The Premier Advanced Recording Technology Forum

THIC Inc.

Coughlin Associates
Data Storage Consulting

Follow the Yellow Brick Road

Roadmaps for Digital Storage

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Presented at the THIC Meeting at the Sony Auditorium, 3300 Zanker Rd, San Jose CA 95134-1940

April 20,2005

Outline

- Storage Market Growth and Storage Hierarchy
- Disk Drive Technology Roadmap
- Magnetic Tape Technology Roadmap
- Optical Disk Technology Roadmap
- Flash Memory Technology Roadmap
- Other Technology
- Conclusions
- Sources

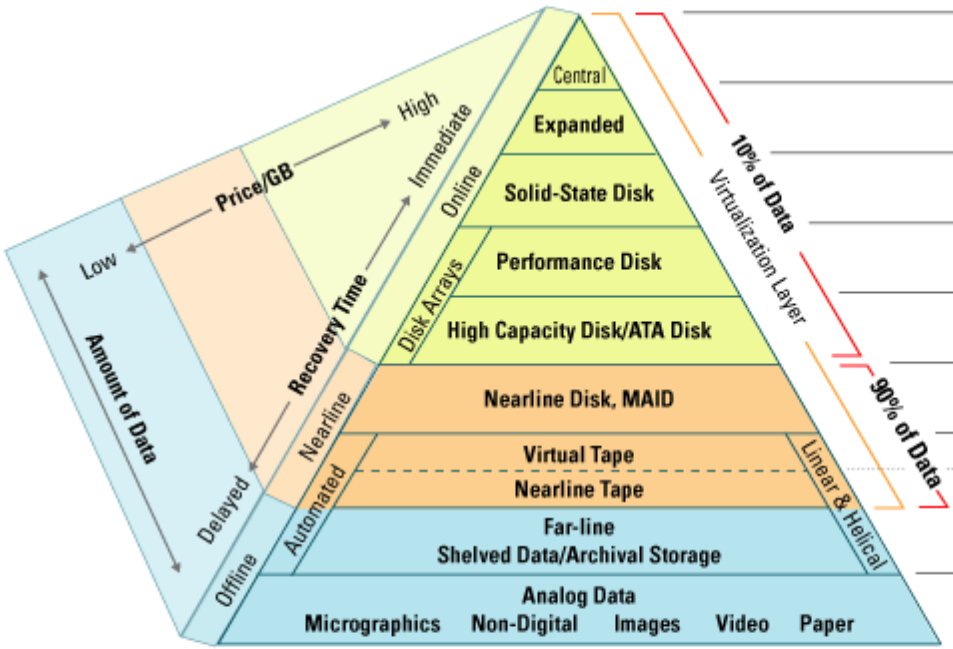
Market Segments

- High Performance Enterprise Storage Arrays
- Static Content Storage Arrays
- Blade Storage
- Desktop and Laptop Storage
- Consumer Electronics
  - Static
  - Mobile
  - Home Networking

Competition in the Storage Hierarchy

- Blade Systems
  - 2.5-inch HDD vs solid state drive for boot and scratch memory
  - Blade level boot vs. SAN boot
- Mobile Consumer Electronics
  - Trade-offs between using semiconductor flash mass storage vs. SFF HDDs
  - How will digital storage be integrated into consumer electronics?

The Storage Hierarchy



Positioning Parameters	Price/GB	Capacity Limit	Access Time/ Performance
Central	$100K–300K	256 GB	±200 GB/sec
Expanded	< $75K	nx32 GB	20–40 ns
Solid-State Disk	$5K–10K	50 GB	< 0.1 ms
Performance Disk	$40–70	GB–TB	4–10 ms
High Capacity Disk/ATA Disk	$30–40	GB–100 TB	10–25 ms
Nearline Disk, MAID	$2–20	TB–PB	< 250 ms
Virtual Tape	$2–10	TB–PB	5–10 sec
Nearline Tape	$.20–$4*	TB–PB	5–10 sec
Far-line Shelved Data/Archival Storage	< $.001*	TB–PB	min, hr, day
Analog Data	+$20	PB–EB	min, hr, day

* Based on recording technology

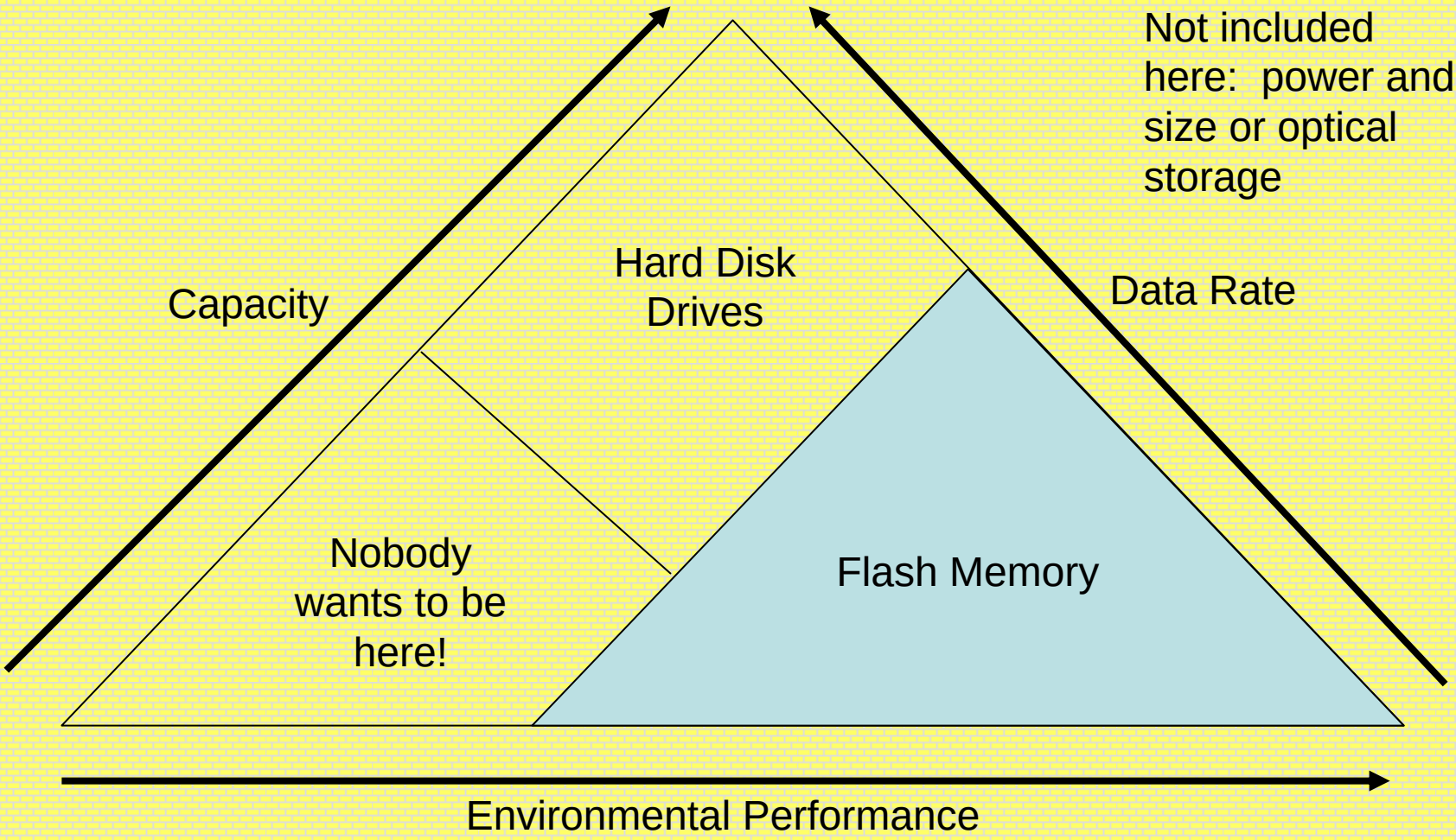
Source: Horison Information Strategies

HORISON Information Strategies

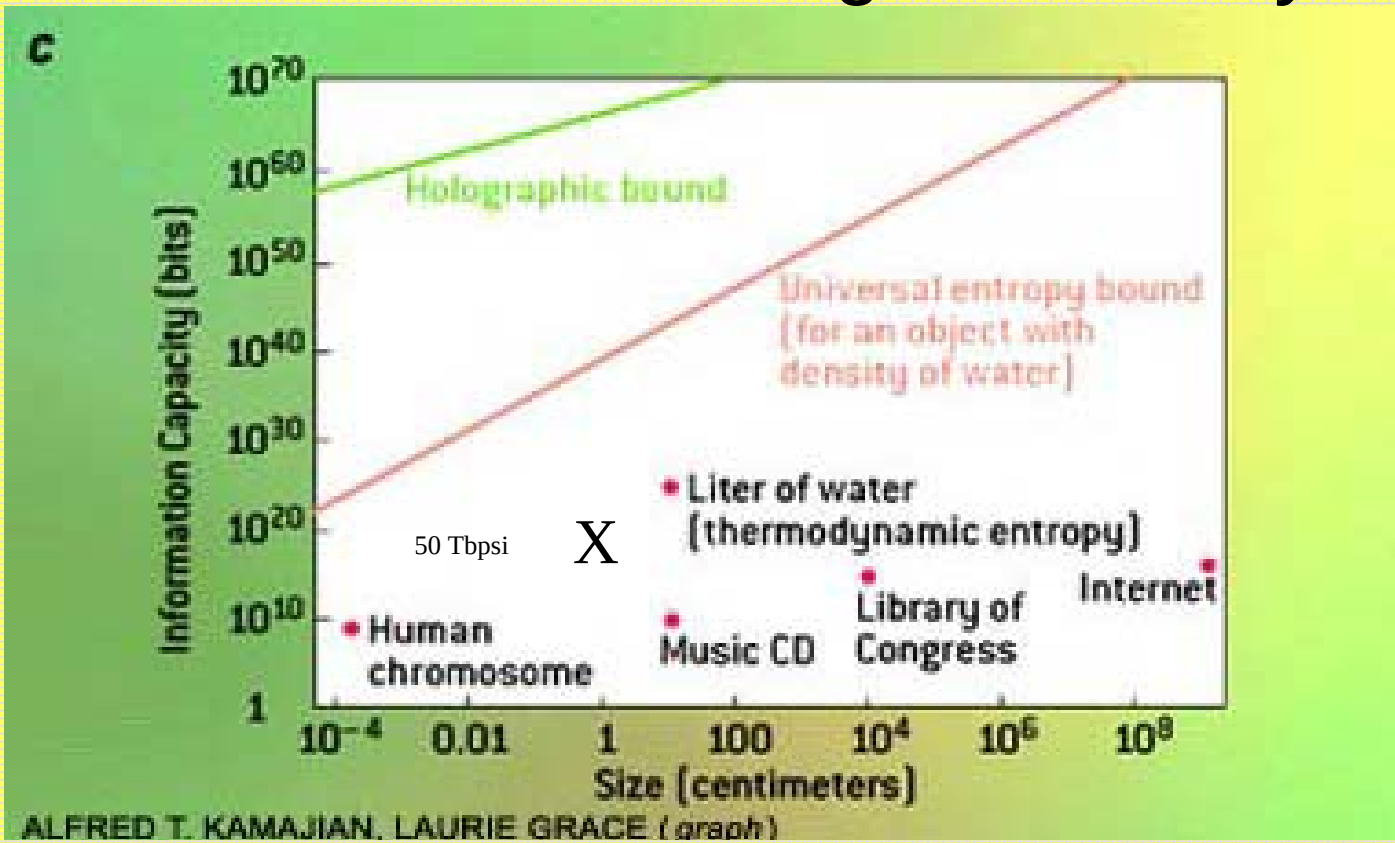
www.horison.com

Storage. New Game. New Rules

A Mobile Storage Hierarchy



The Universe Storage Hierarchy



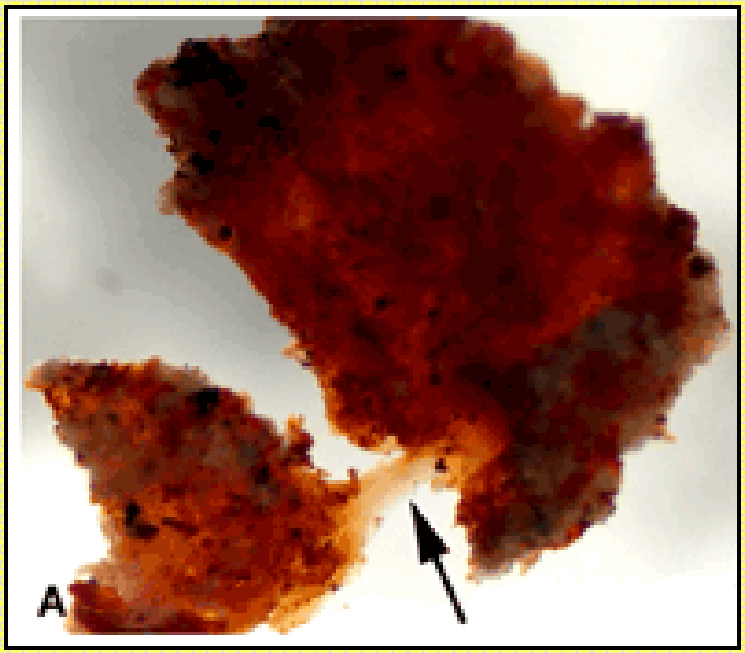
50 Tbpsi X

- Magnetic recording technology may allow up to 50 Tb/in^2 (50 X 10^{18} b/in^2)

