The Role of Future Magnetic Tape Technology for Digital Archive, Preservation and Sustainability

Barry H. Schechtman

Information Storage Industry Consortium

Digital Archive, Preservation and Sustainability Workshop

Baltimore, Maryland

September 22, 2008

Outline

- A bit of background about INSIC
- Excerpts from INSIC 2008 Tape Roadmap
- Questions and discussion about archive user requirements for future tape implementation (with group participation)

Who We Are…

INSIC

the

Information Storage Industry Consortium

the collaborative research consortium for the worldwide information storage industry

Information Storage Industry Consortium

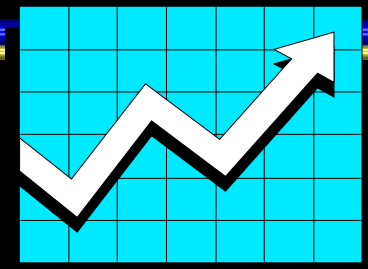
What INSIC is:

- An international storage technology research consortium

What INSIC does:

- Organizes & manages high-risk, pre-competitive, collaborative research projects
- Develops & publishes long-range storage technology and applications roadmaps
- Coordinates & obtains funding for university research in storage technology

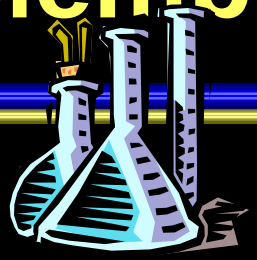
INSIC Corporate Members



ADVANCED RESEARCH CORP.
ALCATEL-LUCENT*
AKI
CYPRESS SEMICONDUCTOR*
DOWA ELECTRONIC MATERIALS*
DUPONT TEIJIN FILMS
FUJIFILM
HEWLETT- PACKARD
HITACHI GLOBAL STORAGE TECHNOLOGIES
HUTCHINSON TECHNOLOGY
IBM
IDC*
IMATION
INPHASE TECHNOLOGIES*
MAGNECOMP
MAXELL
MIPOX INTERNATIONAL
NEC*
PANASONIC
QUANTUM
SAMSUNG (SISA)
SANTOLUBES*
SEAGATE TECHNOLOGY
SILICON LIGHT MACHINES*
SONY
SUN MICROSYSTEMS
TEIJIN DUPONT FILMS
TEXAS INSTRUMENTS*
TODA KOGYO*
TORAY
WESTERN DIGITAL

