

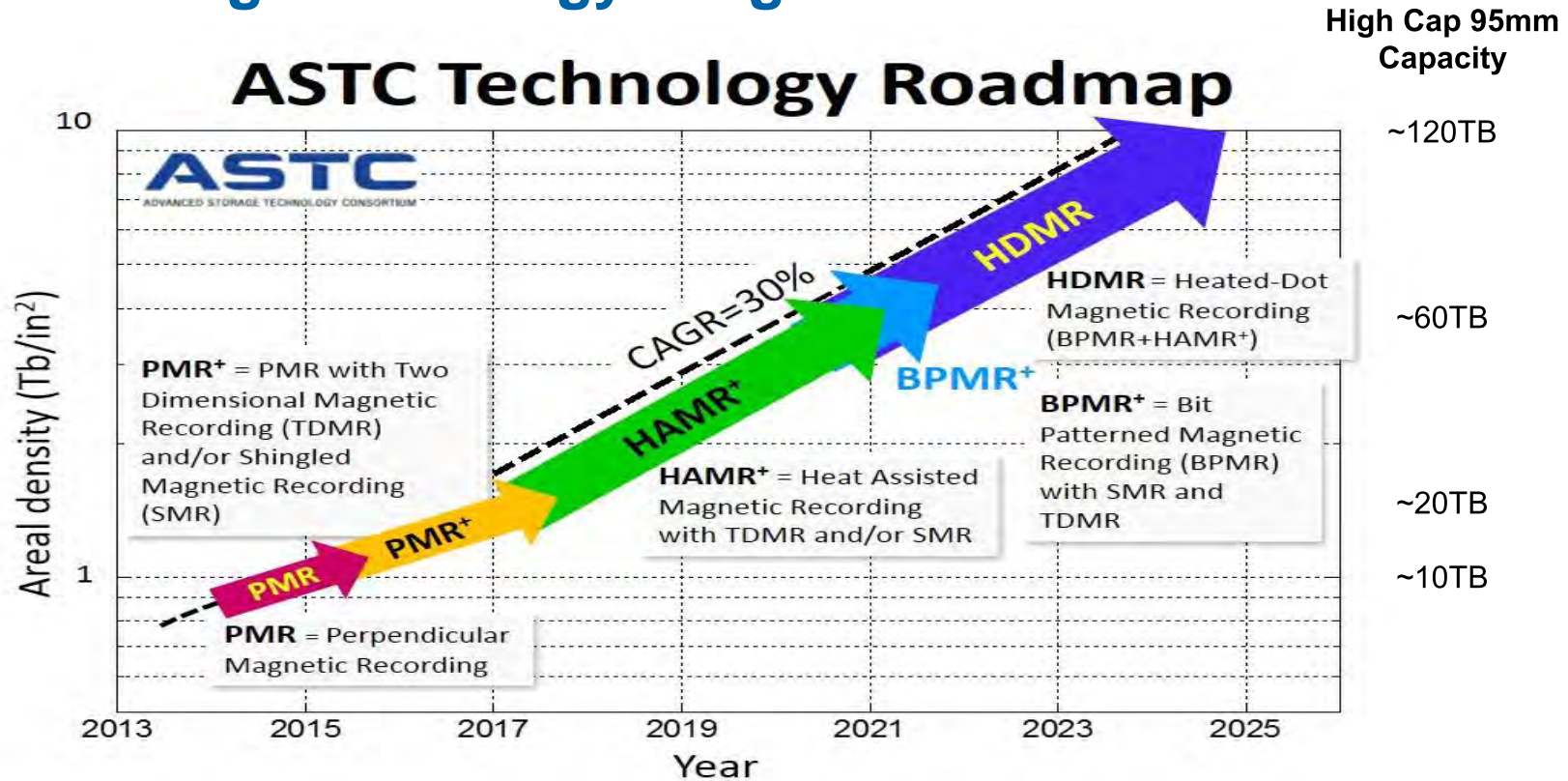


Scaling the Areal Density Mountain

Dave Anderson
Seagate

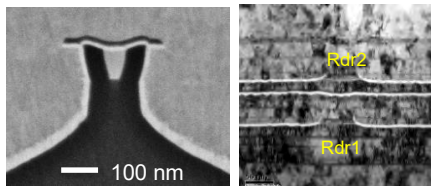
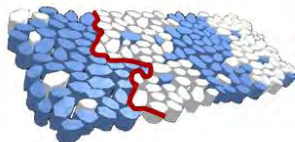


