



INEMI[®]

International Electronics Manufacturing Initiative

Mass Data Storage Roadmap

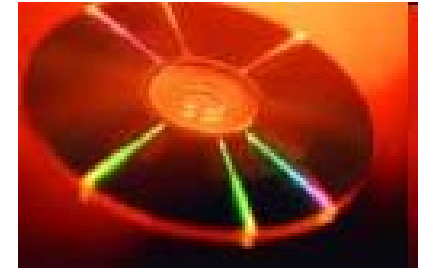
Roger F. Hoyt Chair
Tom Coughlin Co-Chair

Advancing manufacturing technology

iNEMI Mass Data Storage Roadmap

Outline

- iNEMI Overview
- Roadmap Process
- Mass Data Storage Roadmap
- Executive Summary
- Solid State
- Magnetic
 - Hard Disk Drive (HDD)
- Tape
- Optical
- Storage Systems



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iNEMI Overview

(www.inemi.org)

International Electronics Manufacturing Initiative



>60 member companies WW



Mission:

To forecast and accelerate improvements in the electronics manufacturing industry for a sustainable future.



Technical Activities

Product Emulator Groups (PEG'S)

⇒ Technical Working Groups (TWG's)

Technology Implementation Groups (TIG's)



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iNEMI – 2010 Roadmaps

Technical Working Groups (TWG)

Manufacturing Technologies
Board Assembly
Final Assembly
Test, Inspection & Measurement
Component / Subsystem Technologies
Electronic Connectors
Energy Storage & Conversion Systems
Interconnect Substrates – Ceramic
Interconnect PCB - Organic
Large-Area Flexible Electronics
Mass Data Storage
MEMS / Sensors
Optoelectronics
Packaging & Component Substrates
Passive Components
Photovoltaics
RF Components & Subsystems
Semiconductor Technology
Solid State Illumination
Business Processes / Technologies
Information Management
Design Technologies
Environmentally Conscious Electronics
Modeling, Simulation & Design Tools
Thermal Management

Product Emulator Groups (PEG)

Aerospace / Defense
Automotive
Consumer / Portable
Medical
Netcom (Network / Datacom / Telecom)
Office / Large Business Systems

Technical Implementation Groups (TIG)

Board Assembly
Board & System Mfg. Test
Environmentally Conscious Mfg.
Medical
Optoelectronics
Organic Packaging
Organic PCB



CD-ROM with all **Roadmaps**
May be ordered from iNEMI.org
\$250 (NA)
\$325 (outside NA)



Mass Data Storage

2010 Contributors

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iNEMI Mass Data Storage

Executive Summary



Solid State

NAND Flash Memory: Growing in importance, but will not displace HDD

MRAM: now established, volumes may grow with ST or Thermal Switching

Phase change yet to emerge in high volumes

Magnetic

HDD is largest volume, continued growth expected, but rate may slow.

Tape still plays vital archival backup role, helped by LTO standard

Optical

Primary niche is in data transfer applications

Holographic storage too expensive to succeed in marketplace.



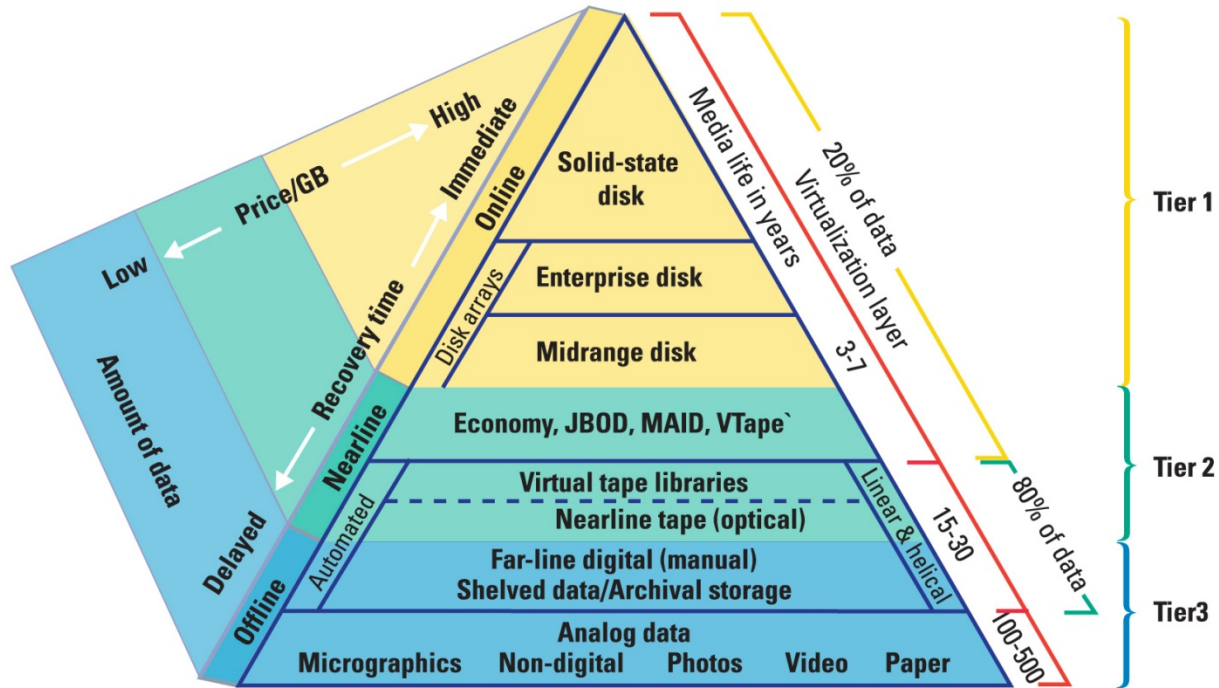
Storage Systems

Architected for cost rather than performance. Power & performance issues may enable viability of SSDs in some enterprise applications.