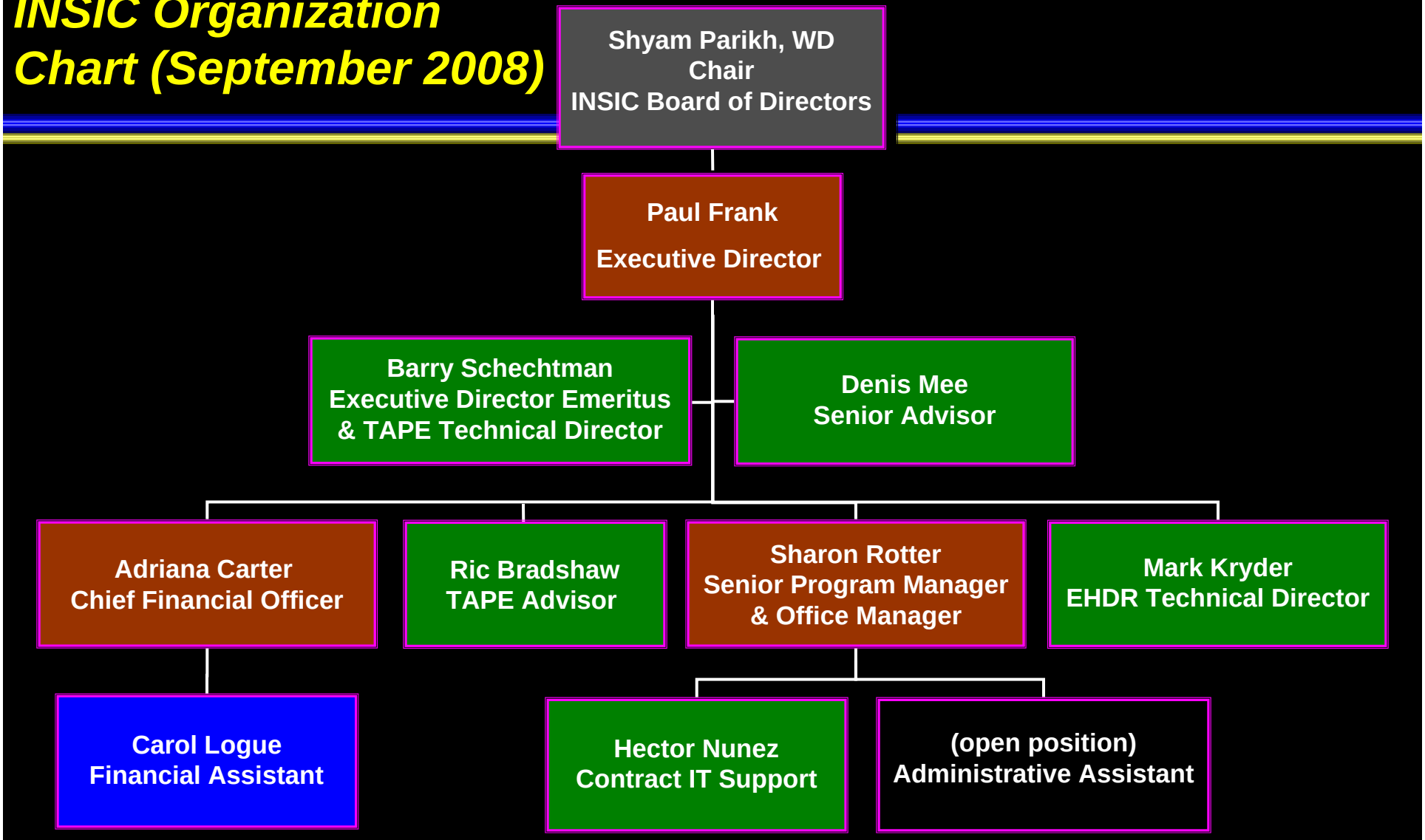
* Limited Member

INSIC Associate Members



ALABAMA
ALBERTA
ARGONNE NAT'L LAB
ARIZONA
ARIZONA STATE
BROWN
CARNEGIE MELLON
CENTRAL LANCASHIRE
COLORADO
COLORADO STATE
DATA STORAGE INSTITUTE (DSI)
GEORGIA TECH
HAWAII
HOUSTON
IDEMA
ILLINOIS
IMRE
IOWA STATE
ISIC
ITRI
JOHNS HOPKINS
LAWRENCE BERKELEY NAT'L LAB
LAWRENCE LIVERMORE NAT'L LAB
LOS ALAMOS NATIONAL LAB
MANCHESTER
MASSEY
MIT
MINNESOTA
MISSOURI
NATIONAL U. OF SINGAPORE
NEBRASKA
NIST
NORTHEASTERN
NORTHWESTERN
OHIO STATE
PURDUE
SANTA CLARA
SHEFFIELD
STANFORD
TEXAS A&M
TSINGHUA
UC BERKELEY
UC SAN DIEGO
U. of the PACIFIC
U. of WASHINGTON
VANDERBILT
VIRGINIA
VIRGINIA COMMONWEALTH
WASHINGTON UNIVERSITY
YONSEI

INSIC Organization Chart (September 2008)



The current INSIC Team consists of

3 full-time employees, 1 part-time employee, 5 part-time consultants/contractors

Information Storage Industry Consortium

THE INSIC RESEARCH PROGRAM

INSIC Collaborative Research Offers…

- A highly efficient means of gaining early, real-time access to the best university-based research available
- The opportunity for industry to guide this research onto pre-competitive problems of common interest
- An effective means of coordinating a collection of university-based research efforts toward a common set of goals, as defined by industry
- A very cost-effective means of supporting this research
- A unique mechanism for bringing university researchers together to work on larger issues
- A means of avoiding duplication of effort by focusing research onto complementary aspects of problems
- A unique pre-competitive forum in which leading industrial and academic researchers can exchange and sharpen their ideas on what's most important for the long-range future

INSIC Joint Research Program
(Technology Areas: 1991-2008)

Hard Disk Drive & Component Technology:

- EHDR Program
- HEADS Program
- HAMR Program
- UHDR Disk Program

Magnetic Tape Recording Technology:

- TAPE Program
- UHDR Tape Program

Optical Disk Drive & Component Technology:

- MORE Program
- SWAT Program
- UCOD Program
- UHDR Optical Program

Holographic Storage Systems & Materials:

- PRISM Program
- HDSS Program

Storage Systems:

- DS2 Program
- Large Block Size Initiative
- NASD Project

Programs shown in blue are currently active

INSIC JOINT RESEARCH PROGRAM
(1991-2008)

PARTICIPATING COMPANIES (54 TO DATE):

Applied Magnetics, Cirrus Logic, Hitachi GST, Hutchinson, IBM, Lucent, Quantum, Read Rite, MEMS Optical, Advanced Research, Texas Instruments, Seagate, Maxtor, Agere Systems, VTC, Western Digital, Komag, Calimetrics, ECD, Polaroid, Hewlett-Packard, Imation, StorageTek, Uniphase, Kodak, Rockwell, Siros/Optitek, GTE, RPC, SDL, Aprilis, Hughes, SRI, Censtor, DEC, Conner Peripherals, Datatape, Metrum, Sony, Iomega, Recording Physics Inc., Bellcore, Euxine Technologies, Bayer, Displaytech, Certance, Samsung, Maxell, Fujifilm, Magnecomp, MIPOX International, Sun Microsystems, Matsushita/Panasonic, Teijin DuPont/DuPont Teijin

PARTICIPATING UNIVERSITIES (43 TO DATE):