Recording Technology Progression - ASTC



- Seagate's HDD technology introductions are consistent with this industry view
 - Tips of arrows indicates approximate capability of technology
 - We have line of sight to capacities exceeding 100TB using these technologies and higher disk counts

Challenges to Higher Capacity Drives



Thermal Stability

Challenge:

To increase areal density we need to reduce grain size. However, if grain size is reduced too much, they become unstable

Solutions:

- Heat Assisted Magnetic Recording (**HAMR**)
- Bit Patterned Media (**BPM**)
- Heated Dot Magnetic Recording (**HDMR**=HAMR+BPM)

Writer/Reader/HMS Scalability

Challenge:

To increase areal density we need to reduce track pitch. We are fast approaching the limits of how narrow we can make writers and readers

Writer Solutions:

- Shingled Magnetic Recording (SMR)

Reader Solutions:

- Two-Dimensional Magnetic Recording (TDMR), ie, Multi Sensor Magnetic Recording (**MSMR**)

Head Media Spacing (HMS):

- Thinner coatings, lower clearances, smoother interfaces, new materials, new clearance control algorithms

Fixed Form Factor

Challenge:

To increase drive capacity we can add more heads and disks to the HDA. However, we are constrained by fixed form factors.

Solutions:

- More discs per HDA - **Helium**
- New form factors

Innovative Technologies



PMR/CMR

**Perpendicular
Magnetic
Recording**

AD Up to ~1.0
Tb/in²

Current
Mainstream
Products



He

**Helium Filled
Hard Drives**

Currently
Shipping



SMR

**Shingled
Magnetic
Recording**

Shipping in
various markets



TDMR

**2D Magnetic
Recording**

Product
Integration 2016
- 2018



HAMR

**Heat Assisted
Magnetic
Recording**

AD ~1.2 to 4.0
Tb/in²

Product
Integration 2016+



HDMR

**Heated Dot
Magnetic
Recording**

~5.0 to 10.0
Tb/in² AD

Initial Product
Integration >2025

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Two Dimensional Magnetic Recording (TDMR)