iNEMI Mass Data Storage

Tiered Storage Hierarchy



Source: Horizon Information Strategies

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NAND Flash



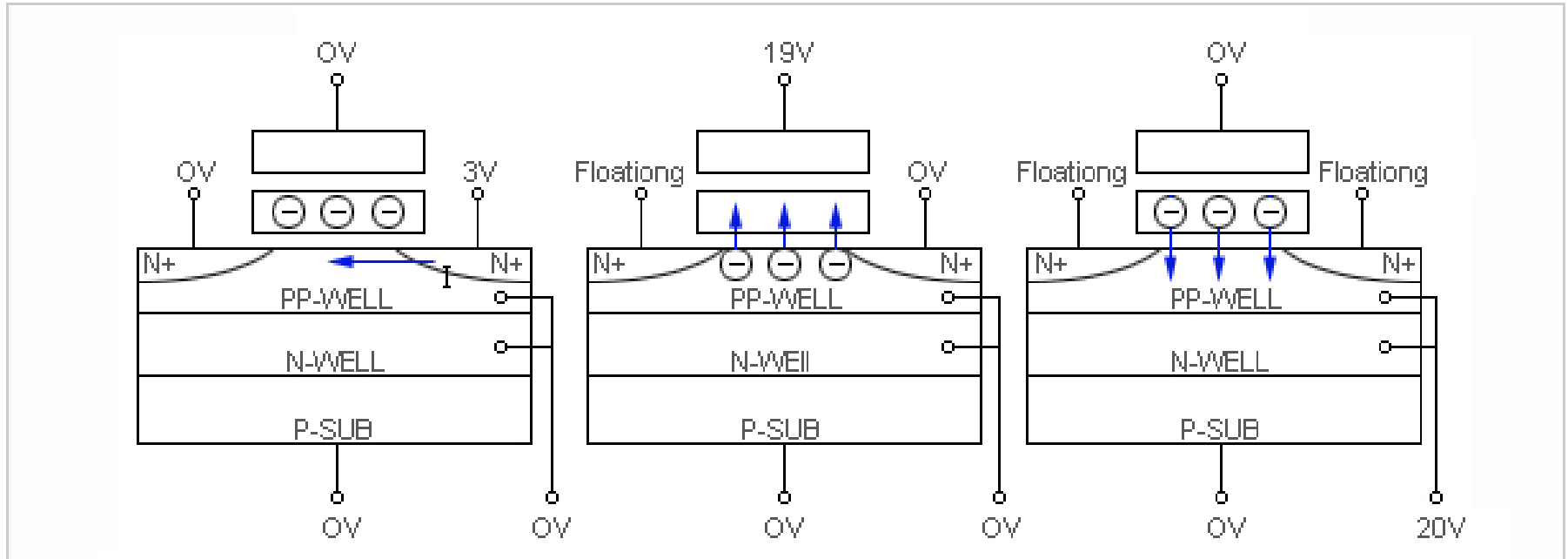
Decreasing Speed/
Increasing Size

Tape/CD-R (Archival Storage) HDD (Mass Storage) NAND (Disk Cache) DRAM (Main Memory) SRAM (External Cache) SRAM (Processor Cache)

- Playing a growing niche role in storage hierarchy
 - Displaced SFF HDD's in MP3/camera/phones
 - Complementary to HDD in many applications
 - Enabled the emergence of SSD & Hybrid HDD
- Multi-level packaging now broadly used
- Price decline faster than Moore's law
 - Multi-bit cell technology improvements expected to continue
- Technology may eventually reach its scaling limits

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Reading

Programming

Erasing

Cross-Section of floating-gate flash memory cell

(Source: Samsung Semiconductor Company)



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NAND flash chip roadmap

	2009	2011	2013	2016	2021
Minimum Feature Size	38nm	28nm	23nm	16nm	8.9nm
Price/GB (\$/GB) * @ \$15/in ²	\$1.16	\$0.61	\$0.38	\$0.17	\$0.052
Average chip density	16Gb	16Gb	32Gb	64Gb	256Gb

* The \$15/in² number is lower than that used in the 2009 iNEMI roadmap and is more reflective of actual manufacturing costs.