Alabama, Alberta, Arizona, Carnegie Mellon, Colorado, Colorado State, Georgia Tech, Harvard, Houston, Illinois, Manchester, Minnesota, MIT, Nebraska, Northwestern, NUS, Pacific, Stanford, UC Berkeley, UCSD, U. of Washington, Vanderbilt, Virginia, Washington University, Missouri, Dayton, George Washington U., Central Lancashire, Cal Tech, Ohio State, Pittsburgh, Rice, Santa Clara U., UCLA, Data Storage Institute, Texas A&M, Sheffield, Virginia Commonwealth U., Hawaii, Brown, Iowa State, Washington State, Massey University

Organizations shown in blue are currently active

Current INSIC Program Participants
September 2008

EHDR (magnetic hard disk drive technology):

Companies (6): Hitachi GST, Hutchinson Technology, MIPOX International, Samsung, Seagate Technology, Western Digital

Universities (16): Alabama, Arizona, Carnegie Mellon, Colorado State, Hawaii, Houston, Illinois, Manchester, Minnesota, Nebraska, Sheffield, Texas A&M, UC Berkeley, UCSD, Virginia, + Data Storage Institute

Funding: Companies, Universities

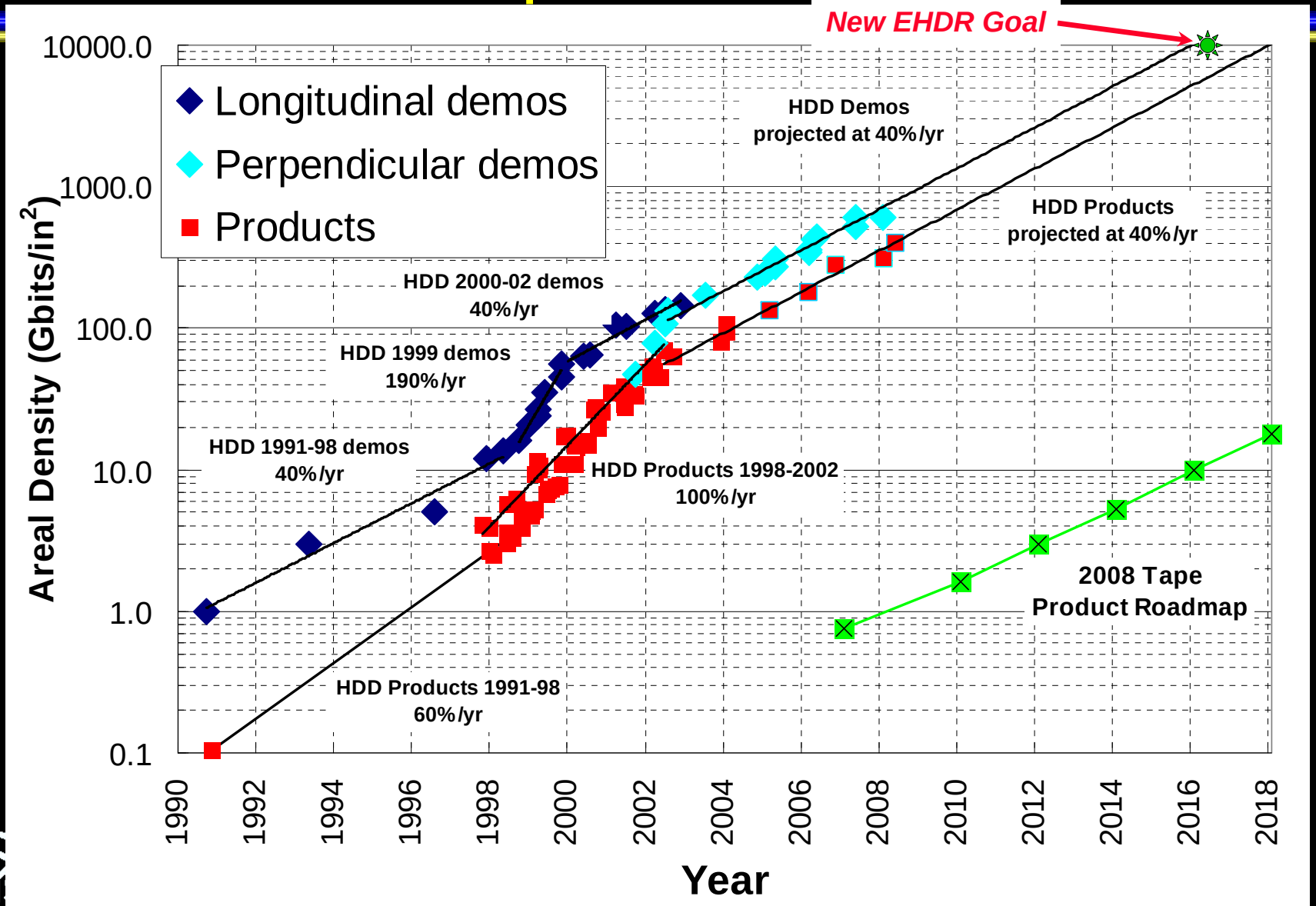
TAPE (advanced magnetic tape technology):

Companies (11): Advanced Research Corp., Fujifilm, Hewlett-Packard, IBM, Imation, Maxell, Panasonic, Quantum, Sony, Sun Microsystems, Teijin DuPont Films/DuPont Teijin Films

Universities (8): Alabama, Arizona, Carnegie Mellon, Iowa State, Massey, Ohio State, Pacific, UCSD