Problem

Reducing the reader width difficult
Reader sees more of adjacent tracks = noise

TDMR solution

Read adjacent tracks
Calculate interference effects and cancel out noise

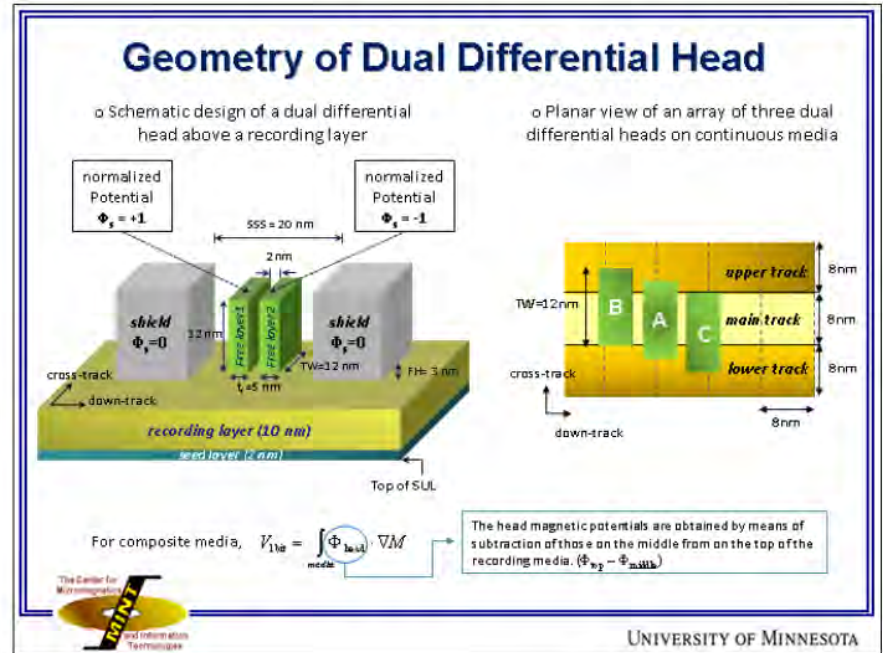
Longer term

knowledge of adjacent tracks & clever encoding
extend the areal density further by writing tracks
closer and closer together

Challenge: How to implement TDMR

Reading multiple tracks with a single reader is too slow

Multiple readers on a single head has engineering challenges



E. Cho, Y. Dong, R.H. Victora, INSIC Annual Meeting 2010

2D Magnetic Recording Works

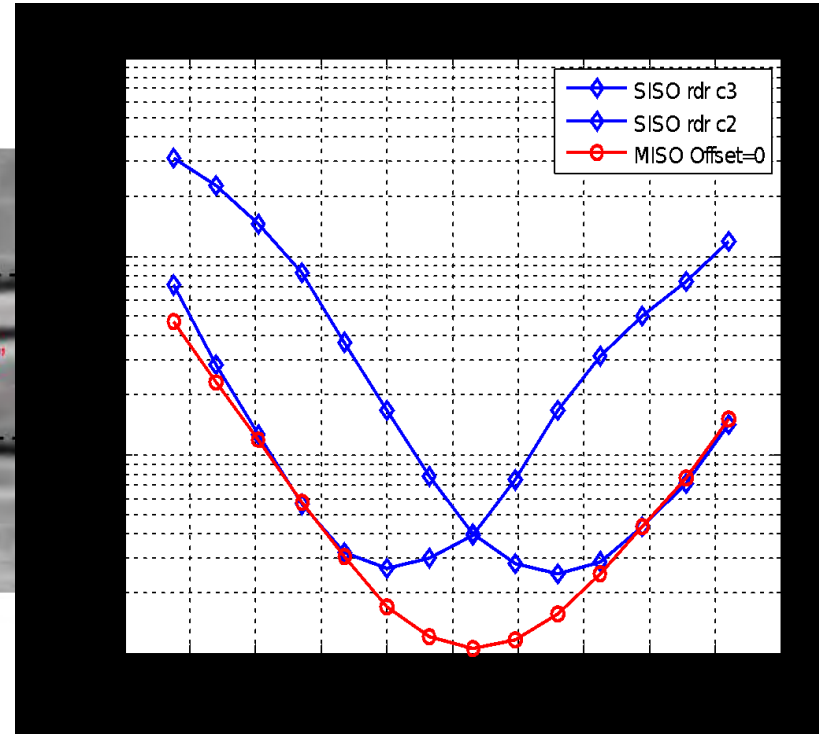
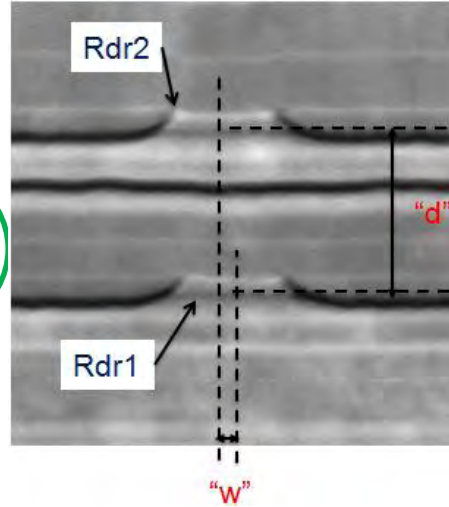
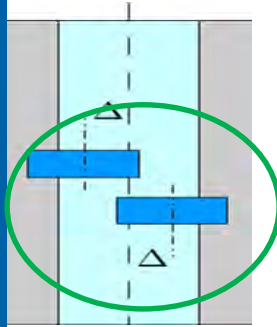