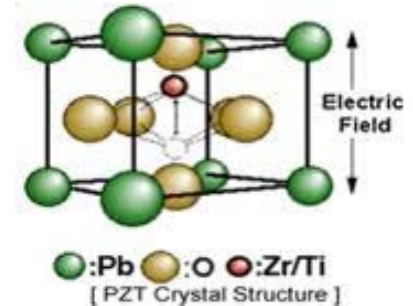
(Source: ITRS Roadmap/Objective Analysis)



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Additional Solid State Memory Technologies

- Ferroelectric RAM (FRAM or FeRAM)
 - Utilizes Perovskite crystal state change
 - In marketplace > 20 yrs
 - Suppliers include Ramtron, Fujitsu
 - Applications: Fare cards, power meters, gaming systems, military
 - Die size & mfg. cost disadvantages may be soluble



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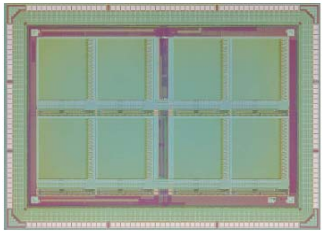
Additional Solid State Memory Technologies



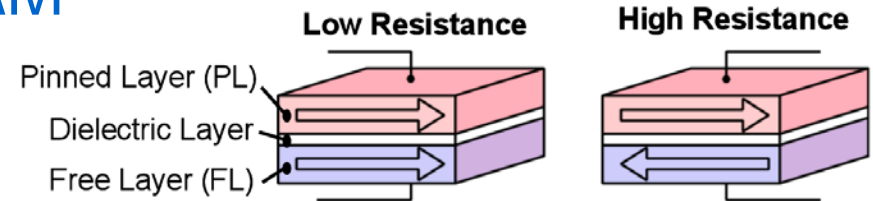
- Phase Change (PCM, PCRAM, or PRAM)
 - Utilizes Chalcogenide materials for amorph/x'tal change
 - may be scalable to 5 nm
 - being sampled for some applications
 - Numerous companies involved: Intel, Micron/Numonyx, Samsung, ST Micro, etc.

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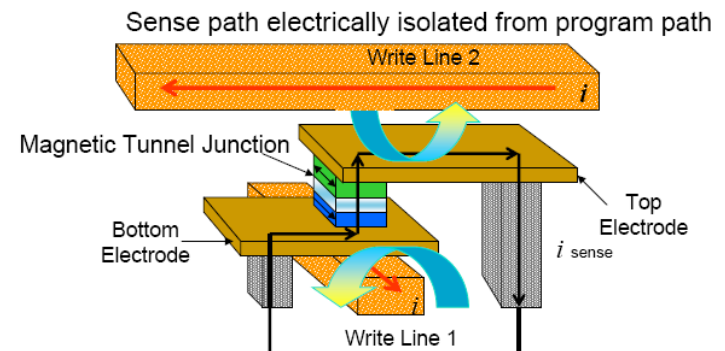
Additional Solid State Memory Technologies MRAM



4Mb MRAM die



- Technology first shipped in 2006
 - Mfr's are selling all they produce
 - storage capacity not large, but robust in harsh environments
- A niche product
 - Requires BEOL processing
 - High Cost/Price



iNEMI Mass Data Storage

	SRAM	DRAM	Flash	FRAM	MRAM	PCM
Read Speed	Fast	Medium	Medium	Fast	Fast	Medium
Write Speed	Fast	Medium	Slow	Fast	Medium	Medium
Array Efficiency	High	High	Medium/Low	Medium	High	High
Scalability	Good	Limited	Limited	Limited	Medium	Good
Cell Density	Low	High	Medium	Medium	Medium	High
Volatile?	Yes	Yes	No	No	No	No
Endurance	Infinite	Infinite	Limited	Limited	Infinite	Limited
Current Consumption	Low/High	High	Low	Low	Low	Low
Low-Voltage	Yes	Limited	Limited	Limited	Yes	Yes
Complexity	Low	Medium	Medium	Medium	Complex	Medium

Attributes of Different Memory Technologies

(Source: Objective Analysis)