Funding: Companies, Universities

HDD & Tape Areal Density Trends
September 2008



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TAPE TECHNOLOGY FORUM II

Tokyo, Japan
October 11-12, 2007

Tape Technology Forum II

We Had: 146 Registered → + 3 remote = 149

Representing: 24 Organizations → + 1 remote = 25

Advanced Research Corporation
Carnegie Mellon University
Dowa Electronics Materials
Fujifilm
Fujitsu
Hewlett-Packard
IBM
Imation
INSIC
Iowa State University
Matsushita/Panasonic
Maxell
NEC
Quantum
Sony
Sun Microsystems
Teijin-DuPont Films
Toda Kogyo
Tokyo Institute of Technology
Toray
U. of Alabama
U. of Arizona
U. of California San Diego
U. of the Pacific

… plus remote participation by the U. of Minnesota

Information Storage Industry Consortium

THE INSIC

ROADMAP & WORKSHOP

PROGRAM

INSIC Roadmaps & Workshops

Why Does INSIC Do Roadmaps & Workshops?

- To articulate the industry's technology vision, providing
  - a common vehicle for communication and measurement of progress, and
  - a validation of the future

- To provide an assessment of threats from competing technologies

- To provide guidance for INSIC's research investment strategy over the next 5~10 year timeframe by identifying
  - key technology issues and hurdles
  - potential gaps in current research strategies
  - new project areas and future research programs

Recent INSIC Roadmap & Workshop Planning

Workshops & Forums Held

2007: Tape Technology Forum II

Forum: October 11-12, 2007 Location: Tokyo, Japan

2007: Joint INSIC/SRC HDD Technology Workshop

Workshop: October 18, 2007 Location: Tokyo, Japan

2008: International Magnetic Tape Storage Roadmap Workshop

Workshop: January 8-9, 2008 Location: San Jose, CA

2008: EHDR Workshop on Ten Terabit/Inch^2 Recording

Workshop: January 31 - February 1, 2008 Location: Berkeley, CA

Workshops in Planning

2008: International Probe Storage Workshop v

Workshop: tentatively, December 9-10, 2008 Location: Pittsburgh, PA

2009: Joint Workshop on HDD Technology (with SRC)…?

Workshop: …no sooner than Spring 2009 Location: …in the U.S.

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INTERNATIONAL MAGNETIC TAPE STORAGE ROADMAP WORKSHOP 2008

IBM Almaden Research Center

January 8-9, 2008

International Tape Roadmap Workshop 2008

- **Registered Attendance: 76 (including 2 via telephone)**

  From: Industry: 70 Universities: 6
  US: 48 Japan: 27 Europe: 1

- **Organizations Represented: 26**

  Industry: 20 Universities: 6
  US: 17 Japan: 9

- **Organizations Participating (number of participants):**

Advanced MicroSensors (1)
Advanced Research Corp (1)
Consultants (1)
Dowa Electronics Materials (3)
DuPont Teijin Films (1)
Fujifilm (4)
Hewlett-Packard (5)
Hitachi Maxell (6)
IBM (9)
IDC (1)
Imation (4)
INSIC (4)
Iowa State U. (1)
Panasonic (3)
Quantum (6)
SAE Magnetics (1)
Sony (7)
Sun Microsystems (9)
Teijin DuPont Films (1)
Toda Kogyo (1)
Toray Industries (2)
U. Alabama (1)
U. Arizona (1)
U. Minnesota (1)
U. of the Pacific (1)
UC San Diego (1)

International Tape Roadmap Workshop 2008

- Leaders: Technology – Bob Raymond *(Sun Microsystems)*
- Applications & Systems – Barry Schechtman *(INSIC)*
- Technology Subgroup Leaders:
  - Heads: Larry Neumann *(Quantum)*
  - Media: Mike Sharrock *(Imation)*
    - Substrates: Brian Weick *(U. of the Pacific)*
  - Transport: Paul Poorman *(HP)*
  - Channel Electronics: Evangelos Eleftheriou *(IBM)*
  - Helical-Scan Recording: Chris Smith *(Sony)*

Applications & Systems Team

Bob Amatruda (IDC)

Brian Findlay (Imation)

John Herron (Sun Microsystems)

Brad Johns (IBM)

Barry Schechtman (INSIC)

Rod Wideman (Quantum)

Dave Woito (HP)