TDMR

2D Magnetic
Recording

Compatible with
PMR, SMR and
HAMR

Product Integration
2016 - 2018



Takeaways

- 2 or more readers on the same track or partially on adjacent tracks
- Current areal density gains in the 5-10% range
- Future work to get larger areal density gains
- Also get 2x read data rate

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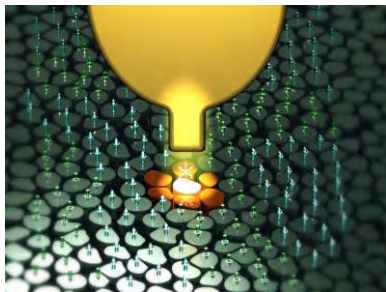
Heat Assisted Magnetic Recording Making Significant Progress



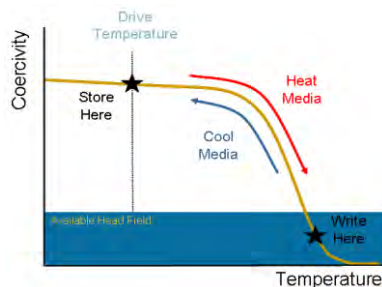
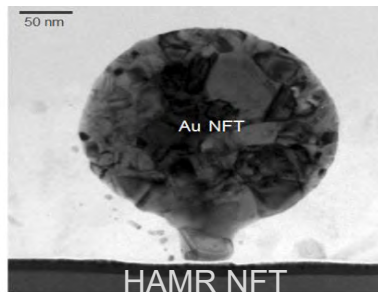
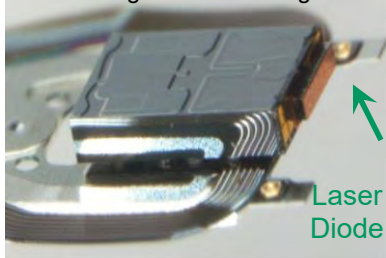
HAMR

Heat Assisted
Magnetic
Recording

AD ~1.2 to 4.0 Tb/in²
Product Integration
2016+



HAMR Integrated Recording Head



- Very stable media to extend areal density
- Media is heated so it can be written.
- Laser is integrated into the HAMR head
- Near field optics allow very narrow and sharp bits to be written.
- Heated, written and cooled in less than a nano-second.

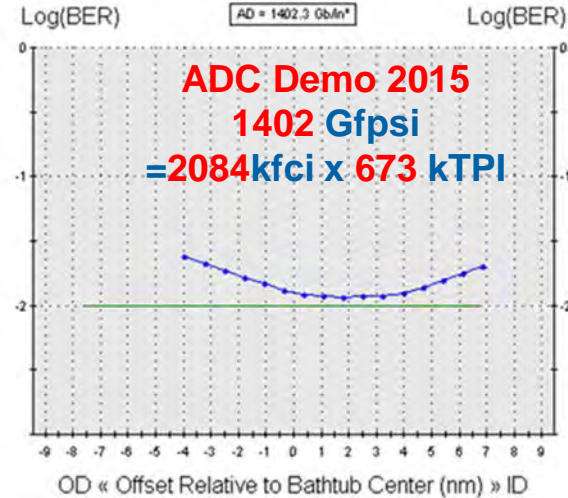
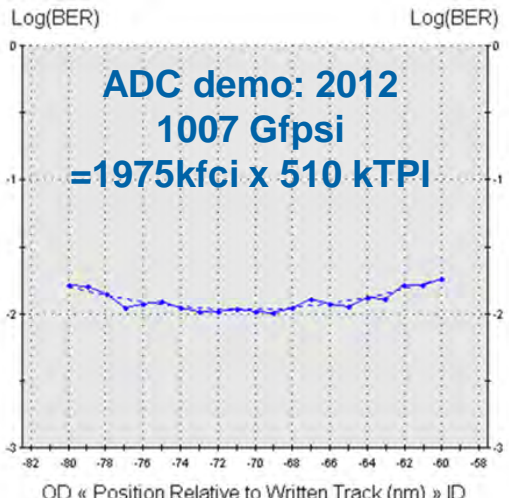
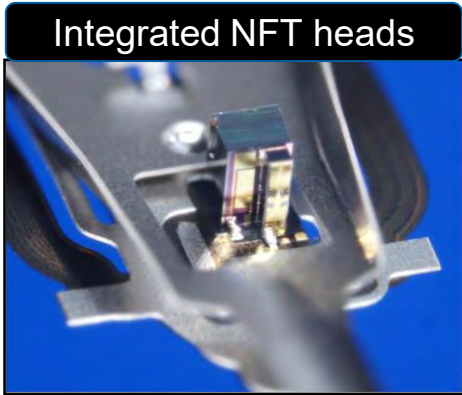
Takeaways