iNEMI Mass Data Storage



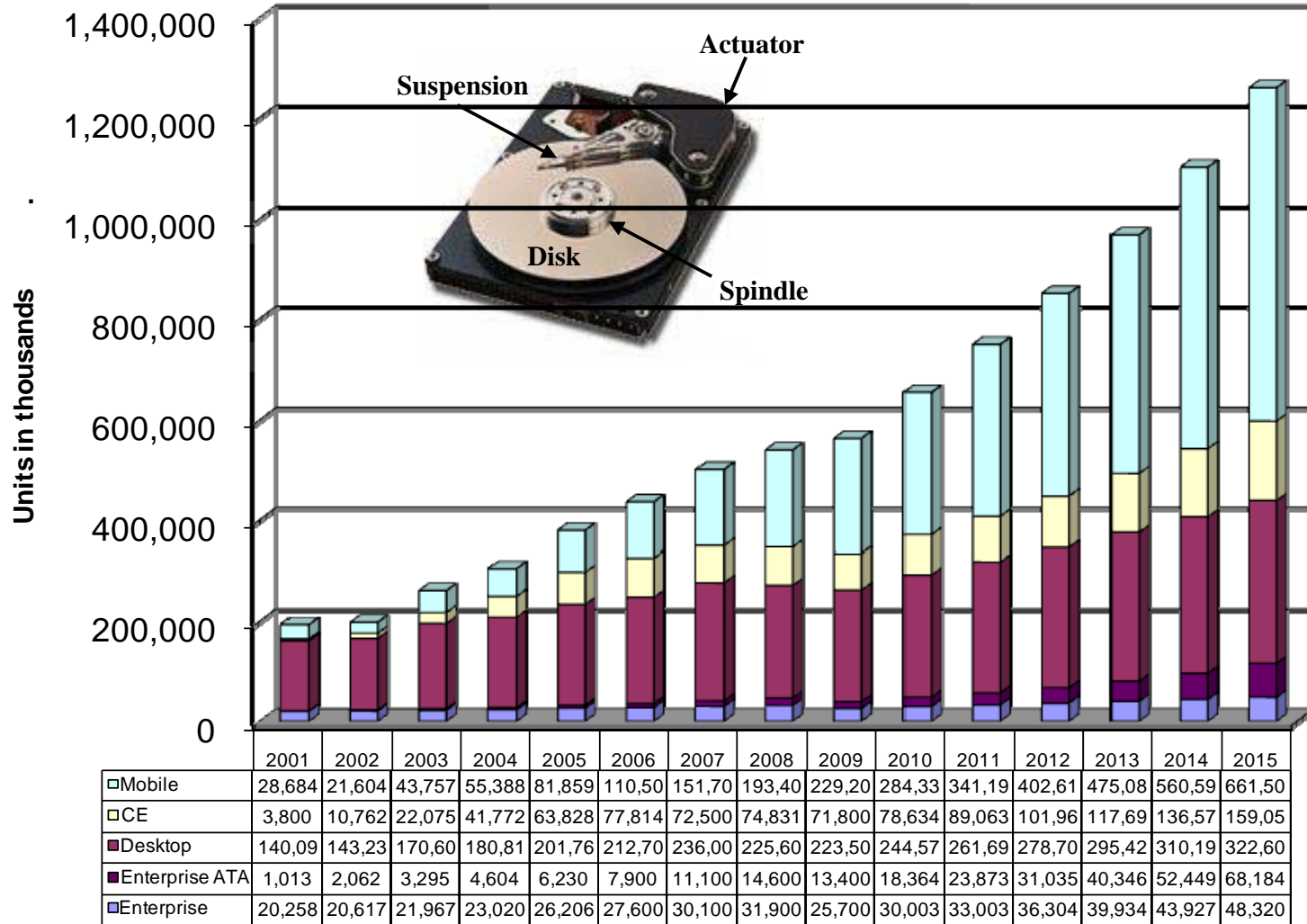
Magnetic / HDD



- HDD demand remains strong, ~650-660 M units in 2010 (563 M in 2009)
 - projected market >1B units by 2013 or 2014
 - first 1TB HDD shipped in 2007
 - 3 TB HDDs shipping today
- Volumes dominated by Desktop and Mobile segments
 - Mobile projected for highest growth
- Strong trend towards vertical integration of HDD mfr's.
may lead to further consolidation of suppliers