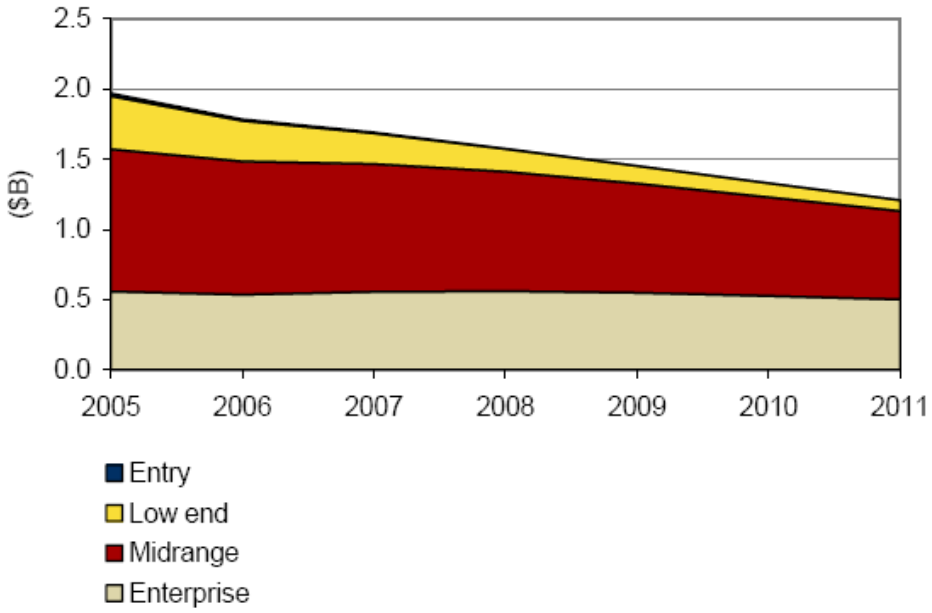
Take Home Messages

- The biggest threat to tape in multi-user IT applications is low-cost HDD storage systems. Optical technologies pose less of a threat.
- Disk systems have eroded tape's share of the backup & restore applications
  - » Disk provides improved process opportunities, e.g.
    - – Data deduplication (effective increase in capacity & data rate)
    - – Continuous data protection
  - » Increasing telecom bandwidth undermines tape's removability advantage
  - » But tape will remain the lowest cost solution for the foreseeable future
- The growth opportunity for tape is in archival applications
  - » In these applications, tape must continue to remain cost competitive to magnetic disk, and must therefore continue its technology progress
    - – Energy cost should be emphasized as a tape advantage
  - » Drive and media usage statistics may be different in archive than in traditional backup/restore and should be understood
  - » Tape providers should seek opportunities to offer complete system level archive solutions

Tape Drive Revenue and Units are Declining

Revenue ($B)

Worldwide Tape Drive Revenue by Segment, 2005–2011

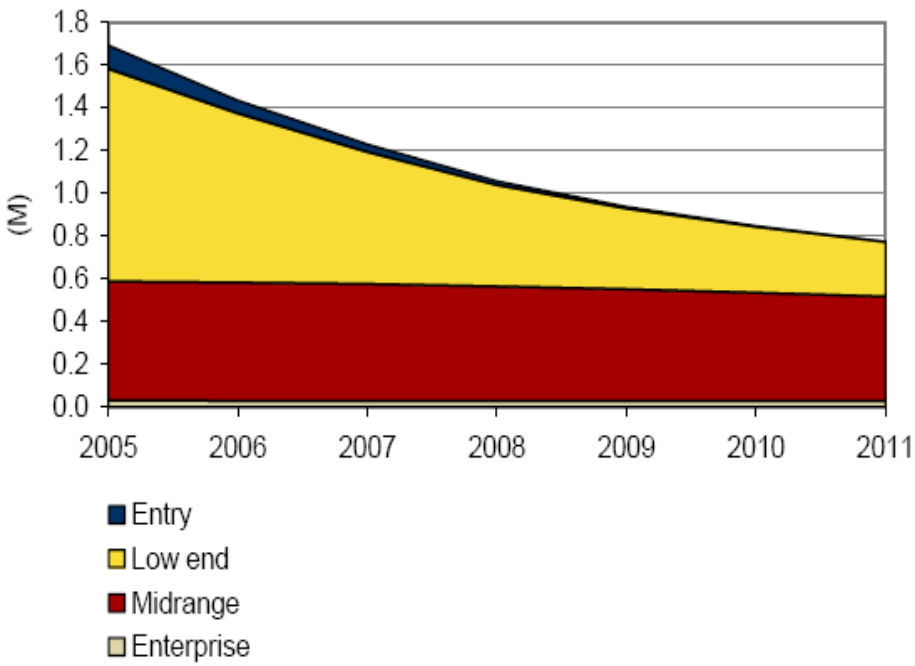


Note: Revenue for enterprise tape drives is represented in end-user values and includes upgrades and controllers where necessary.

Source: IDC, May 2007

Units (M)