Source: Information in the Holographic Universe, August 2003 Scientific American

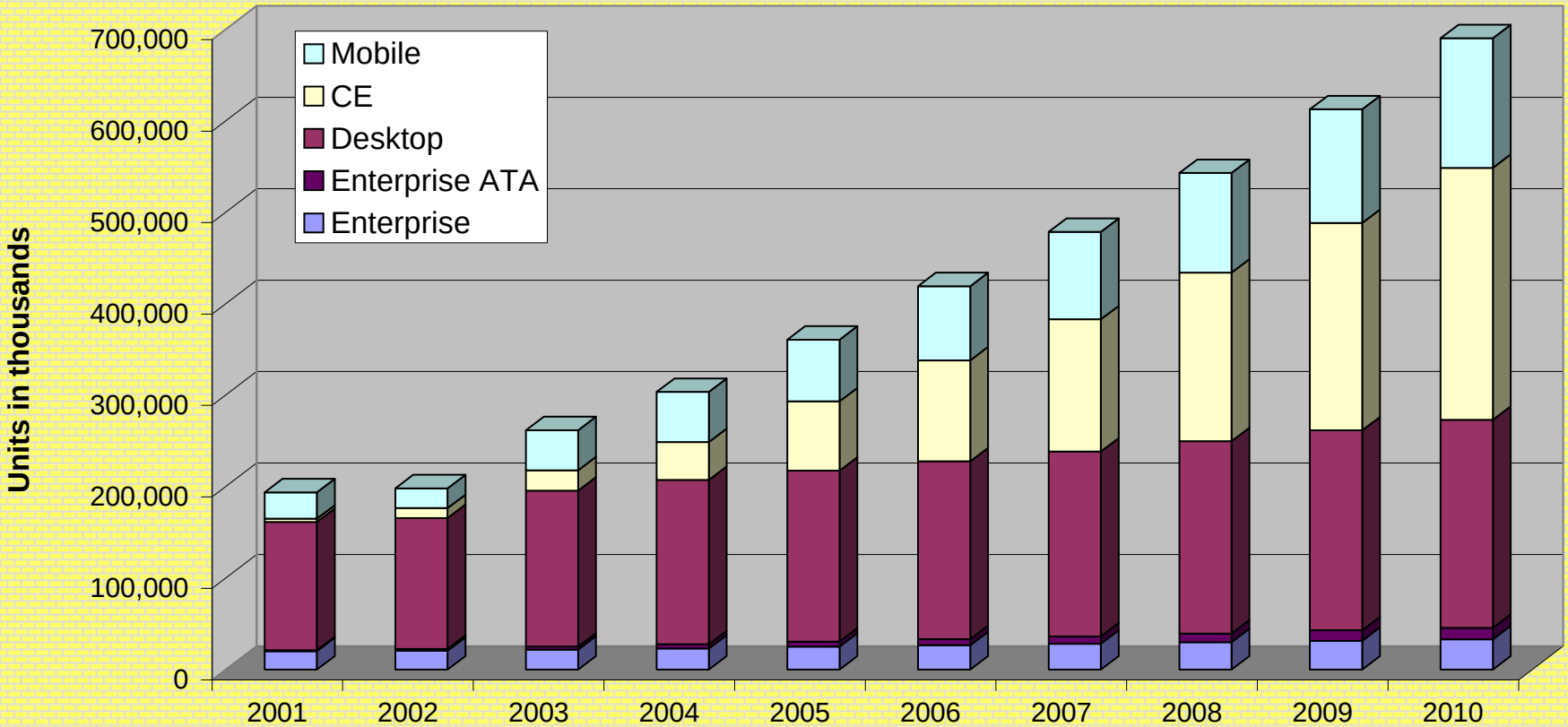
Natural Information Preservation

(70 M Year Old T. Rex Soft Tissue)

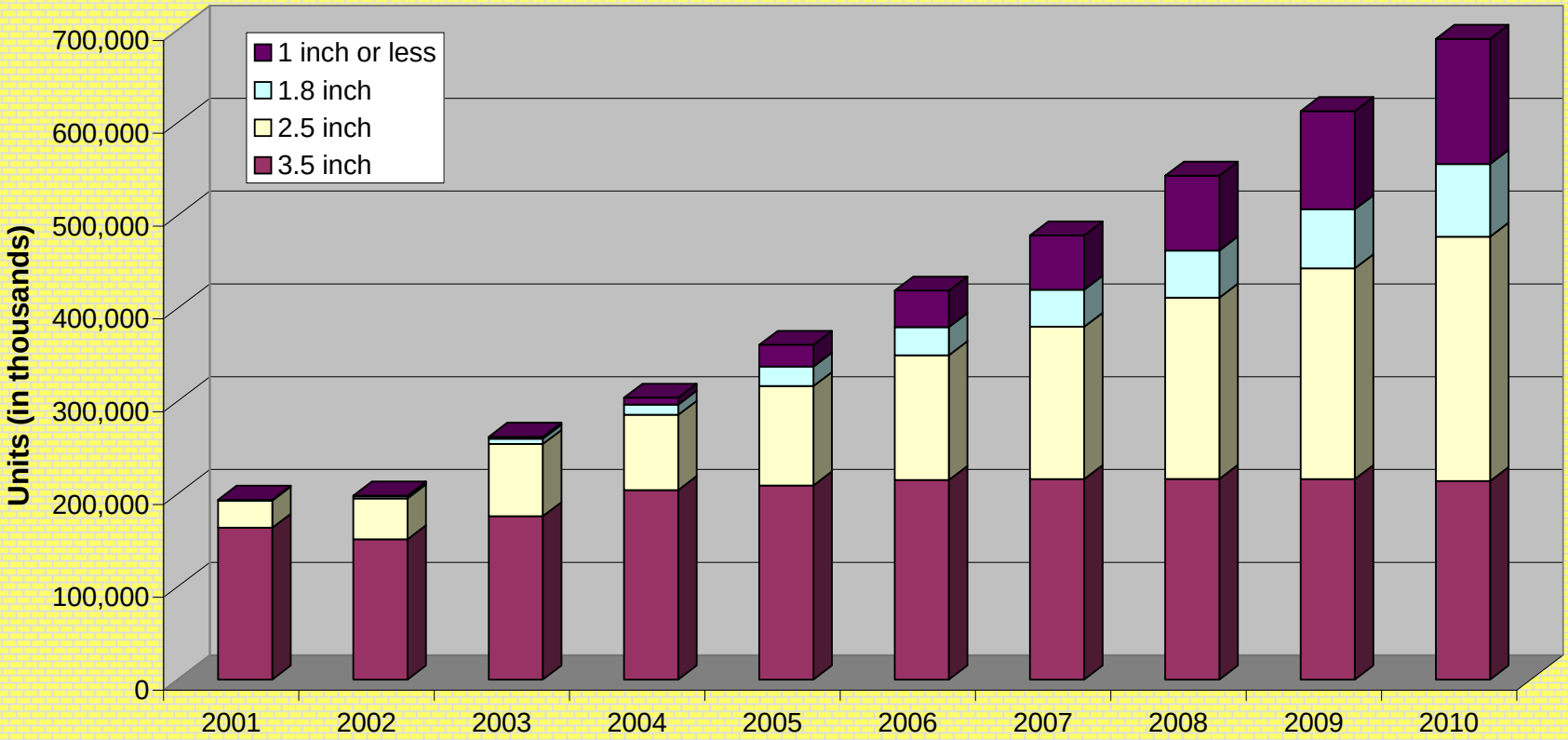


Dinosaurs Had White Meat!