iNEMI Mass Data Storage

Shipped HDD Volumes vs. Time, by Application

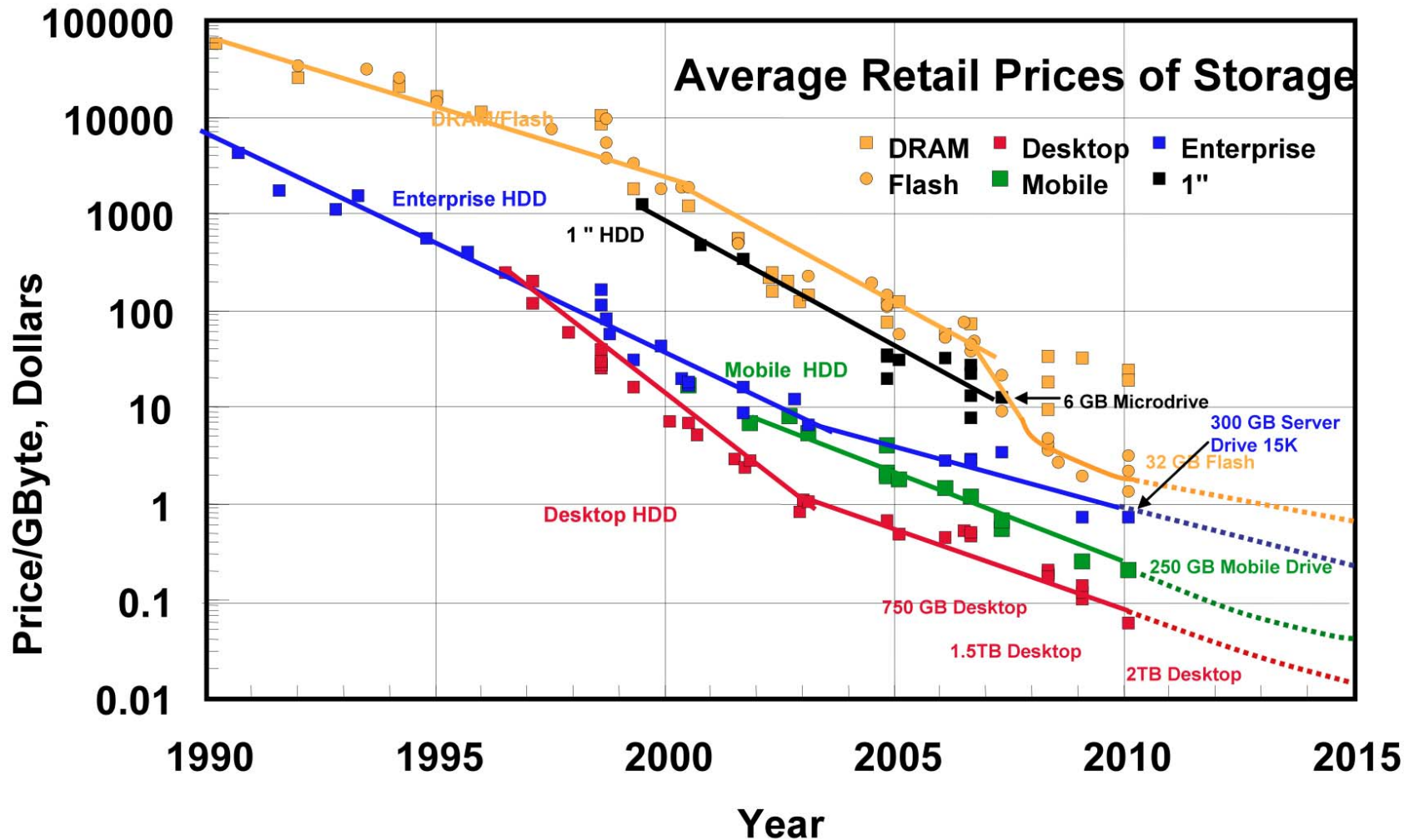


(Source: Coughlin Associates)

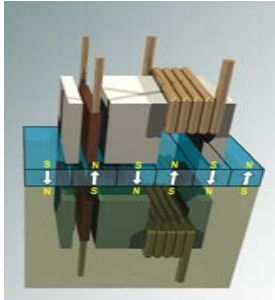


iNEMI Mass Data Storage

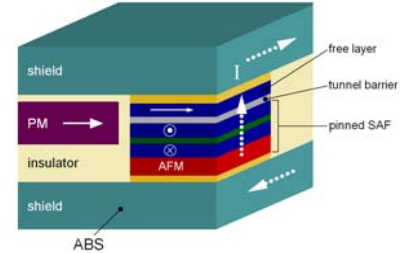
Storage Average Retail Price



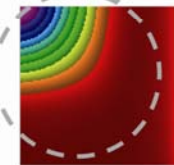
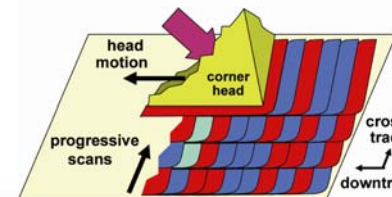
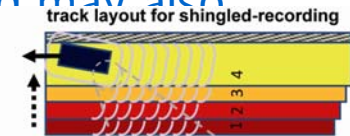
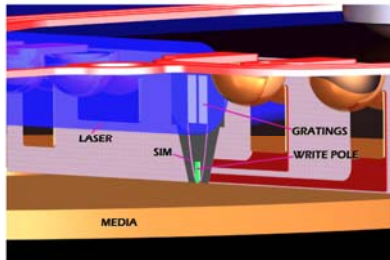
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HDD Technology Advances



- Perpendicular recording & TMR head technology now shipping from all mfr's
- Areal density will grow towards 1Tb/sqi & push lithography limits
 - Discrete Track Recording (DTR), Bit Patterned Media(BPM), Piezo/MEMS based actuators, Heat Assisted Magnetic Recording (HAMR), CPP GMR Heads, Advanced Signal Processing
 - Full disk encrypted drives improved security
- Shingled Recording & Heat Assisted Magnetic Recording may also enable areal density growth



head field contours



Magnetic Mass Data Storage Technology Roadmap—HDD

	Unit	2009	2011	2013	2015	2019	2021
<i>Industry Metrics</i>							
Form Factor	inches	3.5, 2.5, 1.8, 1.3, 1.0	3.5, 2.5, 1.8	3.5, 2.5, 1.8	3.5, 2.5, 1.8	2.5, 1.8	2.5, 1.8
Capacity	GB	60-2,000	120-4,000	180-10,000	300-10,000	700-30,000	1,500-50,000
Market Size	Units (M)	540	775	1,035	1,380	2,410	3,200
Cost/GB (avg.)	\$/GB	<.0.15	<0.10	<0.05	<0.02	<0.01	<0.005
<i>Design/Performance</i>							
Areal Density	Gb/in ²	>500	>800	>1,000	>1,600	>4,800	>10,000
Rotational Latency	ms	2-12	2-12	2-12	2-12	2-12	2-12
Seek Time*	ms	3-5	3-5	3-5	2-5	1.5-5	1-4
RPM		4.2-15K	4.2-15K	4.2-15K+	4.2-15K+	4.2-10K+	4.2-10K+
Data rate	Mb/sec	10-2,200	10-2,500	12-2,800	14-3,200	20-6,400	40-10,000
Power	watts	2-10	1-10	1-10	0.7-9	0.5-8	0.3-6
Reliability	Spec.	MTTF/AFR	New Spec	New Spec	New Spec	New Spec	New Spec