Worldwide Tape Drive Shipments by Segment, 2005–2011

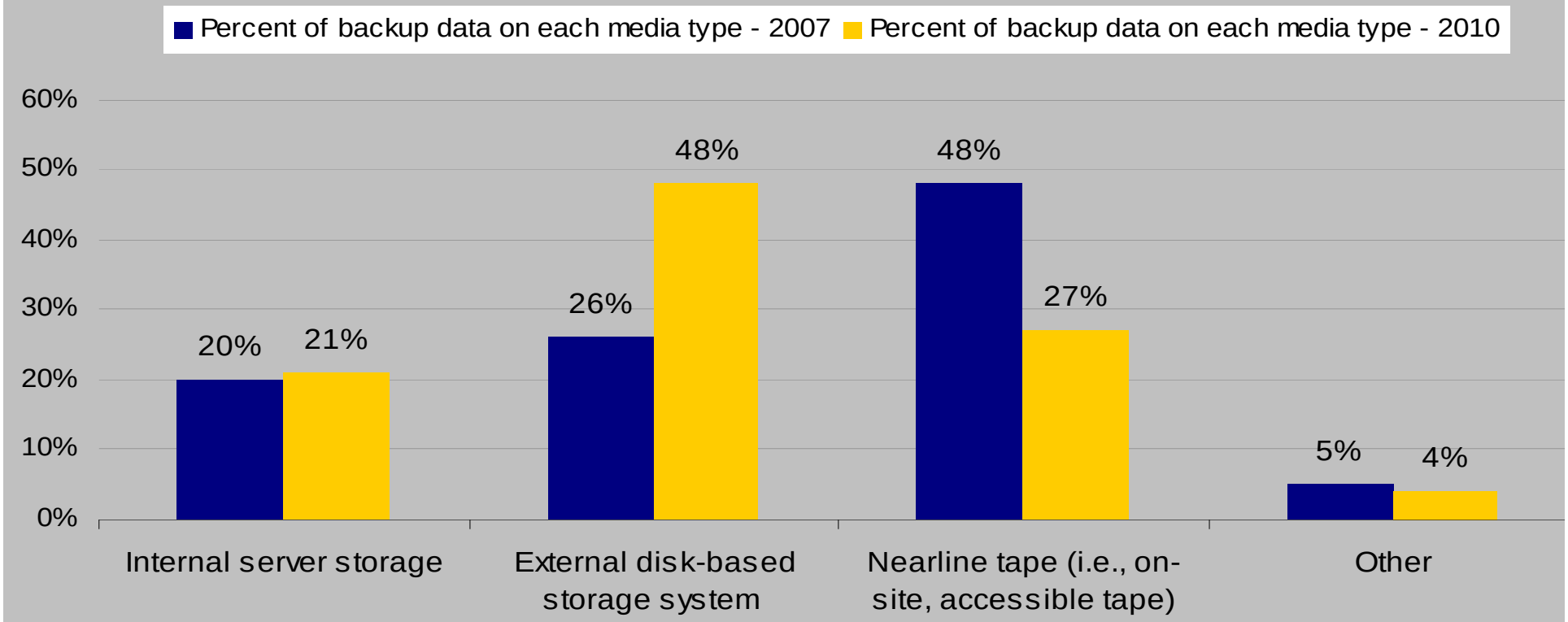


Source: IDC, May 2007

Source:IDC, "Worldwide Tape Drive 2007-2011 Forecast and Analysis," Doc #206655 May 2007