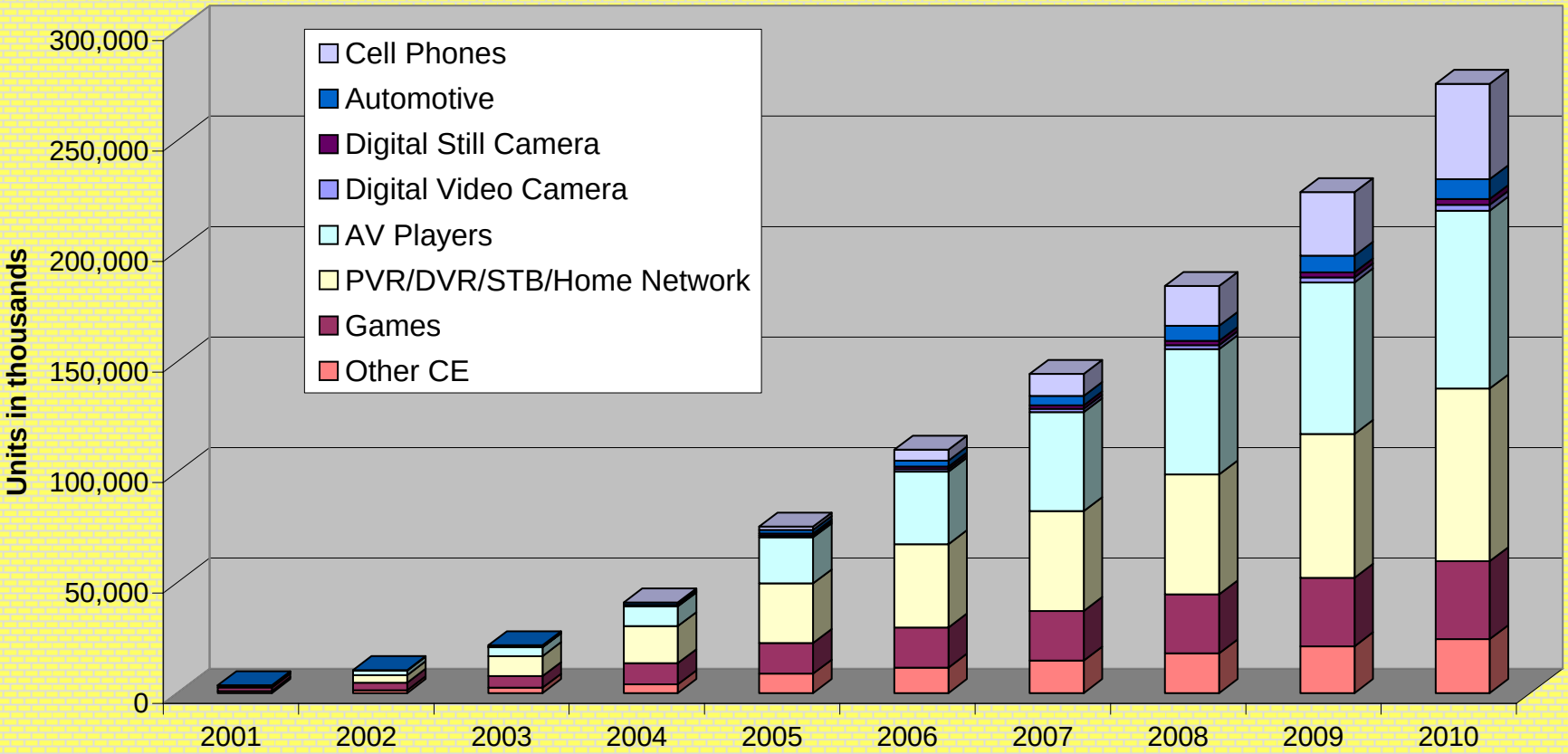
HDD Market Niche Projections



HDD Form Factor Projections

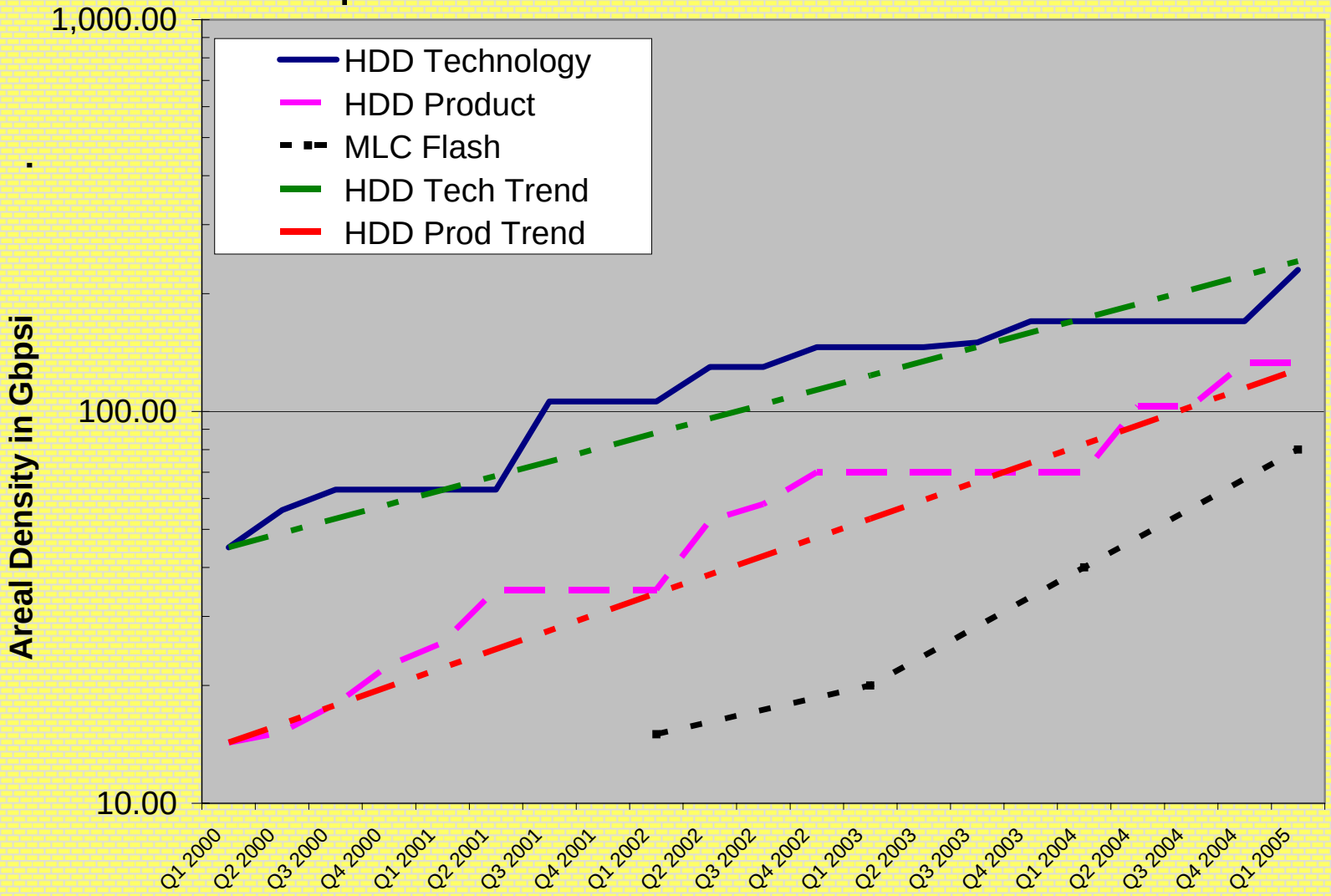


CE Drive Applications



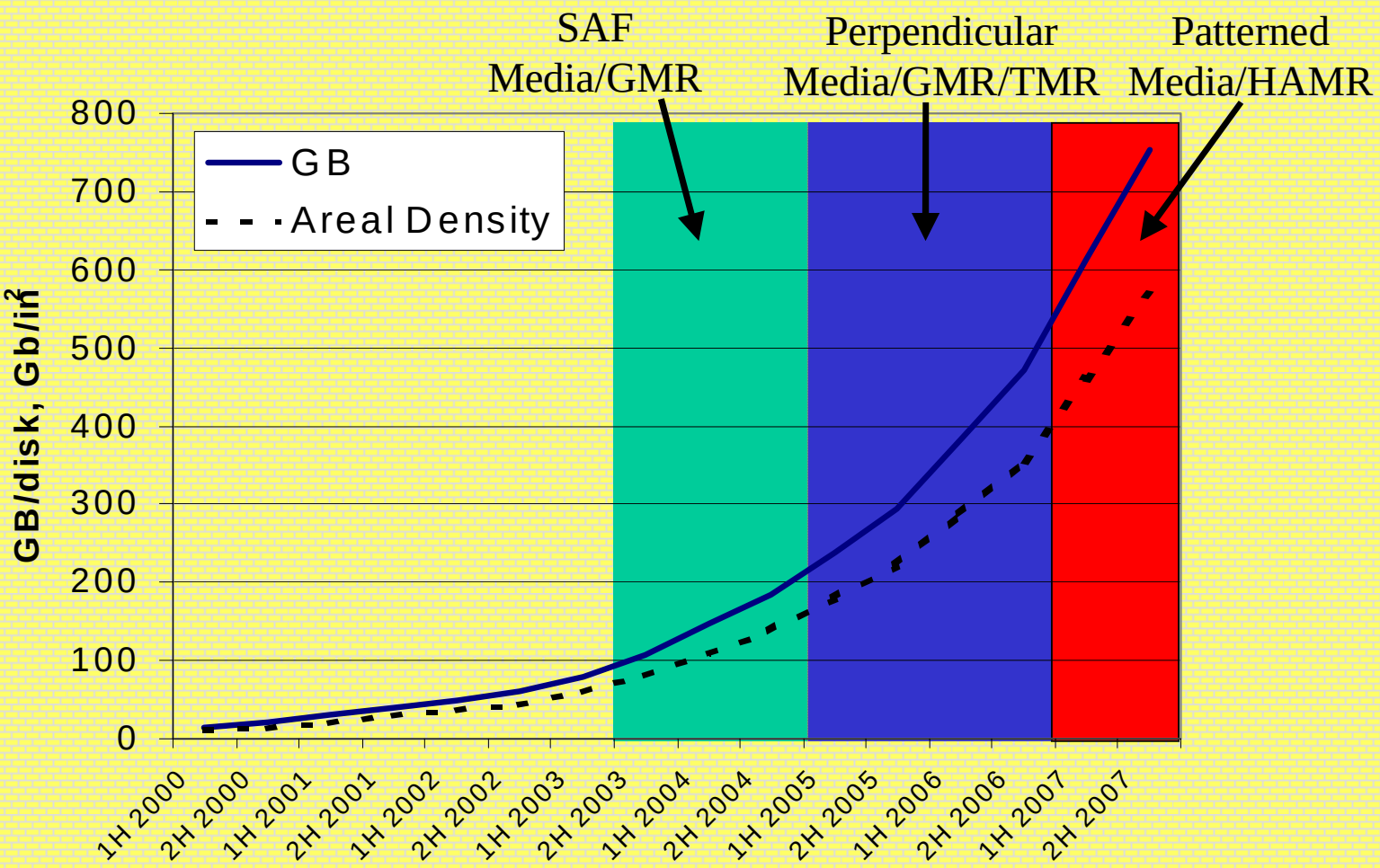
Disk Drive Technology Roadmap

HDD Quarter by Quarter Public Technology Demonstrations and Product Announcements Compared to Toshiba MLC Flash Numbers



Projected Areal Densities and Recording Technologies in Production Hard Disk Drives

(Source: Coughlin Associates)



Perpendicular Recording

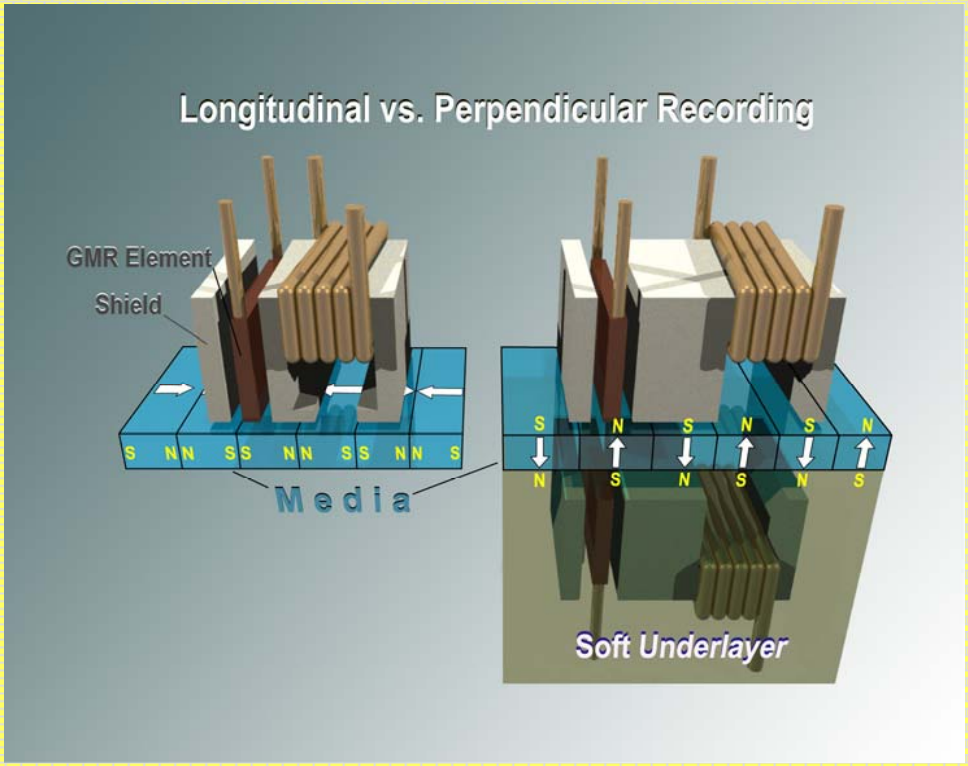
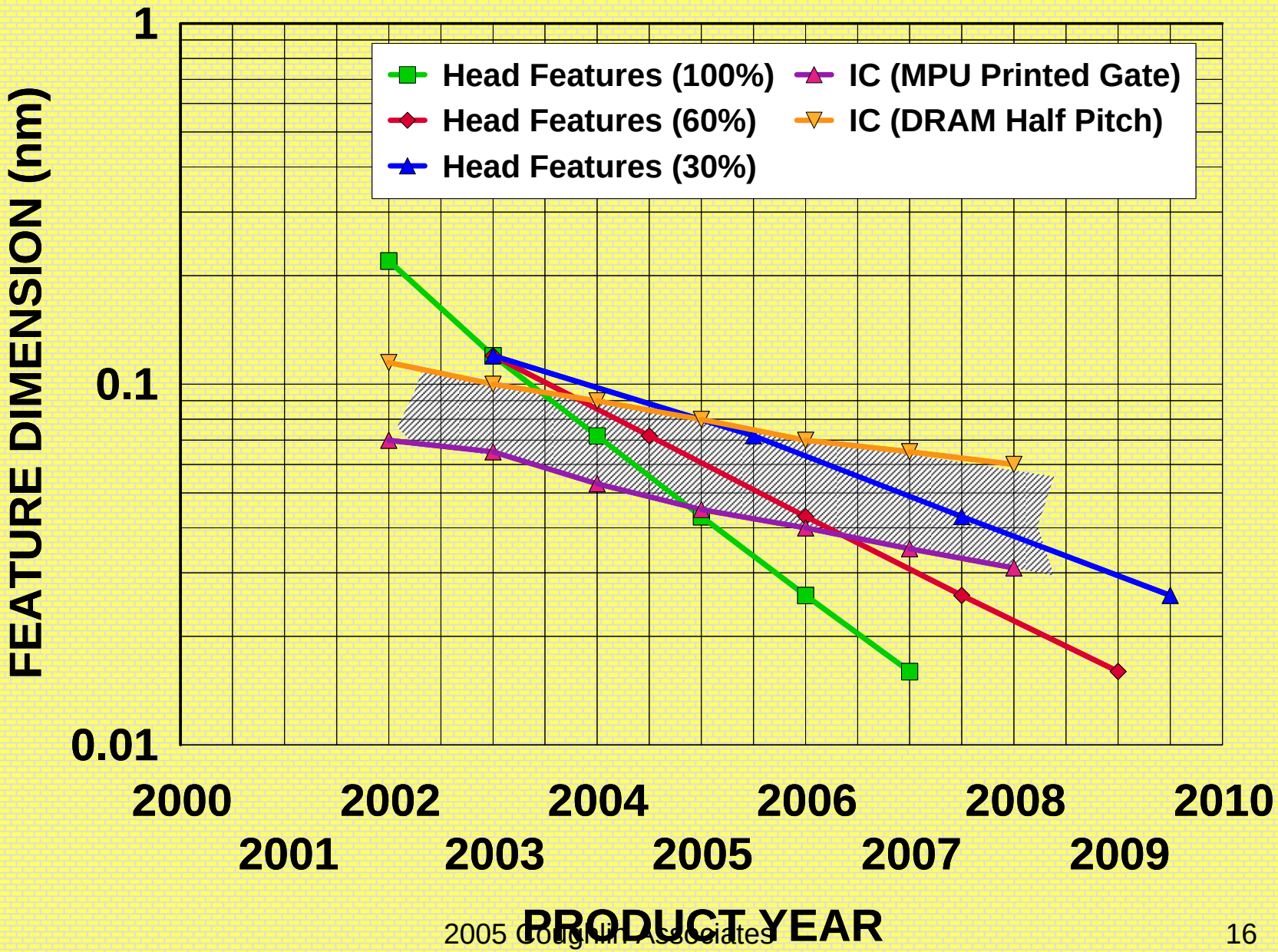
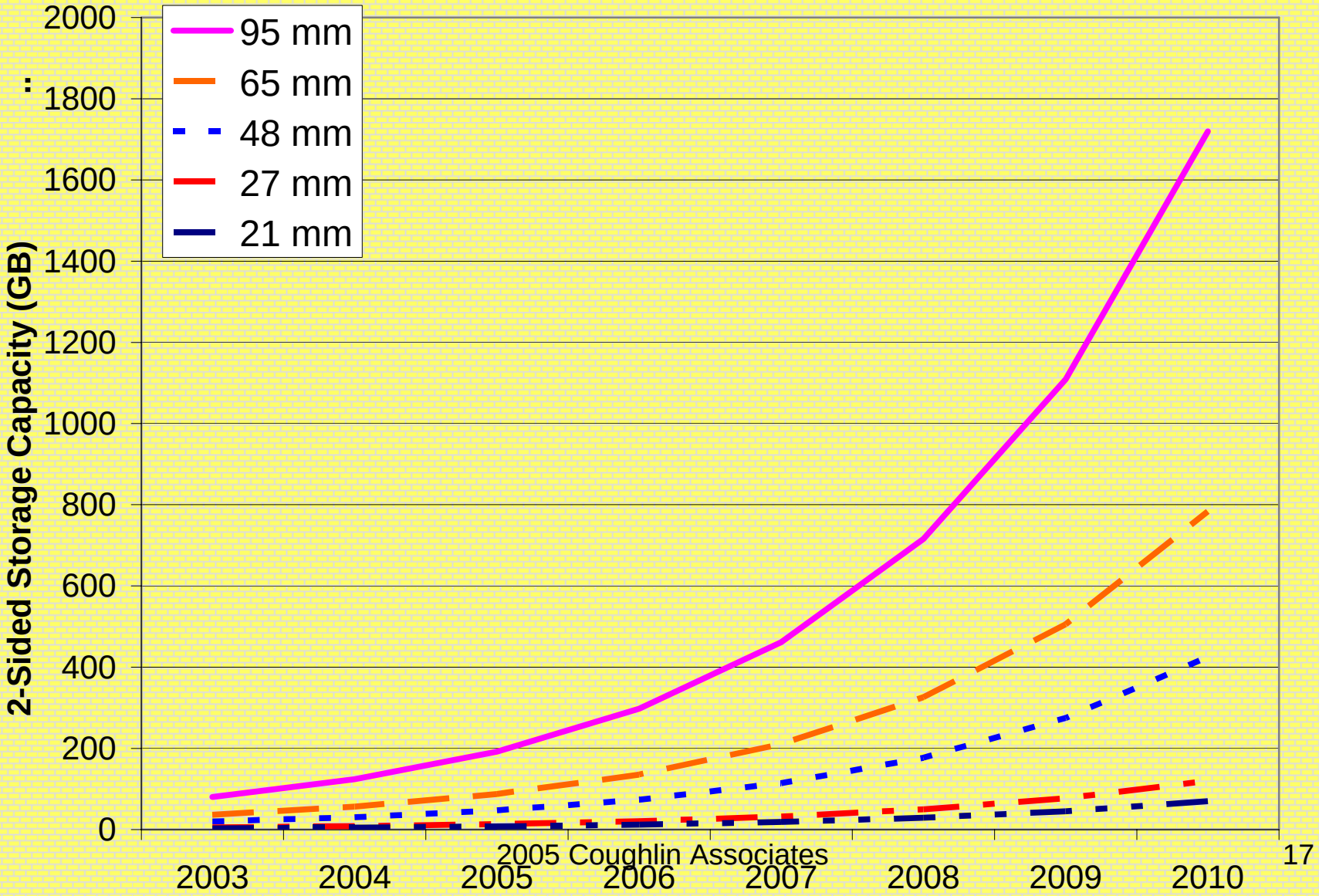