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Tape Storage



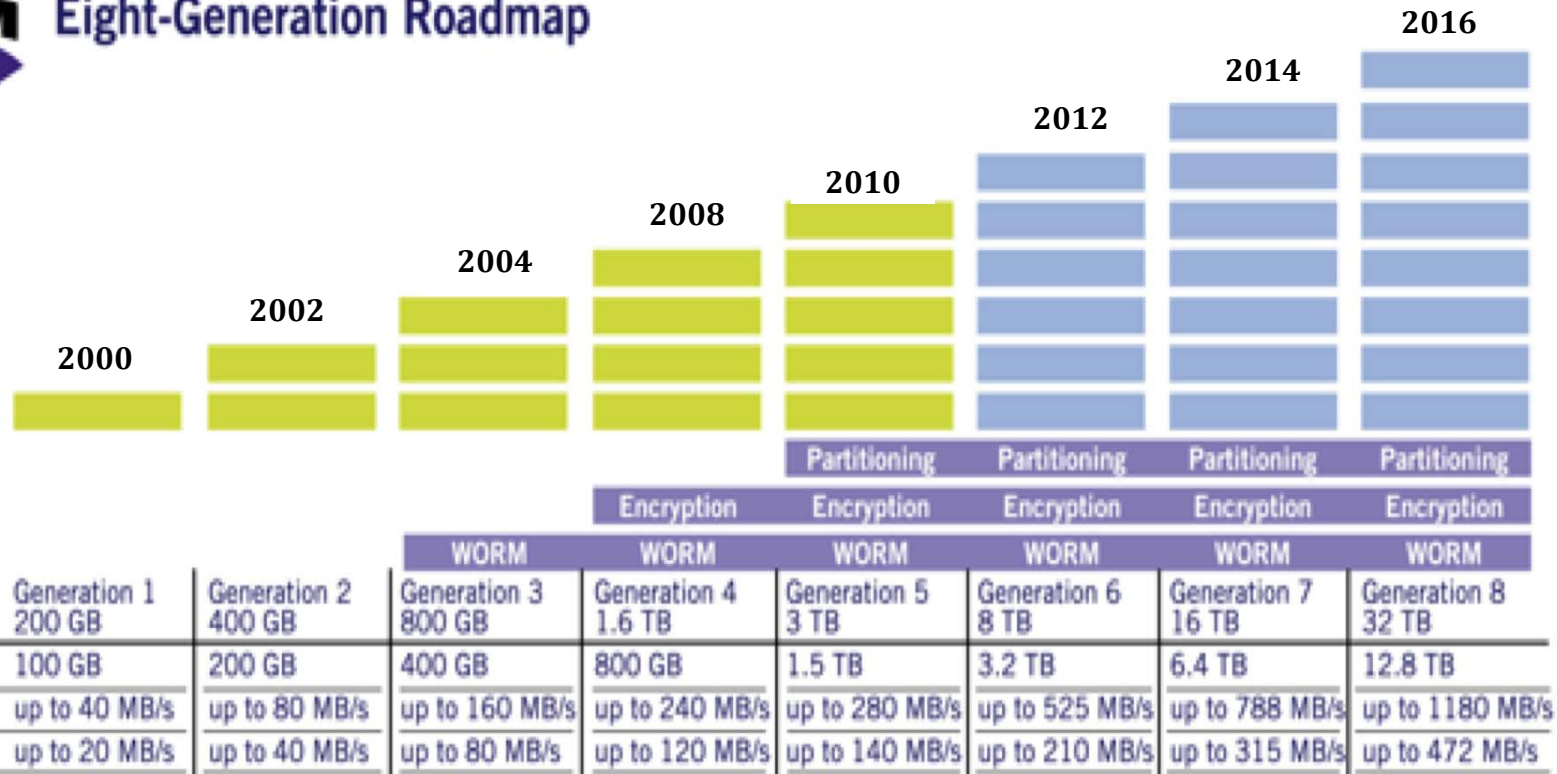
- LTO (= Linear Tape-Open) "Ultrium"
 - the industry wide system archival tape storage standard
- Consortium established by HP, IBM, & Seagate
- Drop-in replacement for DLT, based on 1/2" tape
- An Ultrium drive can:
 - read data from a cartridge in its own generation and at least the two prior generations.
 - write data to a cartridge in its own generation and to a cartridge from the immediate prior generation in the prior generation format



iNEMI Mass Data Storage Tape Storage Roadmap



Eight-Generation Roadmap



Note: Compressed capacities for generations 1-5 assume 2:1 compression. Compressed capacities for generations 6-8 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 HP, IBM and Quantum in the US and other countries.



iNEMI Mass Data Storage

	Unit	2009	2010	2012	2019	2021
Form Factor F/HH=Full/Half Height Longitudinal Tape	inch	5.25 FH, 5.25 HH,3.5	5.25 FH, 5.25 HH,3.5	5.25 FH, 5.25 HH,3.5	5.25 HH,3.5	5.25 HH,3.5
Volumetric Density	GB/in ³	100	200	400	2,000	10,000
Cartridge capacity (native)	GB/TB	800 GB	1,500 GB	3-4 TB	12-24 TB	24-48 TB
Areal Density	Gb/in ²	1.2	2.0	3.0-3.5	5-10	10-20
Data Rate	MB/s/drive	120	160-180	200-280	400-800	800-1,200
Tape Speed (for data)	meters/sec	6-8	8-10	10-12	12-15	12-15
Head tracking precision required	+/- μm	0.5	0.35	0.2	<0.1	<0.1
Key Requirements						
Heads	type	MR	MR	MR	MR/GMR	GMR/TMR
Number of data channels	Number	16-24	16-24	16-24	16-32	16-32
Detection channel	type	E PRML	E PRML	E PRML, LDPC	E PRML, LDPC TURBO- CODE	E PRML, LDPC TURBO- CODE
Magnetic film	type	dual-layer particle metal	multi-layer particle metal film	multi-layer particle metal film	multi-layer particle metal film	multi-layer particle metal film
Tape/media thickness	μm (micron)	6	5	4.5	<4	<4
media substrate material	type	PEN Aramid*/ adv. polymer	PEN Aramid*/ adv. polymer	PEN Aramid*/ adv. polymer	Aramid*/ adv. polymer	Aramid*/ adv. polymer