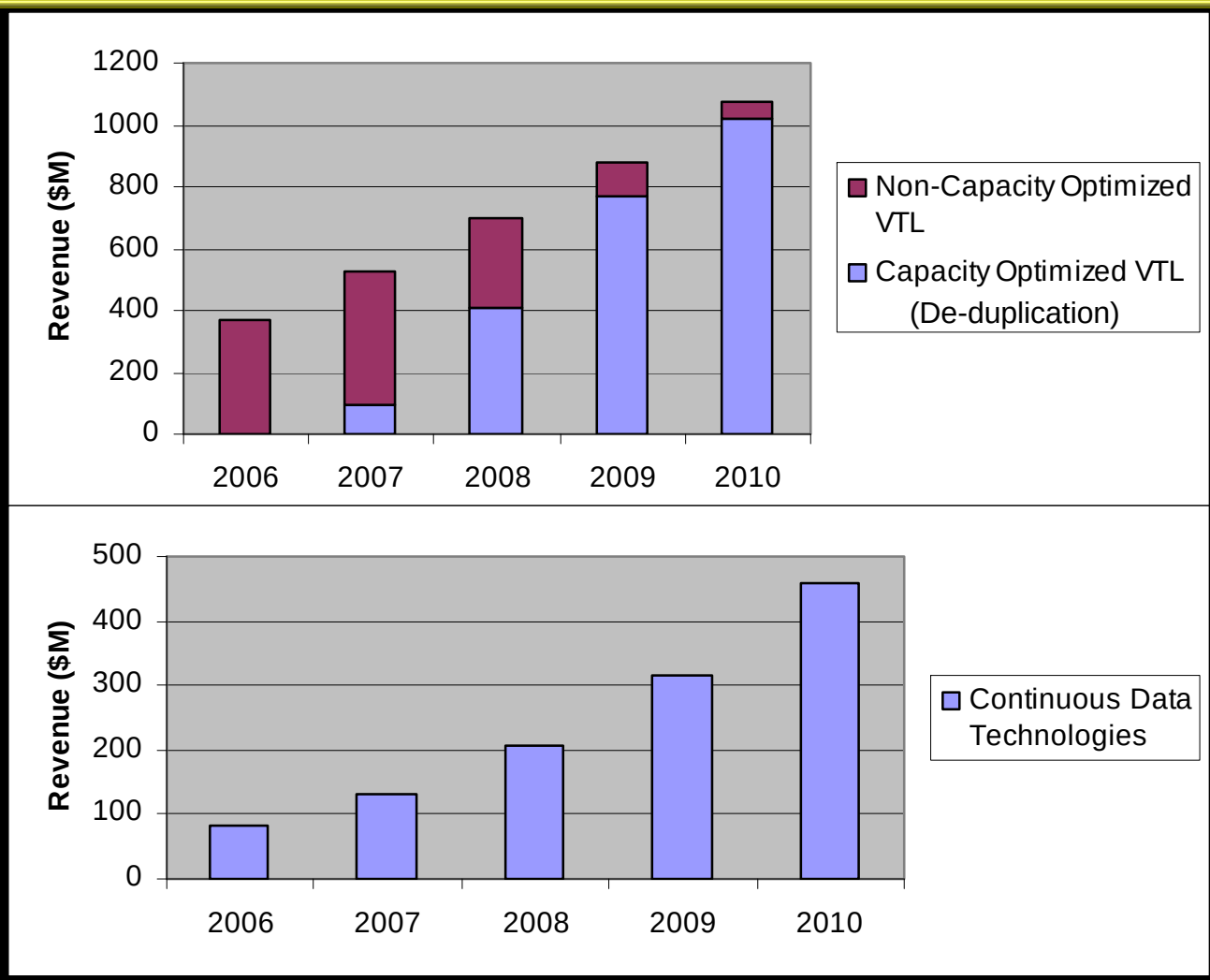
On-Site Backup Data by Media Type

Approximately what percentage of your organization's total on-site backup data is currently stored on each of the following storage media types? Please also indicate what you expect these percentages to be in 2010? (N = 364)



Source: "Data Protection Market Trends" Enterprise Strategy Group Research Report, January 2008

Disk Offers New Process Opportunities



Source: *Next Generation Data Protection Market Forecast 2006-2010*; Taneja Group, Dec. 2006

But Disk Failures are Greater than Projected

Awarded Best Paper!

Disk Failures in the Real World: What Does an MTTF of 1,000,000 Hours Mean to You?

Bianca Schroeder and Garth A. Gibson, *Carnegie Mellon University*

Excerpt from conclusions:

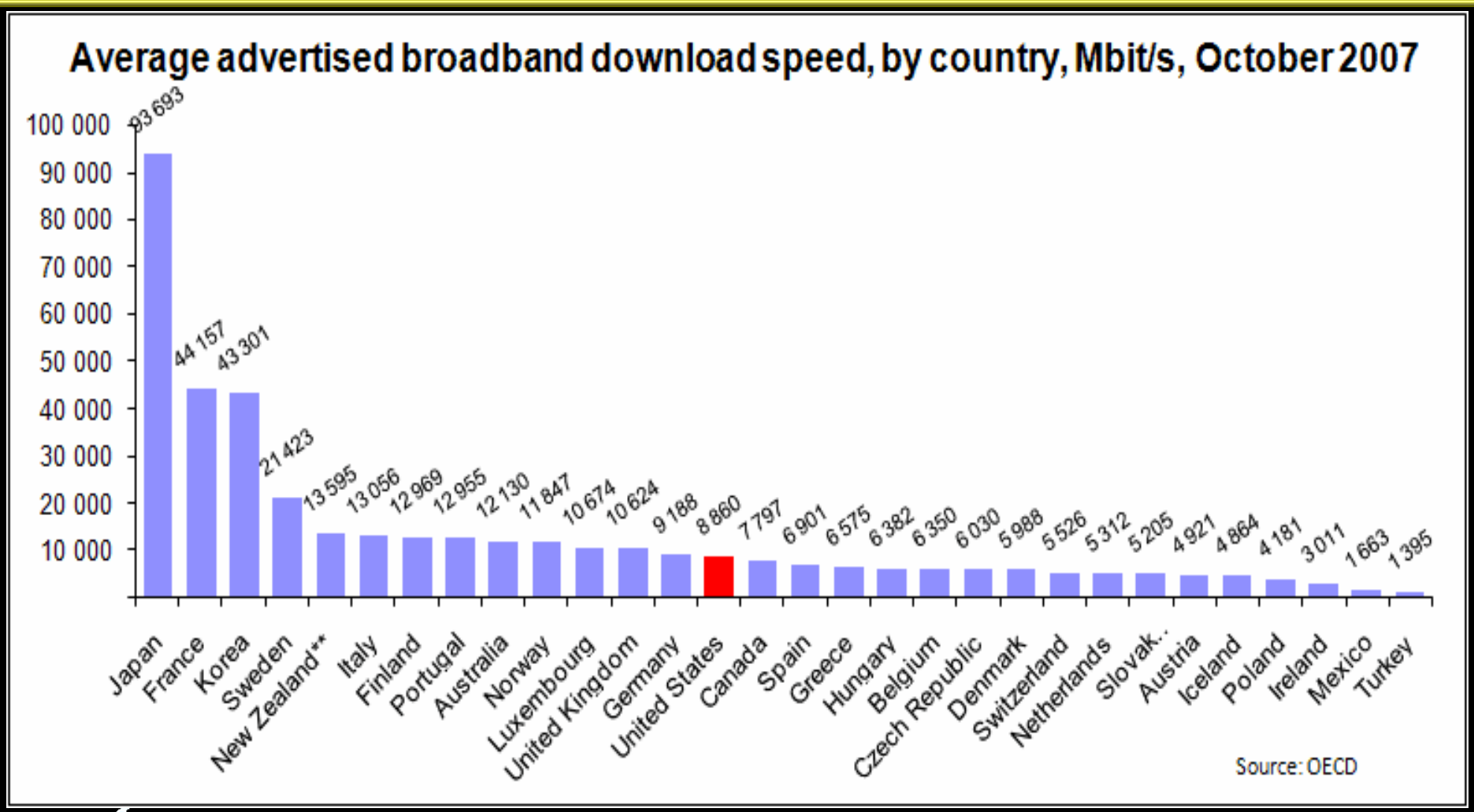
Large-scale installation field usage appears to differ widely from nominal datasheet MTTF conditions.

