (SMR), a hard drive technology that records data on overlapping rather than parallel tracks, much like roof shingles (hence the name). The company says this results in an industry-leading storage density, low power consumption and ever-reliable storage solution. However, since SMR requires the writing of entire tracks, the drive is suited for active archive duties rather than frequent update workloads". [Gizmag]

Shortly after this during 2015 HGST followed up with another version of the He-filled HDD with 10 TB of storage to address the performance concerns associated with SMR. The company employed the perpendicular magnetic recording (PMR) method instead of SMR that will not only enable even higher density storage but faster write performance as well.

**BPMR: Bit-patterned Media Recording**

This is a fundamentally different approach to magnetic recording. Instead of conventional granular media recording, this method proposes creating a fabricated media with a magnetic layer containing dotted arrays of bit-sized areas in servo pattern. This is extremely challenging as the dot size has to be on the order of 10 nm or lower. Fabrication technology required for this is still emerging and this is seen as an approach with great promise in the years to come.

The following roadmap published by Advanced Storage Technology Consortium (ASTC), founded by IDEMA, Hitachi GST, Marvell, Seagate, WD and Xyratex maps out the potential hard drive advances achieving up to 10 TB/in$^2$ by year 2025.

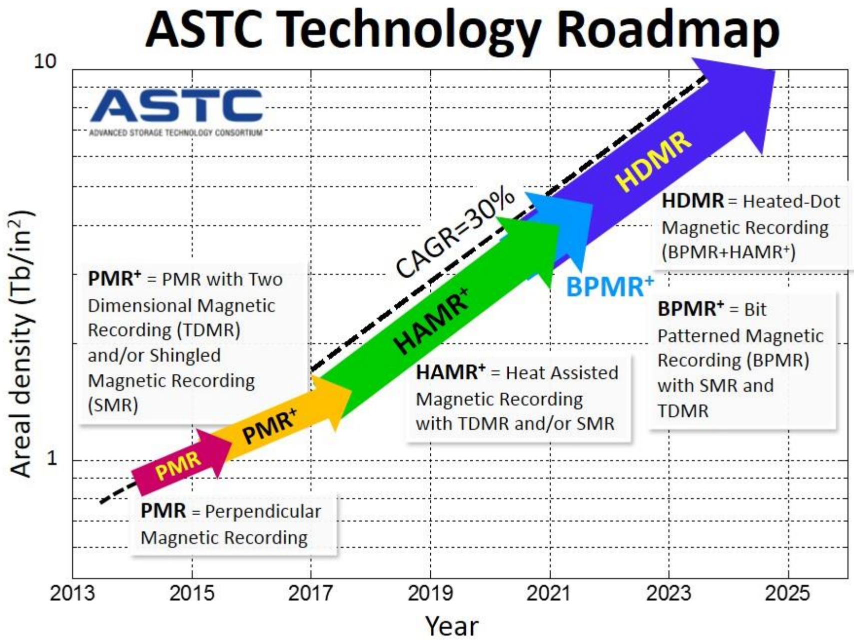


**Figure 3: IDEMA - ASTC Technology Roadmap**

## Future Directions for EMC

While performance continues to be the tilting factor in favour of flash memory technologies, capacity and price factors will play a key role in deciding the product mix.

The wisdom of industry experts strongly suggest that magnetic storage media such as tape disks and hard drive disks are here to stay for up to two more decades. This conclusion is driven by a number of developments as we have elaborated on above which point to certain technologies maturing to market readiness within the next 2 to 3 years. The product roadmap has to be managed in an agile way to be able to respond in an accommodative and dynamic fashion. Even a brief lag in the ability to exploit a new potential could set us back years, necessitating catch up acts.

The host of developments happening in different areas of storage present a number of opportunities for EMC. The attempts to successfully commercialize a number of these technologies are being driven by storage industry consortiums and not just by individual secondary storage vendors. This provides us the opportunity to get involved early in the development of these technologies. By active participation in many of these industry initiatives, we can shape the evolution of this industry rather than responding to paradigm shifts that make sudden impacts.

## Summary

EMC is leading the industry in terms of software-defined storage and data centre, All-Flash Arrays, and Enterprise Hybrid Cloud. As an industry that is passing through a state of extreme flux, EMC has to strike the right balance between staying ahead of competition in the current market scenario while remaining cognizant of developments happening in the basic sciences associated with the wider data storage and computing industry. While staying close to customers enable us to address their immediate needs effectively, staying abreast of advances in fundamental sciences can lay the foundation for us to become leaders of innovation and trendsetters.

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