iNEMI Mass Data Storage



Optical

- Optical storage has evolved primarily into a data storage transfer technology
 - Software delivery
 - Digital AV
- Diverse set of technologies (CD, DVD, DVD-R, DVD-RW, Blu-ray, MO, Holographic, 2-photon etc.)
 - Standard Blu-ray growth may be hampered by direct download to HDD technology
 - May need to increase capacity & lower cost to meet challenge of Flash SSD

Mass Data Storage

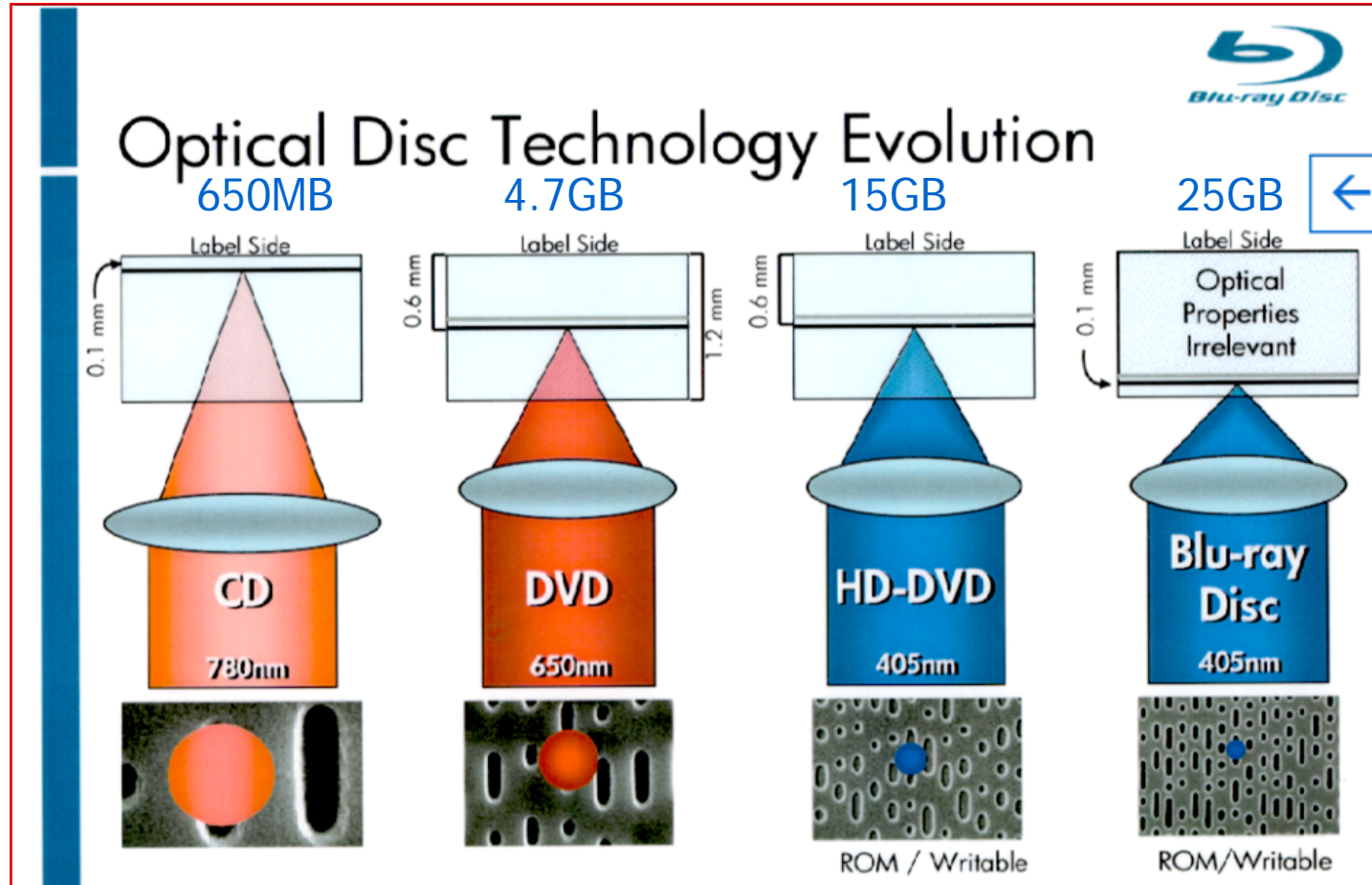
Optical Storage Market Segments

Market Segment	Description
Consumer Electronics (CE)	CD-DA, DVD-Video, DVD+/-R, DVD+/-RW, DVD-RAM, Mini-Disc,& BD/HD DVD.b
PC Workstation	All non-application specific CD/DVD storage and 3.5" MO (5.25" MO was sometimes used for archival storage in medical image processing workstations and similar applications, but the volume is very low).
Professional	UDO and Sony's Professional Disc for DATA (both are "blue laser" technologies); 3.5" MO is sometimes used by this segment, but penetration is relatively low. 5.25" MO no longer in production.
Data Center (Enterprise)	Legacy 5.25" MO, 12"/14" WORM, & Sony's Professional Disc for DATA. Only UDO has ongoing sales. Much greater emphasis on optical disc library (ODL) solutions & more rugged drives.