- HAMR need for increase in areal density.
- Significant progress made, still focusing on reliability and area density.

HAMR ADC Growth and Product readiness- It Works!

Accomplishments:

- ADC = +1.6 Tb/in²
- Reliability
- Integrated heads/drive



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Initial Product
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Heated Dot Magnetic Recording = BPM + HAMR

Continuous FePt film patterned @ 1Tdpsi to 5Tdpsi

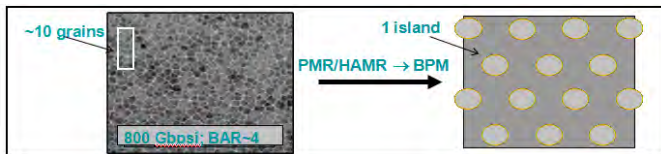


HDMR

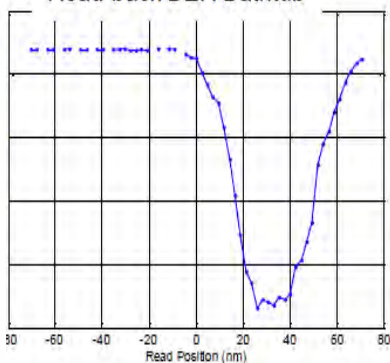
Heated Dot
Magnetic Recording

~5.0 to 10.0 Tb/in² AD

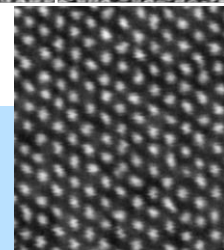
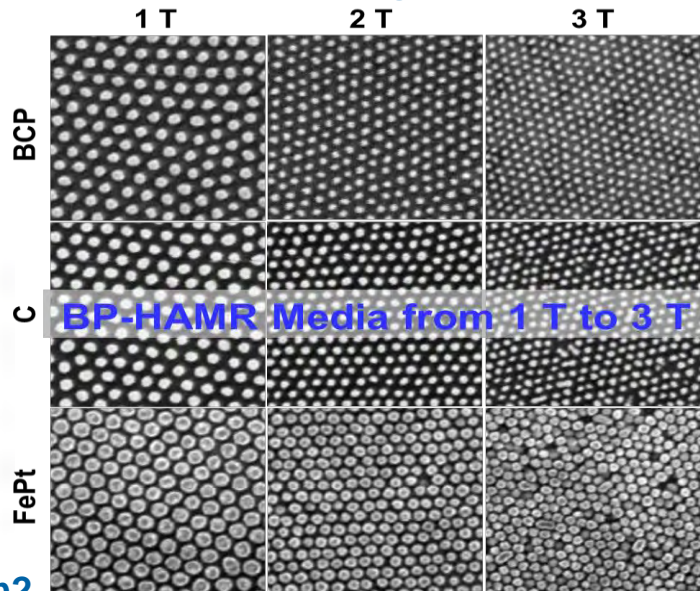
Initial Product
Integration >2025