Illustration from Seagate

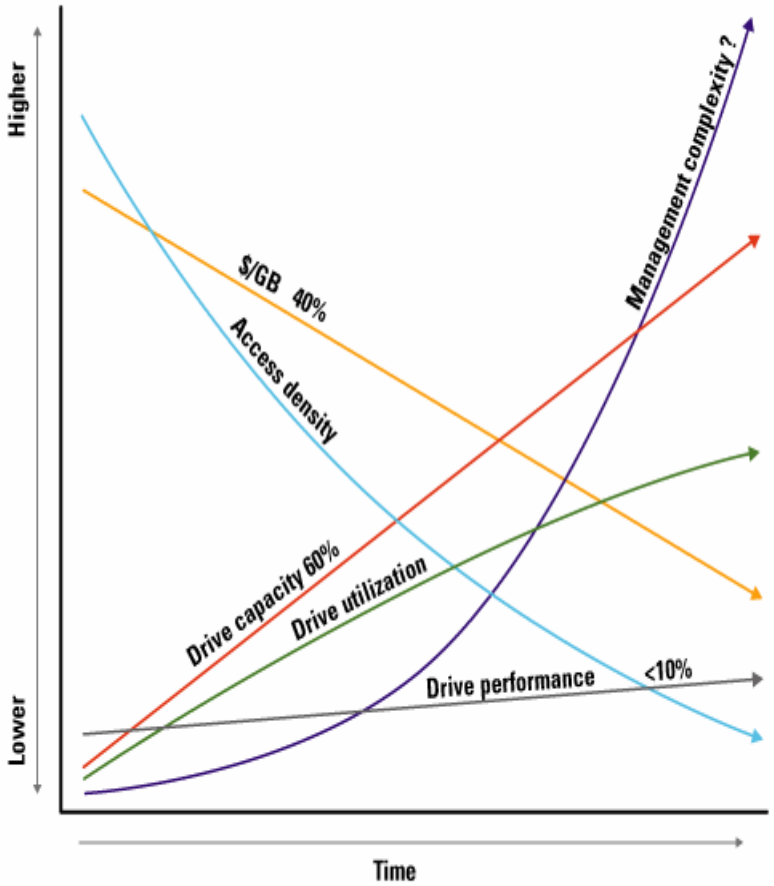
- Perpendicular Recording improves thermal stability of recording, thus increasing areal density
- Development of perpendicular recording systems could cause an increase in areal density growth similar to that with the introduction of the MR head in the early 1990s
- We could find areal density growth in the next few years again exceeding 60% annually
- Not all companies will convert to perpendicular recording at once, still life left in longitudinal recording


Head Features (100%)
Head Features (60%)
Head Features (30%)
IC (MPU Printed Gate)
IC (DRAM Half Pitch)
FEATURE DIMENSION (nm)
1
0.1
0.01
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
PRODUCT YEAR

Projected Capacity vs. Form Factor



Disk Dynamics



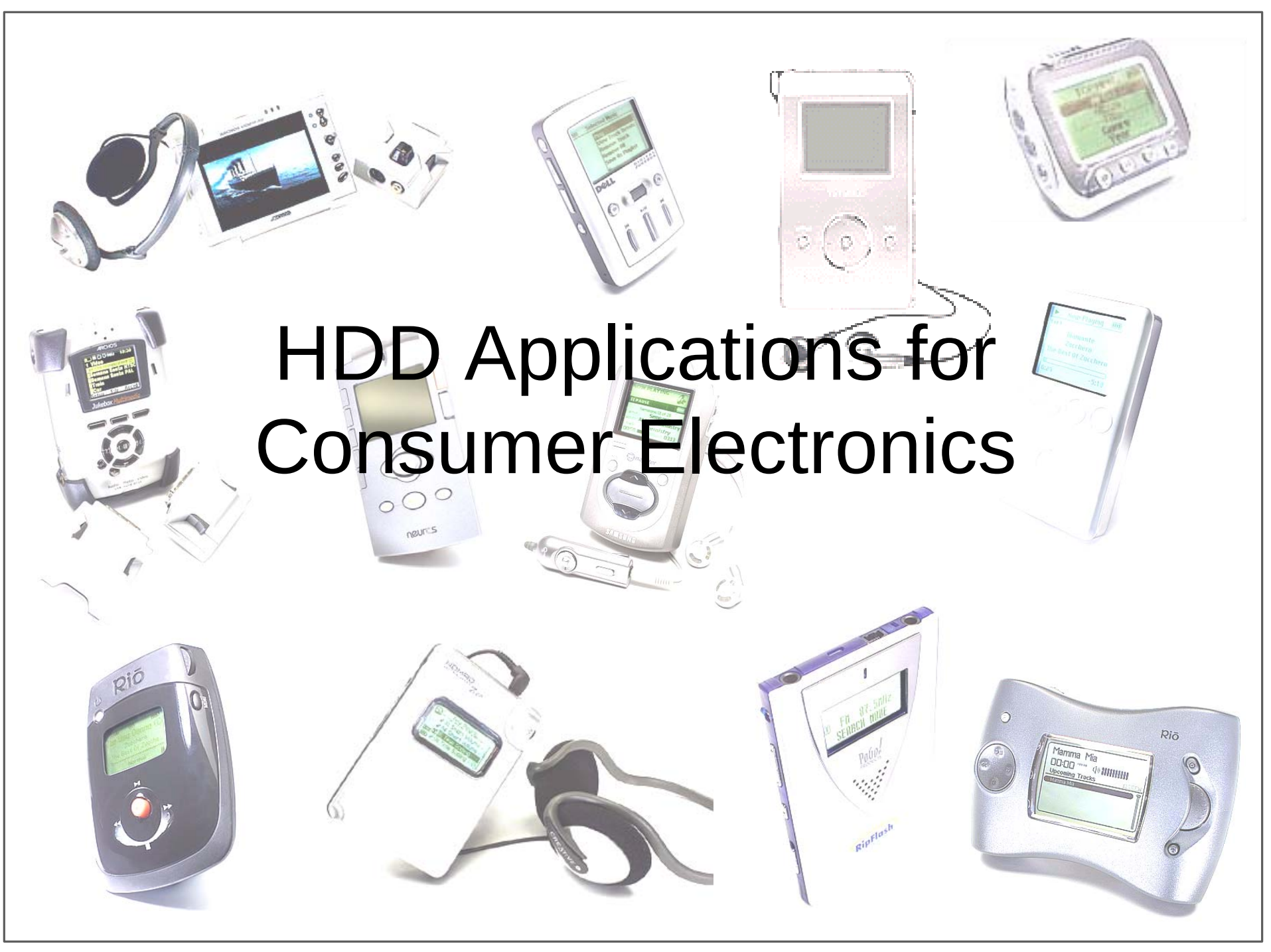
- Many dynamics at work in disk drive industry
- Drive capacity doesn't scale with drive performance
- Access density declines
- Utilization levels decline to maintain drive performance
- Management complexity increases due to files, blocks and too many tools

Source: Horison Information Strategies

HORISON Information Strategies

www.horison.com

Storage. New Game. New Rules


HDD Applications for
Consumer Electronics
DELL
Rio
RipFlash
Mamma Mia
Upcoming Tracks

Hitachi New Drives

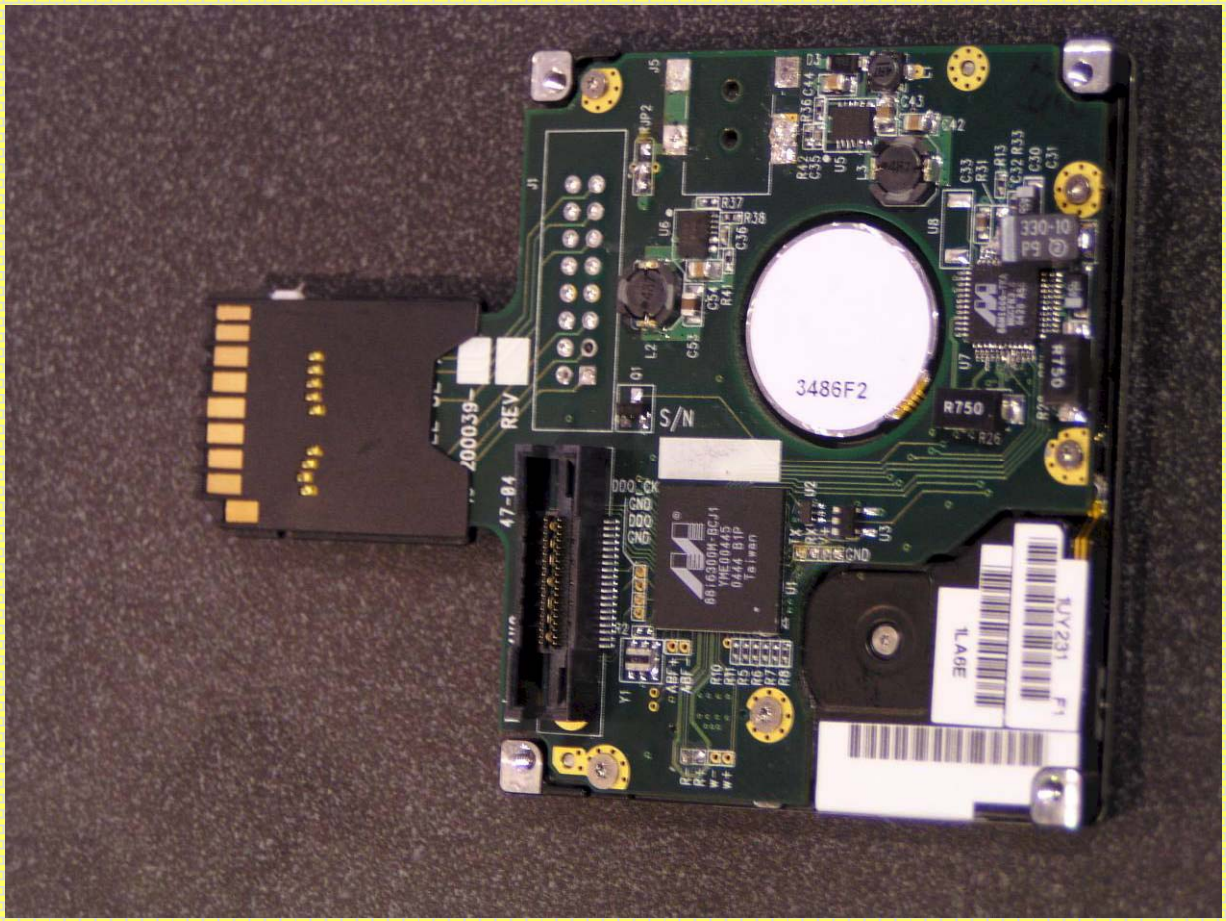
MIKEY

- **Smallest Microdrive**
- **Available in 2nd half 2005**
- **Embedded version only**
  - **PATA, CE-ATA, MMC-like**
- **8 – 10GB capacity**
- **Targeting small handheld products, including multimedia phones**