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Optical Storage



- Blu-ray disc won the HD optical format war

Mass Data Storage

Major Optical Storage Technologies

Technology	Description
CD/DVD	95% of Market; Mature Technology, SW/AV Dist., +-R/+RW, DVD-ROM < 10% pf DVD media repl.
Blue-Laser Disk (BD)	Video recording, PC/Workstation app's., RO, R(WO), RE(RW), Blu-ray is format winner, HD-DVD discon. in 2008
Ultra Density Optical (UDO)	Only optical disk format for enterprise app's. Conceived by Sony, currently Plasmon/ASTI 2 nd Gen. BD Tech. Announced 4/2010 BDXL – High capacity recordable/rewriteable 4 layers – 100-128 GB IH-BD (intra-Hybrid), 2-25 GB BD layers
Versatile Mini-Disc (VMD)	EVD (Enhanced Versatile Disc) – proposed in 2005 by New Media Enterprises – 5 GB capacity VMD= 8 layers = 40GB capacity for HDTV
Magneto-Optic	Sony Mini-Disc, 2.5" FF, 1GB capacity for Audio recorder, sold mostly in Japan.
Holography	In-Phase now out of business. Following was their goal: Target: 300GB disk \$150 @ 715 GB/in ² Drive ~\$1800. Reliable/Affordable over long term? Mfg. High capacity & throughput achievable?



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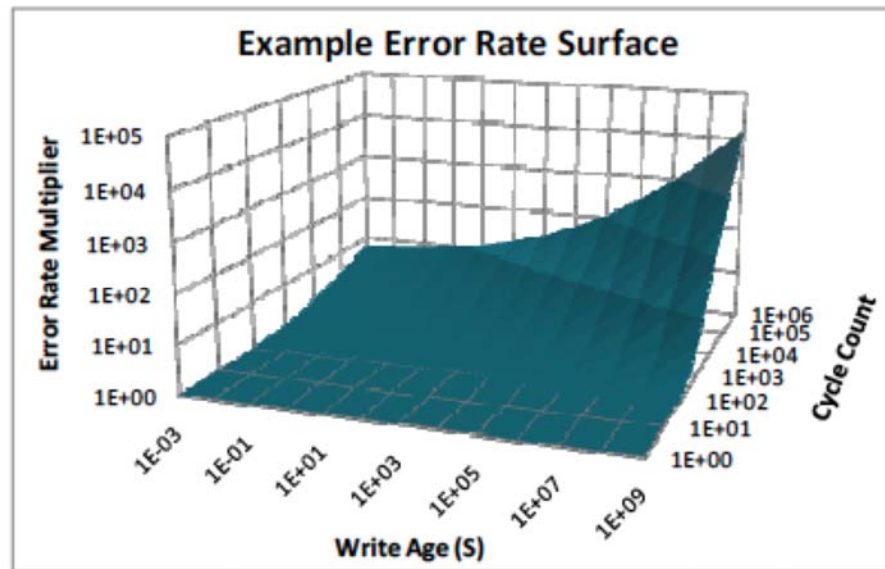
Storage Systems



Area	Situation
Enterprise	Shipped capacity to 53,000PB by 2013 (44% CAGR), Revenue flat @\$30Bn, migration from performance to capacity/cost optimization, HDD cost 10X<SSD Flash. 15% of HDD, < 5% of Flash revenues
Cloud	Impact of Cloud storage services yet to be seen. Communication line speed may be bottleneck. i.e. LTO-5 (1.5TB) would take 5 hrs @ 1Gb/sec. Lossless compression may help.
Consumer	Cost <u>the</u> key driver. Data compression widely used. SSD can provide rapid startup and performance, but costly. Backups use HDD, DVD, & CD.

iNEMI Mass Data Storage Storage Systems

- \$55B capital to replace all 2009 HDD enterprise capacity with NAND Flash
- Error rate behavior for NAND Flash more complicated than for HDD's
 - dependent on write cycle count & age of data:

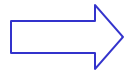


NAND Flash Raw Error Rate Behavior

Ref: S. R. Hetzler, "system Impacts of HDD and Flash Reliability", IDEMA hard Disk and Solid State Drive Reliability Symposium, May 2008

iNEMI Mass Data Storage

Average Electrical Power usage in Data Centers



Chillers	33%	
UPS	18%	
AC	9%	
Other (lights, surveillance, PDAs...)	10%	
Non-IT equipment total electricity	70%	
IT equipment averages 30% total IT electrical consumption		
Servers	35%	10.5%
Storage	30%	9.0%
Networks	23%	6.9%
Other	12%	3.6%



source: Horison, Inc.

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Solid State

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Thank you !

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