Read-back BER Bathtub



BER = -2.43 @ 1Tb/in²

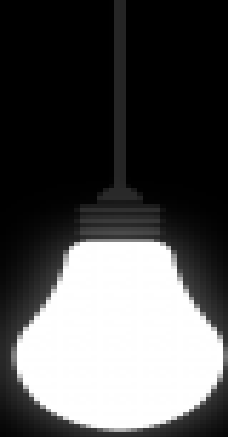


5 T

Spinstand testing and drive integration

Takeaways

- BPM: Multiple grains per bit to a single magnetic island per bit
- Demonstrated 1.5 Tdpsi Spinstand
- HDMR at 5Tdpsi and beyond looks feasible



WHY HARD DISK DRIVES REMAIN ESSENTIAL



2005: Installation Pope Benedict

2013: Installation Pope Francis



2005: Installation Pope Benedict



DATA NEVER SLEEPS 3.0

How much data is generated every minute?

Data is being created all the time without us even noticing it. Much of what we do every day now happens in the digital realm, leaving an ever-increasing digital trail that can be measured and analyzed. Just how much data do our tweets, likes and photo uploads really generate? For the third time, Domo has the answer—and the numbers are staggering.



THE GLOBAL INTERNET POPULATION GREW 10.5% FROM 2013-2015 AND NOW REPRESENTS

3.2 BILLION PEOPLE.

With each click, share and like, the world's data pool is expanding faster than we can comprehend. Businesses today are paying attention to scores of data sources to make crucial decisions about the future. The team at Domo can help your business make sense of this endless stream of data by providing executives with all their critical information in one intuitive platform. Domo delivers the insights you need to transform the way you run your business. [Learn more at www.domo.com.](http://www.domo.com)



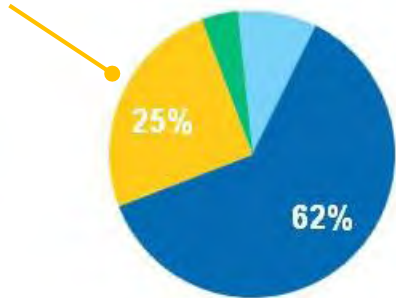
SOURCES: FACEBOOK, TWITTER, YOUTUBE, INSTAGRAM, PINTEREST, APPLE, NETFLIX, REDDIT, AMAZON, TINDER, BUZZFEED, STATISTA, INTERNET LIVE STATS, STATISTIC BRAIN.COM

Move Toward Mobility: Shifting the Location of Data

2010

62% of the storage was shipped into the client market...