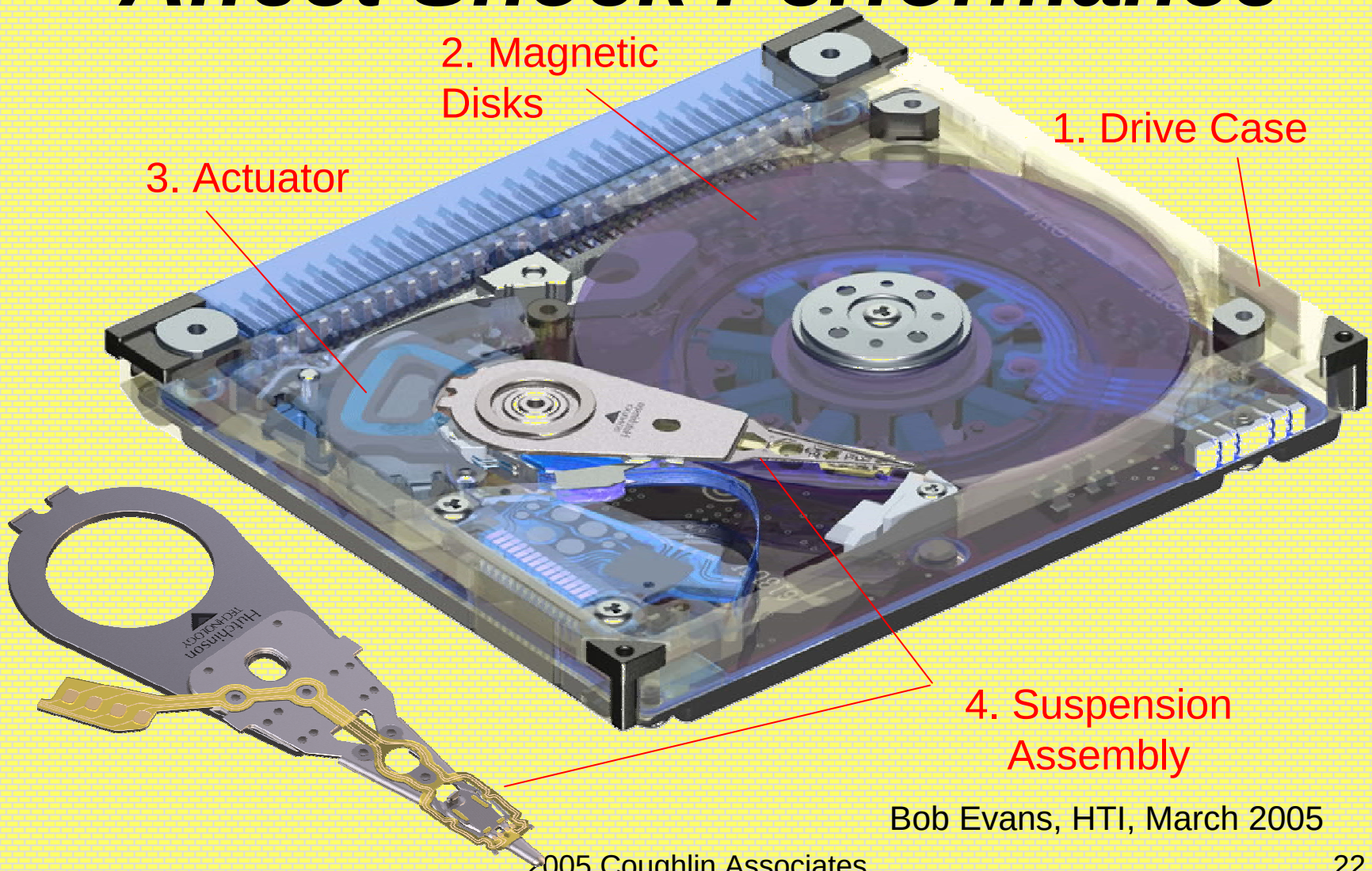
SLIM

- **Smallest 1.8” hard drive**
- **Single disk and 2-disk versions**
- **60 – 80GB capacity**
- **Available in 2nd half 2005**
- **Embedded version**
  - **PATA, CE-ATA (future)**
- **Targeting handheld audio and video products**

CE-ATA Prototype in Marvell Booth at 2005 CES



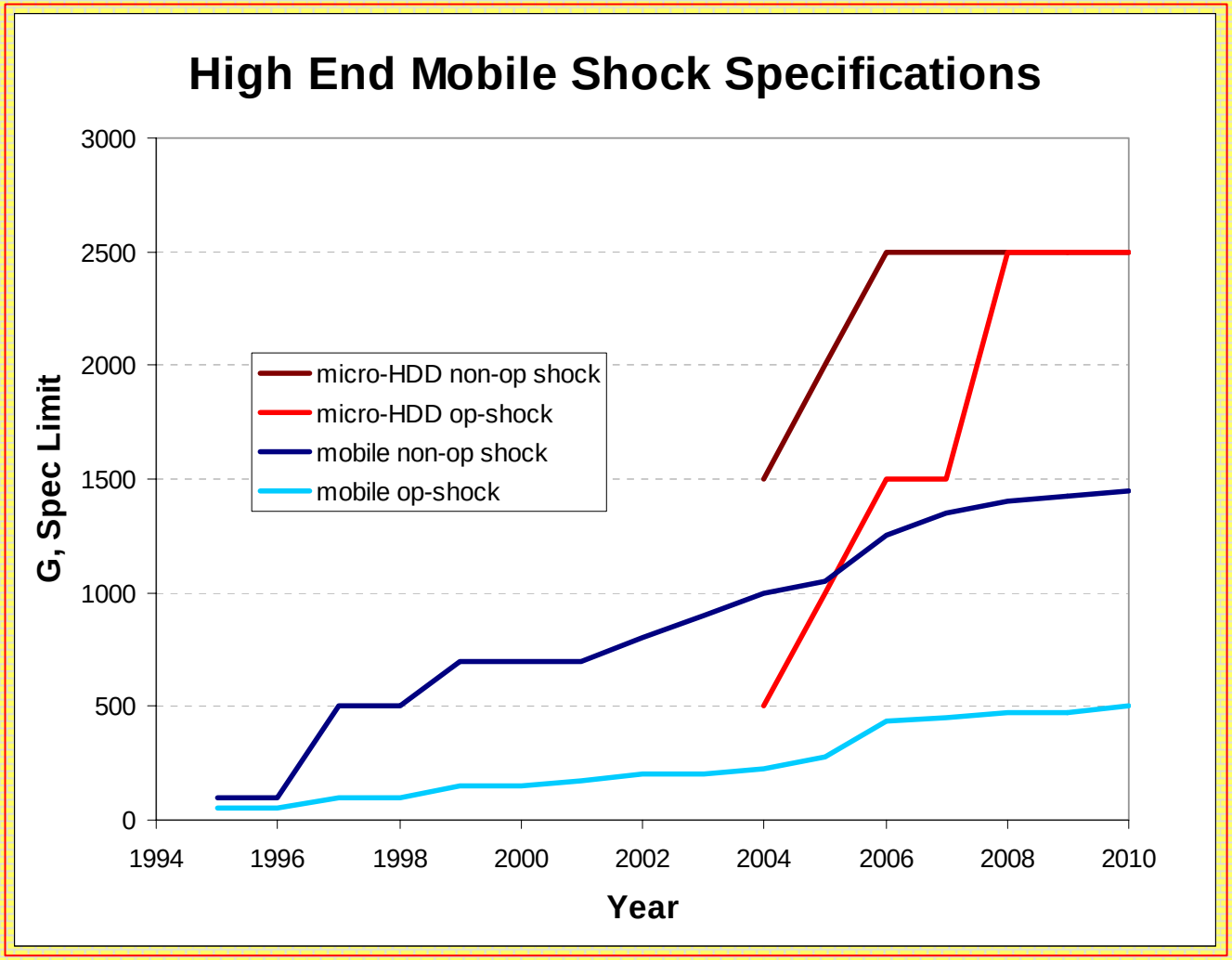
Four Major Drive Components Affect Shock Performance



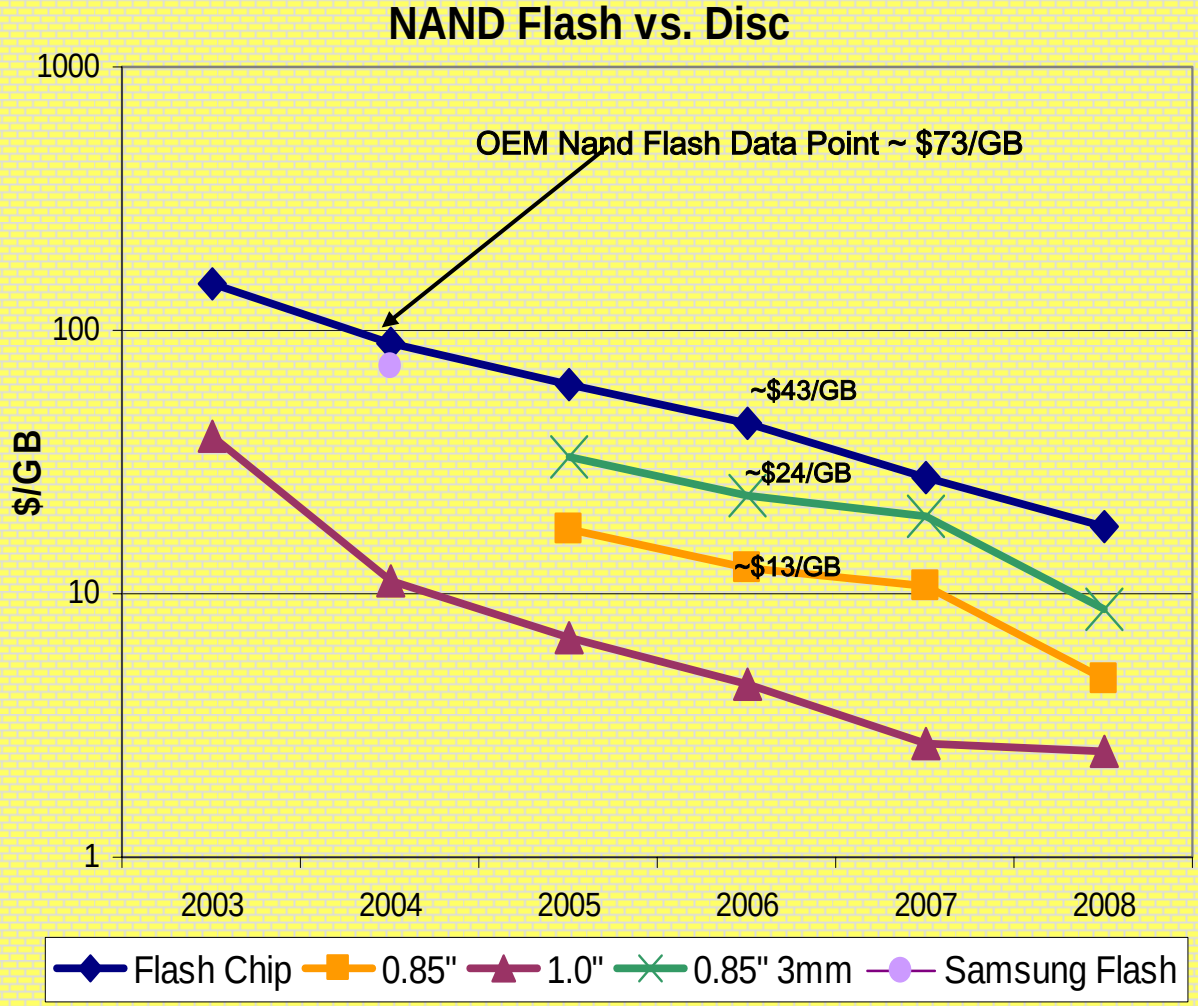
Bob Evans, HTI, March 2005

Bob Evans, HTI, March 2005

History of Shock Requirements



$/GB Advantage of HDDs Less for Smaller Drives



Market Risks

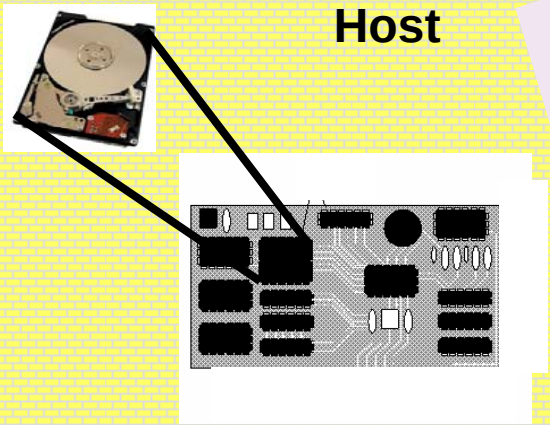
- Nand flash pricing reductions to combat HDD entrance
- 3.3 mm high risk due to $/GB compared to flash
  - Need cell phone real estate to allow 5mm HDD solutions

Source: Seagate, 2005 Storage Visions Conference

Two Extreme Poles of CE Disk Drive Integration

--Driven by Cost--

Total Integration into the Host



Disk Drive Becomes A Chip

Total Integration onto the Drive

Disk Drive Companies Become Contract Manufacturers for Host Companies

Magnetic Mass Data Storage Technology Roadmap — HDD

	Unit	2003	2005	2007	2009	2015
Industry Metrics						
Form Factor (dominant form factor is bold)	inches	**3.5**, 2.5, 1.8,1.0	**3.5**, 2.5, 1.8, ≤1.0	3.5, **2.5**, 1.8, ≤1.0	3.5, **2.5**, 1.8, ≤1.0	**2.5**, 1.8, ≤1.0
Capacity	GB	2-320	2-1200	4-1400	10-1600	20-4600
Market Size	units (M)	226	280	310	350	500
Cost/MB (avg.)	$/MB	0.01	<0.003	<.002	<0.002	<0.001
Design/Performance						
Areal Density	Gb/in^2	70	>100	>200	>400	≥1000
Rotational Latency	ms	2-6	2-12	2-12	2-12	2-12
Seek Time*	ms	3-5	3-5	3-5	2-5	2-5
RPM		4.3-15k	4.3-20k	3.6-20k	3.6-20k+	3.6-20k+
Data rate	MB/sec	80-100	10-150	10-250	10-400	>400
Power	watts	2–12	2–12	2-10	1-10	0.5-8
Reliability	Spec.	MTTF/AFR	MTTF/AFR	New Spec	New Spec	New Spec
Key Component Requirements						
Read Head	type	GMR	GMR	GMR/ TMR	GMR/ TMR	GMR/ TMR
Slider	type & size (% of 5.52 mm^2)	20%	20%	20%	20%	10%
Clearance	nm	10	<10	<10	<10	<10
Disk	type	AlMag, Glass	AlMag, Glass	AlMag, Glass	AlMag, Glass	AlMag, Glass
Disk Static Coercivity	Oe	5000	7000	8000	9000	10000
Magnetic Recording Technology		Longitudinal	Longitudinal/Perpendicular	Perpendicular	Perpendicular, HAMR	Perpendicular, HAMR, Patterned Media
Electronics/Channel	type	Noise Predictive GPR	Noise Predictive GPR	Noise Predictive GPR	Iterative GPR (Turbo)	Soft ECC
Channel Bandwidth	MHz	480	500-1200	80-2000	80-3200	>3200
SNR	dB	20	<20	<20	<20	<20
Actuator	type	Conventional	Conventional	dual/micro	dual/micro	dual/micro
Spindle	type	Ball bearing/Fluid	Ball bearing/Fluid	Ball bearing/Fluid	Fluid	Fluid

*Seek time is one third full stroke seek time that does not include improvements due to caching

Magnetic Tape Technology Roadmap

SAIT

S-DLT

LTO

Half-Inch Tape Cartridges

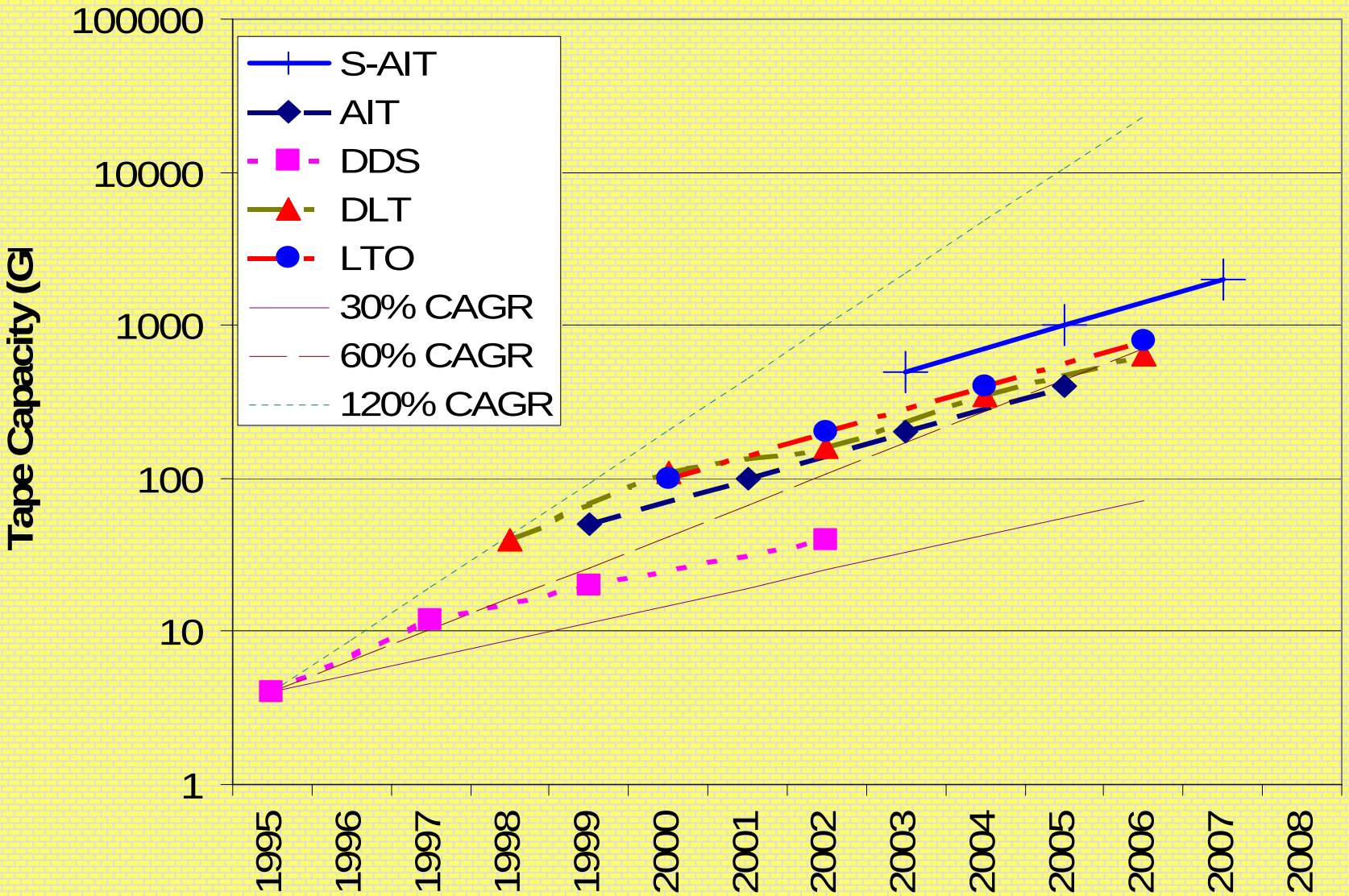
Tape with Tape Drive

- Tape for many, is still digital archive media of choice
- Tape data access is on the order of minutes vs. milliseconds or seconds for disk
- Tape media costs have been somewhat underwritten by VCR tape production, implications for future of tape costs
- ½ inch tape capacities of up to 10 TB projected

Tape-based Digital Content Storage System

Sony Petasite Tape Library

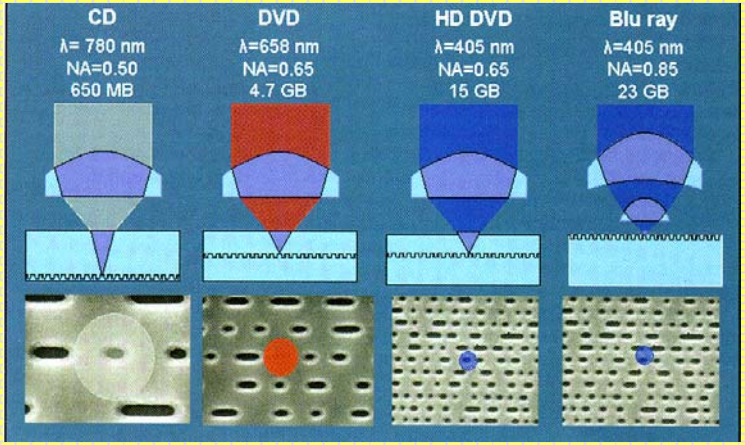
Active tape format CAGRs are about 40%. Disk Drive CAGRs are expected to be ~60%

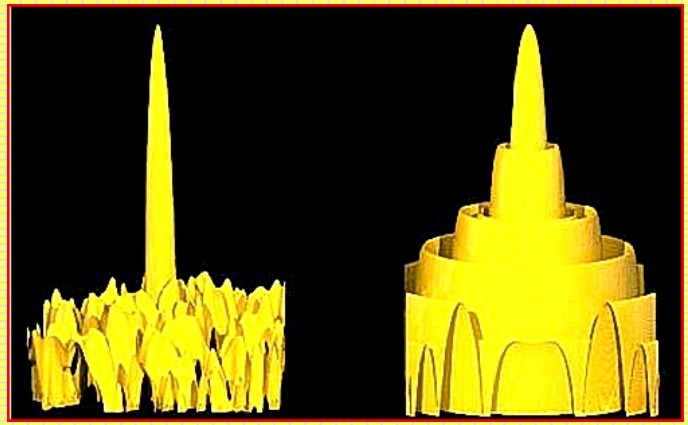


Magnetic Mass Data Storage Technology Roadmap — Tape

	Unit	2003	2005	2007	2009	2015
orm Factor	inch	5.25,3.5	5.25,3.5	5.25,3.5	5.25, 3.5	5.25,3.5
ongitudinal Tape						
olumetric Density	GB/in^3	5.5	22	100-200	200-400	500-1000
Cartridge capacity (native)	GB/TB	200 GB	300-500 GB	1-2 TB	1,75-4 TB	4-10 TB
Areal Density	Gb/in^2	.12	.70	2-3	3.5-5.25	8-12
Data Rate	MB/s/drive	5-30	30-100	100-200	100-400	400-800
Tape Speed (for data)	meters/sec	2-8	4-11	4-25	5 -30	8-50
Head tracking precision required	+/- μm	1	.5	~.1	.1	<.1
ey Requirements						
Heads	type	MR	MR/GMR	GMR	GMR	GMR
Number of data channels	Number	4-16	4-24	4-32	4-40	4-64
Detection channel	type	EPRML	E^2 PRML	E^2 PRML	E^2 PRML, TURBO-CODE	E^2 PRML, TURBO-CODE
Magnetic film	type	dual layer metal particle	dual-layer metal particle metal film	multi-layer metal particle metal film	multi-layer metal particle metal film	multi-layer metal particle metal film
Tape/media thickness	μm (micron)	9	6	<=6	<6	<4
media substrate material	type	PEN	PEN Aramid*/ adv. polymer	PEN Aramid*/ adv. polymer	PEN Aramid*/ adv. polymer	Aramid*/ adv. polymer
elical Tape						
Areal Density	Gb/in^2	.69	4-6	8-12	10-15	15-20
Data Rate	MB/s/drive	6-12	12-50	100-200	100-400	400-800
Cartridge Capacity (native) Note: the high range in last three columns is due to introduction of single-reel ½" cartridge.	GB/TB	50+ GB	200-400 GB	1-4 TB	2-8	8-14 TB
Head-Tape speed	meters/sec	17-34	22-36	35-42	35-46	40-54
Head tracking precision required	+/- μm	0.49	0.33	0.08	0.07	0.05
ey Requirements						
Tape thickness	μm	6	4	2.0	<2.0	<2.0
Media Substrate Material	Type/Pet*	PEN/PA*	PA *	PA or better	PA or better	PA or better

*polyethylene ethyl teraphalate/ polyethylene ethyl napthalate/polyamid (aramid)