77 Exabytes

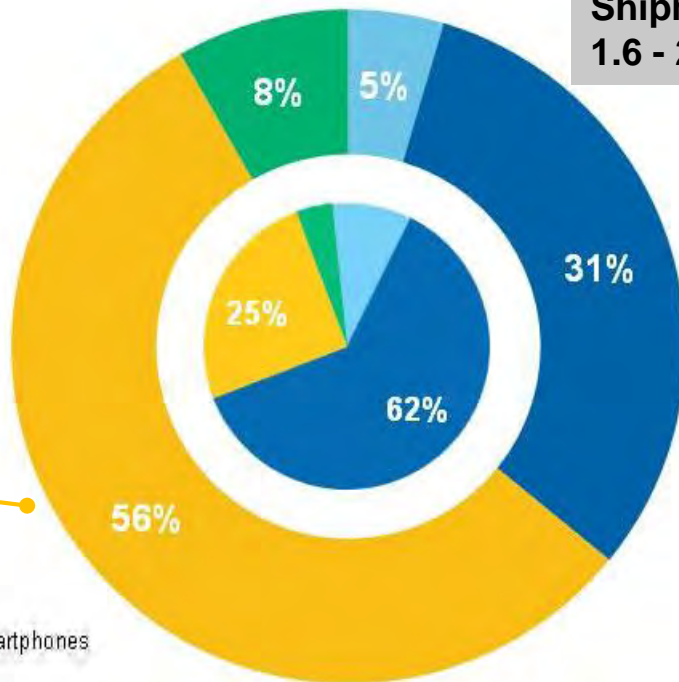


2020

dramatic shift to the cloud

2020 HDD Shipments: 1.6 - 2 ZB

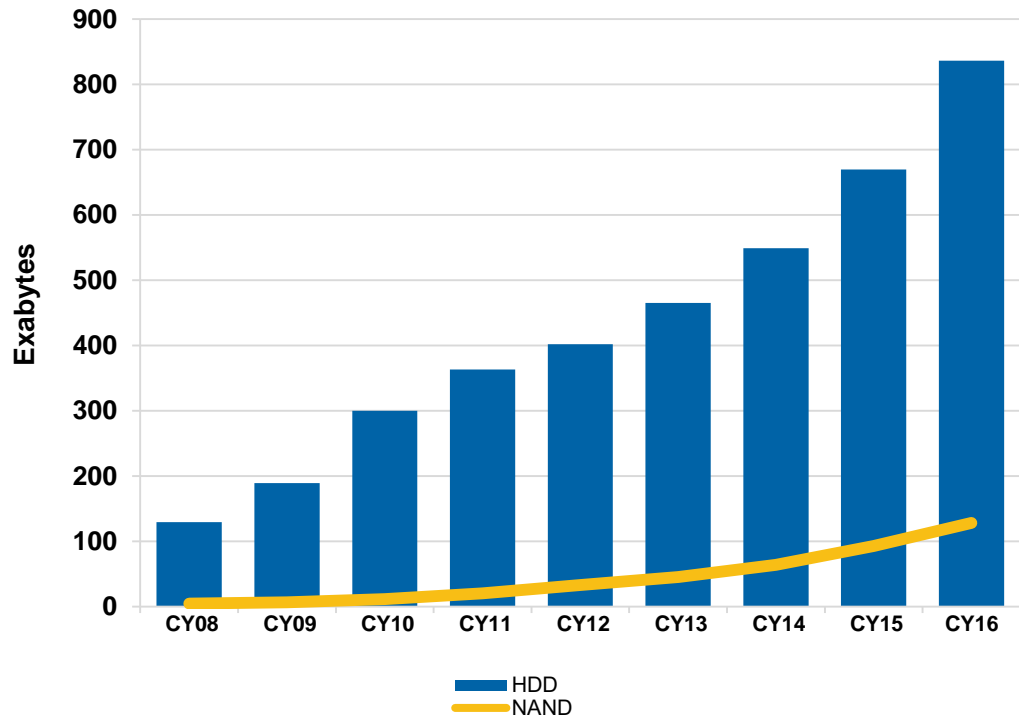
1,121 Exabytes



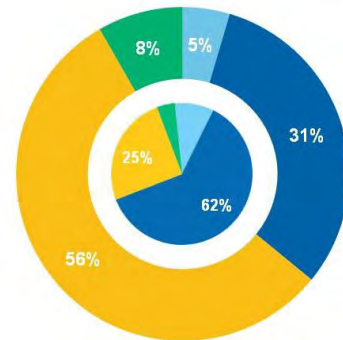
Consumer Electronics Client Compute Cloud Computing Tablets & Smartphones

No Replacement for HDD Soon

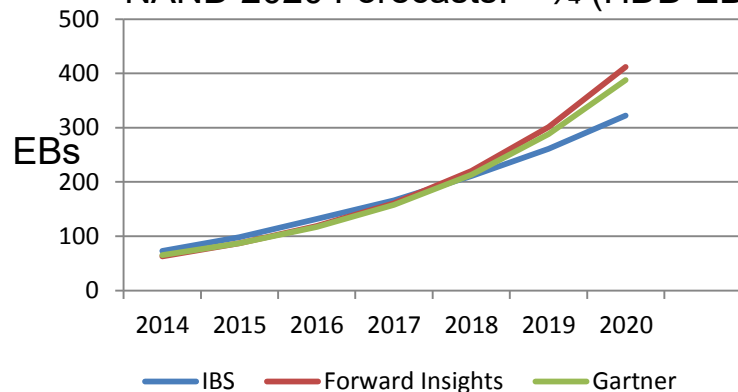
HDDs dominate the storage market



2020 HDD Shipments: 1.6 - 2 ZB



NAND 2020 Forecasts: < 1/4 (HDD EBs)





THANK YOU