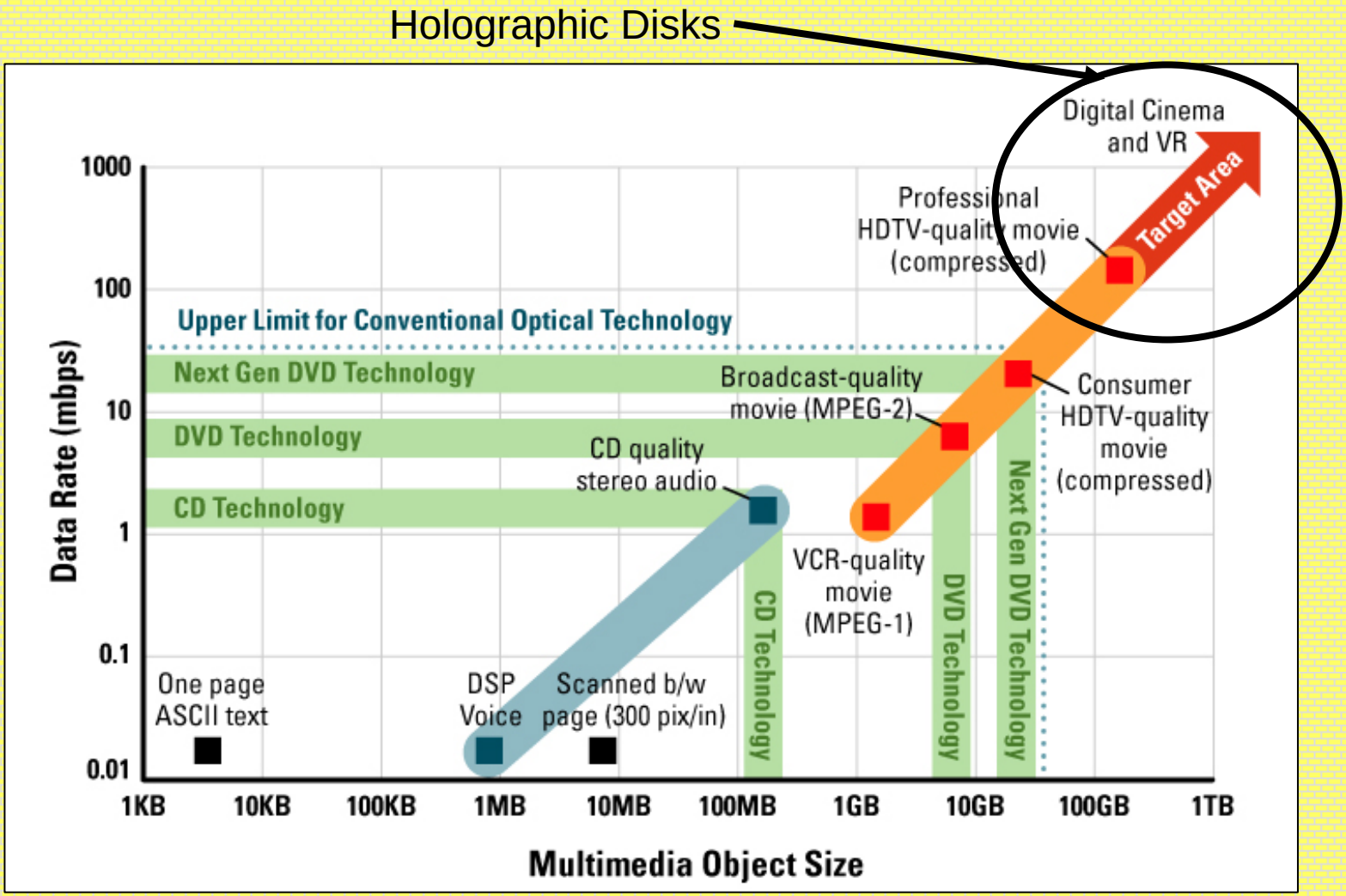


Optical Disk Technology Roadmap

Blue Ray Optical Disks and Drive

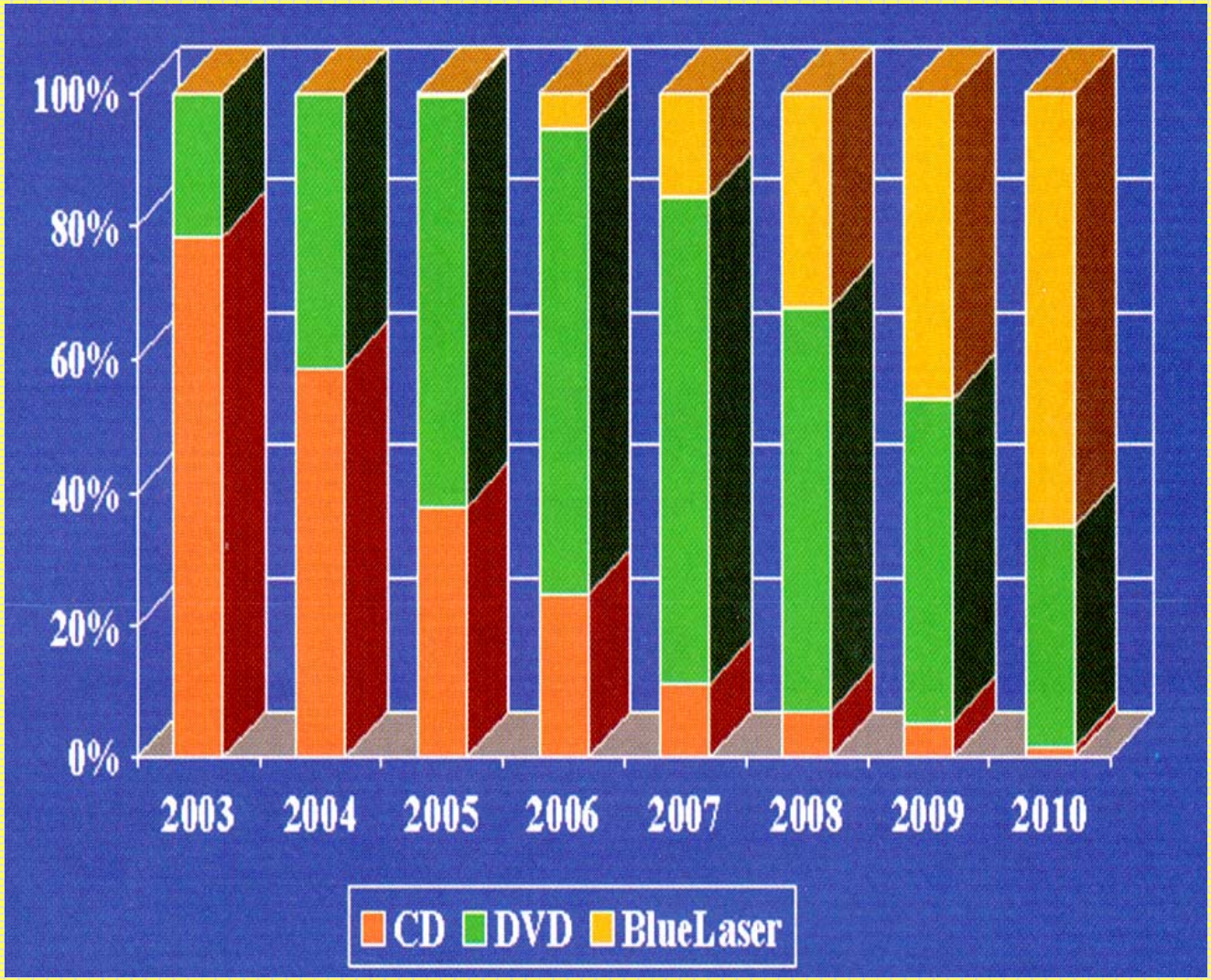
By end of 2005 Blu Ray and HD-DVD Disks will be available with capacities up to 50 GB!

Optical Content Distribution Trends



Source: Telcordia 3/03

Percent Shipments of CD, DVD, and Blue Laser Hardware Units, Period 2003-2010



(Source: *Strategic Marketing Decisions in Mediaware,* May/June 2004, p.36

First-Generation Blue Disk Optical Storage Products

	Toshiba/NEC	Matsushita	Sony	Plasmon
name	HD DVD	BD Recorder	Prof. Disc for DATA	UDO
market segments	1	1	2,3,4	2,3,4
1-layer capacity (GB)	15 (RO)/20 (RW)	25	23.3	15 (each disc side)
2-layer capacity (GB)	30 (RO)/32 (RW)	50	NA	NA
media types	RO/RW	RO (TBD) RW	WO/RW	WO/RW
rewritable media type	phase change	phase change (10,000 cycles)	phase change (10,000 cycles)	phase change (10,000 cycles)
data rate (MB/s)	8.5	8.5	9 write 11 read	2-4 write (with verification) 4-8
seek time (ms)	?	?	110 (CAV) 280 (CLV)	25
file format	micro-UDF	BD proprietary	BD proprietary	per ECMA 350
disc diameter (mm)	120	120	120	130
thickness (mm)	0.6 x 2	1.2	1.2	1.2 x 2
wavelength (nm)	405	405	405	405
NA	0.65	0.85	0.85	0.70
modulation code	ETM	(1,7)PP	(1,7)PP	(1,7)RLL
read channel	PRML	PRML	PRML	PRML
track pitch (nm)	40	320	320	370/400
track density (tpi)	63,500	79,375	79,375	68,649 (max)
min. mark length (nm)	204	149	160	314
recording density (bpi)	182,677	226,772	211,653	107,795
areal density (Gb/in^2)	11.6	18	16.8	7.4
first shipment	(2005)	July 2004	November 2003	October 2003
drive price (US$)	TBD	2,800	2,995 (int) 3,299 (ext)	3000
media price (US$)	TBD	35 (25 GB RW) 70 (50 GB RW)	45	60 (30 GB WO) 75 (30 GB RW)
ODL	No	No	Sony 19" rack mount	Plasmon G-Series
3rd party software	TBD	TBD	Yes	Yes

Near-Term Roadmap, Optical Disk Storage Products — 2005-2009

Product Name	Form Factor	Disc Type/ Diameter (mm)	Capacity (GB)	Write/Read Options	First Shipments	Market Segments
AOD/ HD DVD	5.25" HH	replicated & phase change/ 120mm	15/20	RO/RW	2005	1,2
AOD/ HD DVD (dual layer)	5.25" HH	replicated & phase change/ 120mm	30/32	RO/RW	2007	1,2
Blu-ray Disc (BD)	5.25" HH	replicated, dye layer & phase change/ 120mm	23/25/27	RO/WO/RW	2004-05	1,2
Blu-ray Disc (dual layer)	5.25" HH	replicated, dye layer & phase change/ 120mm	25/50	RO/WO/RW	2004-05	1,2
DataPlay Blue	SFFD	replicated & phase change/ 32mm	3	RO/WO	2006	1,2
Digital MultiDisc (DMD)	5.25" HH	replicated & phase change/ 120mm	15-60 (3-12 layers)	RO/WO	2005-07	1
EVD (dual layer)	5.25" HH	Replicated & dye layer/ 120mm	6 11	RO WO	2006-07	1
Hi-MD	2.5" HH	MO/ 64.8mm	1	RO/RW	2004	1,2
Holographic (InPhase)	5.25" (11" or 17" long)	photopolymer/ 130mm	200	WO	2005-06	3,4
Holographic (Optware)	19" RM	photopolymer/ 130mm	200	WO	2005-06	3,4
Prof. Disc for DATA -2	5.25" HH	phase change/ 120mm	50	WO/RW	2005-06	3
Prof. Disc for DATA -3	5.25" HH	phase change/ 120mm	100	WO/RW	2007-09	3
3.5" ISO MO	3.5" HH	MO/ 86mm	4.6-6.9	RW	2005-06	2,3
UDO-2 (dual layer)	5.25" HH	phase change/ 130mm	60	WO/RO	2005-06	3,4
UDO-3 (dual layer)	5.25" HH	phase change/ 130mm	120	WO/RO	2007-09	3,4
UV-ray Disc (dual layer)	5.25" HH	replicated & phase change/ 120mm	334	RO/WO/RW	2009	1,2

Long-Term Roadmap, Optical Disk Storage Products — 2010-2015

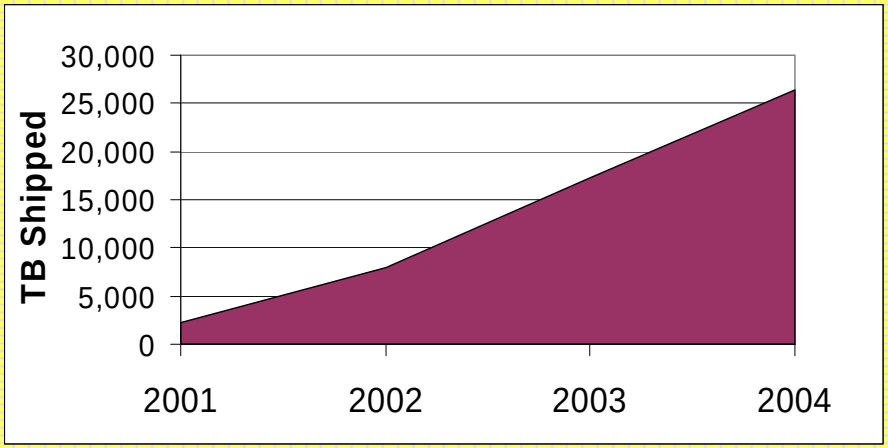
Product Name	Form Factor	Disc Type/ Diameter (mm)	Capacity (GB)	Write/Read Options	First Shipments	Market Segments
AOD HD DVD (quad layer)	5.25" HH	replicated & phase change/ 120mm	60/80	RO/RW	2010-11	1,2
Blu-ray Disc (quad layer)	5.25" HH	replicated, dye layer & phase change/ 120mm	92/100/108	RO/WO/RW	2009-10	1,2
DataPlay Blue (dual/quad layer)	SFFD	replicated & phase change/ 32mm	6-12	RO/WO	2010	1,2
Digital MultiDisc Blue	5.25" HH	replicated & phase change/ 120mm	150-200 (10 layers)	RO/WO/RW	2010	1
EVD Blue (dual layer)	5.25" HH	replicated & dye layer/ 120mm	24 40	RO WO	2010-12	1
Hi-MD Blue	2.5" HH	MO/ 64.8mm	4-6	RO/RW	2010	1,2
Holographic (InPhase)	5.25" FH	photopolymer/ 130mm	1600	WO/RW	2012-15	3,4
Holographic (Optware)	5.25" FH	photopolymer/ 130mm	1000	WO/RW	2012-15	3,4
Prof. Disc for DATA-4 (quad layer)	5.25" HH	phase change/ 120mm	200	WO/RW	2010	3
3.5" ISO MO	3.5" HH	MO/ 86mm	13.8-18.4	RW	2011-12	2,3
UDO-4 (quad layer)	5.25" HH	phase change/ 130mm	240	WO/RO	2010-12	3,4
UV-ray Disc (quad layer)	5.25" HH	replicated & phase change/ 120mm	864	RO/WO/RW	2014-15	1,2

Optical Storage Component/Subsystem Attributes

Component/Subsystem	2005	2007	2009	2015	Comments
Laser Wavelength (nm)	405-780	405-780	375-650	256-405	Through 2009, convergence on 405nm is expected. Beyond about 2010, UV lasers and media must be planned, if not implemented.
Laser Power (mW)	3-30	3-30	3-30	3-30	Recording speed and recording layer sensitivity are the pacing factors. Historically , this has been the range in laser powers for each generation.
Objective Lens NA	0.45-0.85	0.60-0.85	0.60-1.5	0.60-2.5	Assumes the introduction of NFR to obtain NA >1.
Disc Types	replicated, WO, RW, holographic	replicated, WO, RW, holographic	replicated, WO, RW, holographic	replicated, WO, RW, holographic	Media types will probably stay the same. WO should survive the roadmap period.
Recording Layers	2	2-4	2-6	2-20	Each side of the disc. By 2009, areal densities will be so high that cartridge media will be required.
Data Encoding/Read Channel	RLL/PRML	RLL/PRML	RLL/PRML	TBD	Multi-level, multi-layer, NFR, and combinations will require significant coding and signal processing as 100 Gb/in^2 areal densities are approached.

Flash Memory Technology Roadmap

Flash Memory



14 formats and growing…

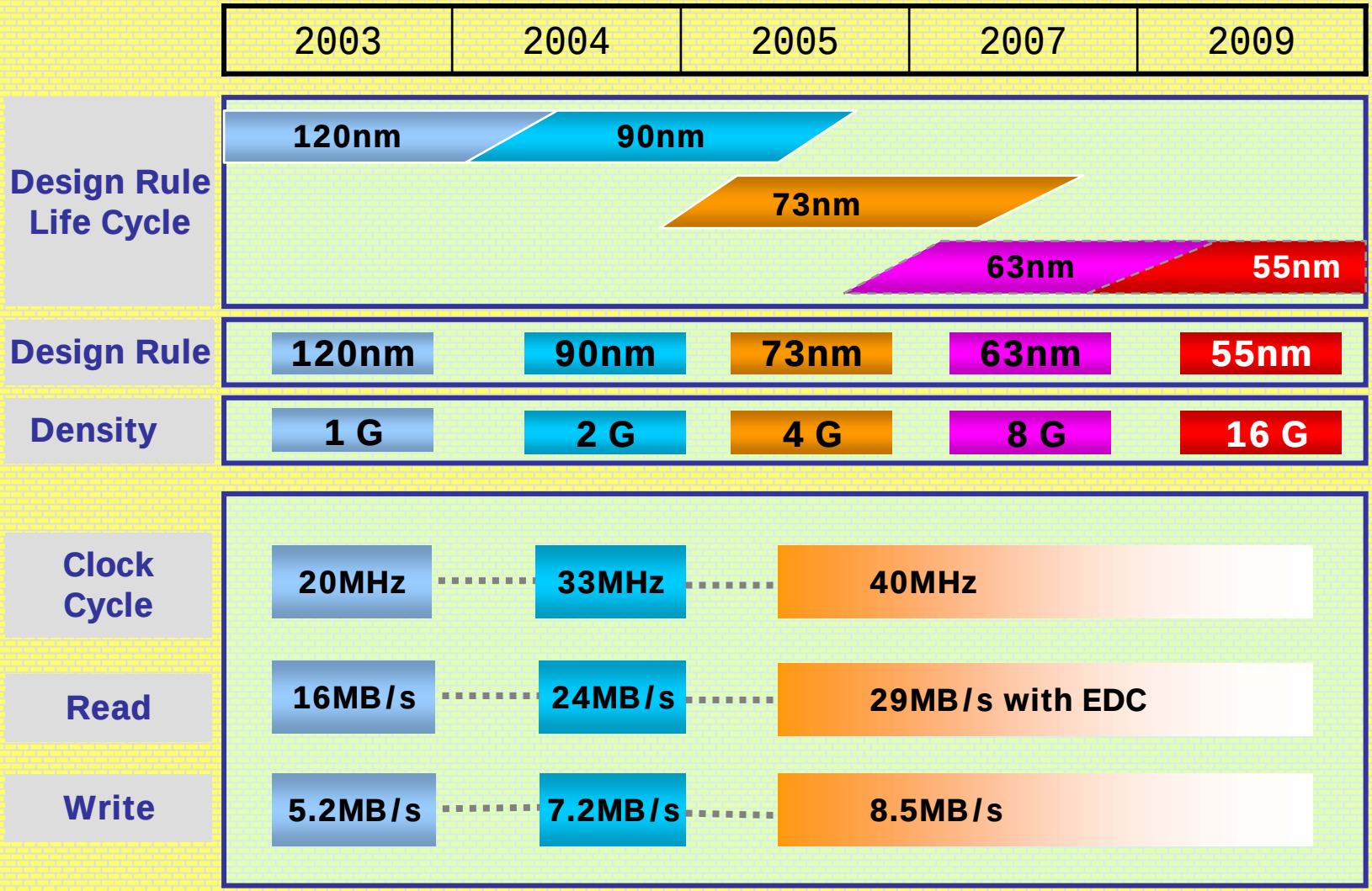
Flash Format	Size	Capacities
Compact Flash Type I	**42.8 x 36.4 x 3.3 mm**	Standard Capacity (MB) 32 64 128 256 512 1024 2048 Performance Capacity (MB) 256 512 1024 2048 4096
Smart Media Card	**45.9 x 37.0 x .76 mm**	Capacity (MB) 32 64 128
Multimedia Card	**32.0 x 24.0 x 1.4 mm**	Capacity (MB) 16 32 64 128
SD (Secure Digital) Card	**32.0 x 24.0 x 2.1 mm**	Capacity (MB) 16 32 64 128 256
SD Expansion Card Palm OS Devices	**32.0 x 24.0 x 2.1 mm**	Capacity (MB) 32 64 128 256 512
xD Picture Card Olypus & Fuji Digital Cameras	**20.0 x 25.0 x 1.7 mm**	Capacity (MB) 64 128 256 512
Memory Stick **(Standard & Magic Gate)** Sony Devices	**50.0 x 21.5 x 2.8 mm**	Capacity (MB) 16 32 64 128
Memory Stick Pro **(Standard & Magic Gate)** Sony Devices	**50.0 x 21.5 x 2.8 mm**	
Memory Duo Stick **(Standard & Magic Gate)** Sony Devices	**50.0 x 21.5 x 2.8 mm**	
Memory Duo Stick Pro **(Standard & Magic Gate)** Sony Devices	**31.0 x 20.0 x 1.6 mm**	

(1) Capacities as of September 2003

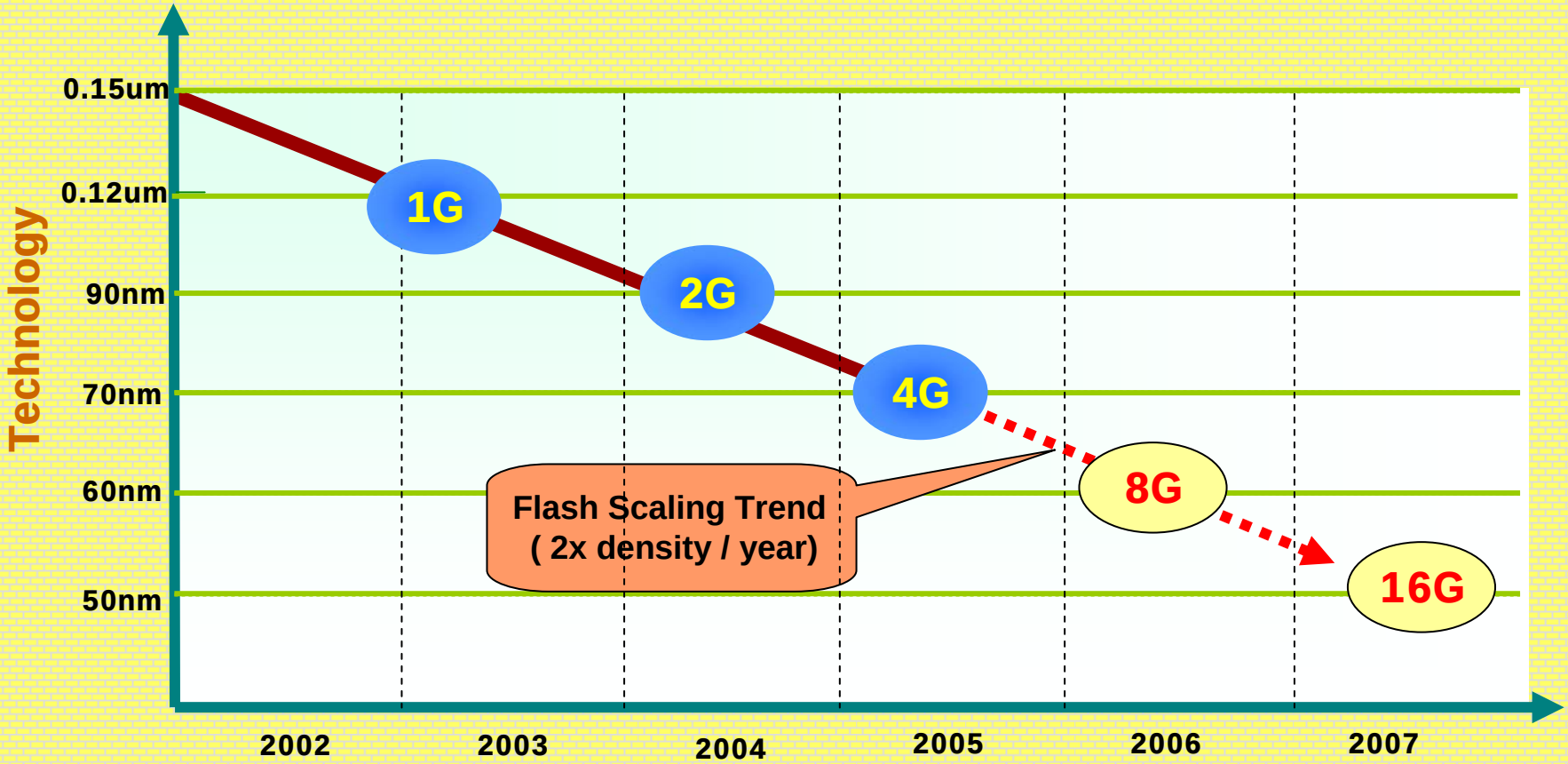
NAND Flash Chip Roadmap

	2003	2005	2007	2010	2015
Design Rule (Minimum Feature Size *f* in nanometers)	145	116	94	65	36
Cell size (f^2)	5.5	5	4.5	4.3	4
Average bits/cell	1.14	1.46	1.82	3.00	4.00
Die Size in mm^2	85	113	190	307	1007
Cost/GB ($/GB) @ $40/$in^2$ usable silicon	119.77	57.37	32.76	26.80	19.26
Average chip density (megabits)	360	957	2,932	14,848	211,813

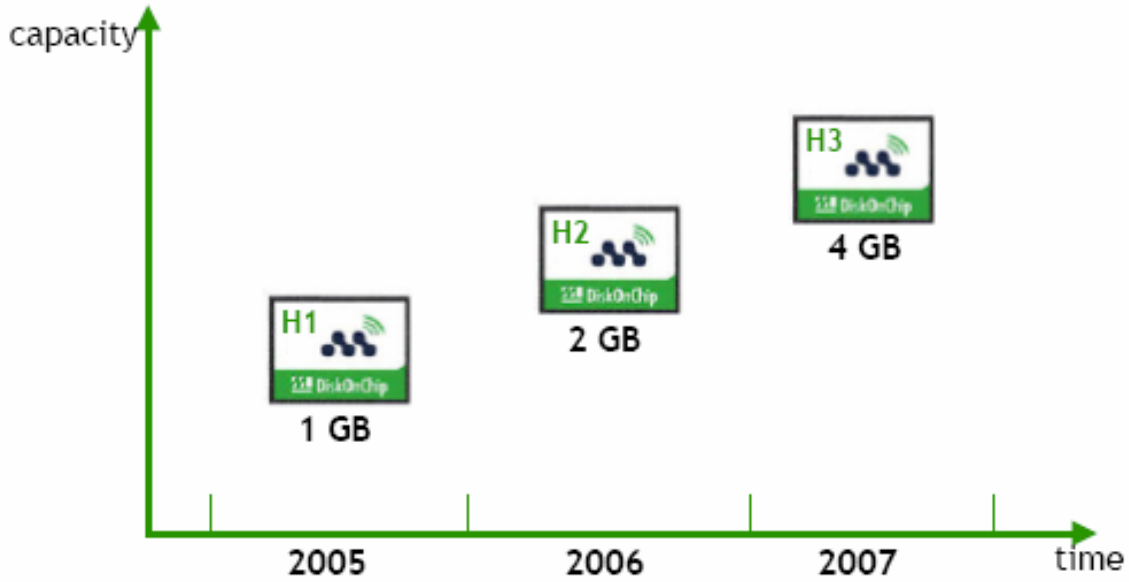
SEC Flash Process Technology (Samsung)



Flash Density Trend



Under $50 DiskOnChip Roadmap



M-Systems

Other Storage Technologies

Nonvolatile Magnetic Random Access Memory (NVRAM) Roadmap

	2003	2005	2007	2009	2015
Metric					
Design Rule (Minimum Feature Size *f* in micrometers)	0.25	0.20	0.15	0.1	0.05
Cell size (f^2)	12	11	10	8	6
Areal density @ 50% Array Efficiency (Mb/in^2)	420	900	1400	3900	20,700
Cost / Mb ($/Mb) @ $40/$in^2$ usable silicon	0.1	.05	0.03	0.01	0.002
Performance					
Write / read time (ns)	20	15	10	8	6
Data rate (write or read limit) (MHz)	100	100	100	200	300
Energy to write 1 bit (picojoule)	300	250	200	200	150
Energy to read 1 bit (picojoule)	100	100	100	100	75
Key Attribute					
SNR (dB)	25	25	25	25	25
Faulty bits allowed (out of spec for any reason)	1 in 10^4	1 in 10^4	1 in 10^5	1 in 10^6	1 in 10^7
Chip yield (per wafer)	90%	92%	95%	95%	95%

Additional Storage Technologies to Watch

- ***Ferroelectric Random Access Memory (FRAM)***
- ***Ovonic Unified Memory (OUM)***
- ***Programmable Metallization Cell Memory (PMCm)***
- ***Probe Based Storage (PBS)***

Conclusions

- Storage applications are increasing in capacity demand, driving all digital storage technologies
- HDDs are following a 50-60% annual areal density growth rate, fueling new applications in high capacity ATA-array storage as well as consumer electronic applications
- Flash memory and small form factor HDDs are pushing technology development to vie for mobile consumer electronics applications
- Optical storage capacity will increase going forward to meet the needs for content distribution as multimedia resolution increases
- New solid state and probe based storage technologies are being developed and are seeking applications in mobile and other electronic product applications

Sources

- **2005 Entertainment Creation and Distribution Digital Storage Report**, Coughlin Associates
- **2004 NEMI Mass Storage Roadmap Report,** various authors
- Talks from the **2005 Storage Visions Conference** (www.storagevisions.com) and the **February 2005 IDEMA SFF HDD and Flash Memory Symposium** (www.idema.org)

For more information go to the tech papers section of www.tomcoughlin.com

The End