- Field **replacement rates** of systems were **significantly larger than we expected** based on datasheet MTTFs
- For drives less than five years old, field replacement rates were larger than what the datasheet MTTF suggested **by a factor of 2-10**. For five to eight year old drives, field replacement rates were **a factor of 30** higher than what the datasheet MTTF suggested.

Full paper available at:

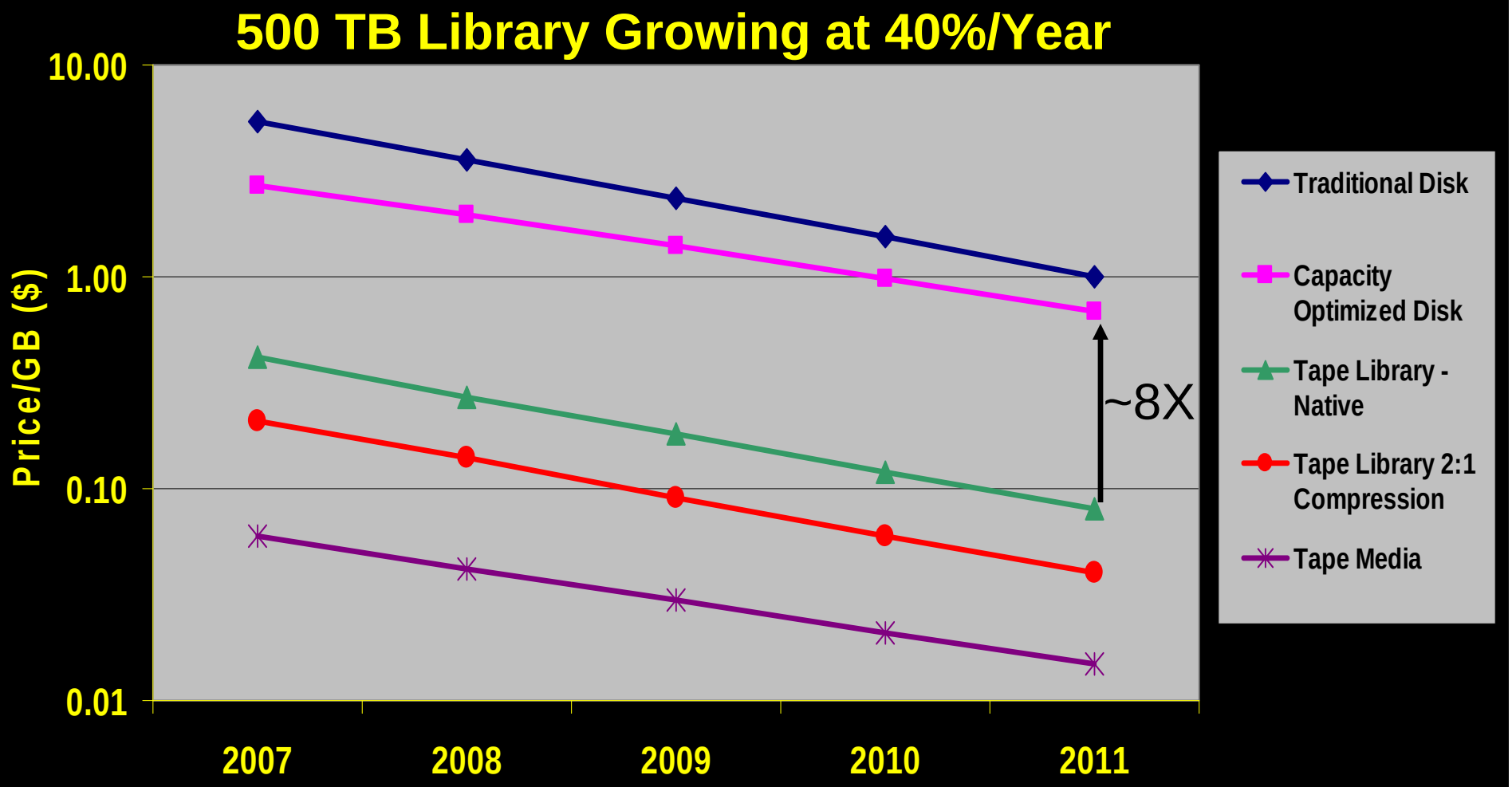
Full paper available at: http://www.usenix.org/events/fast07/tech/schroeder.html

Faster Telecom Speeds Facilitate Off-Site Data Location



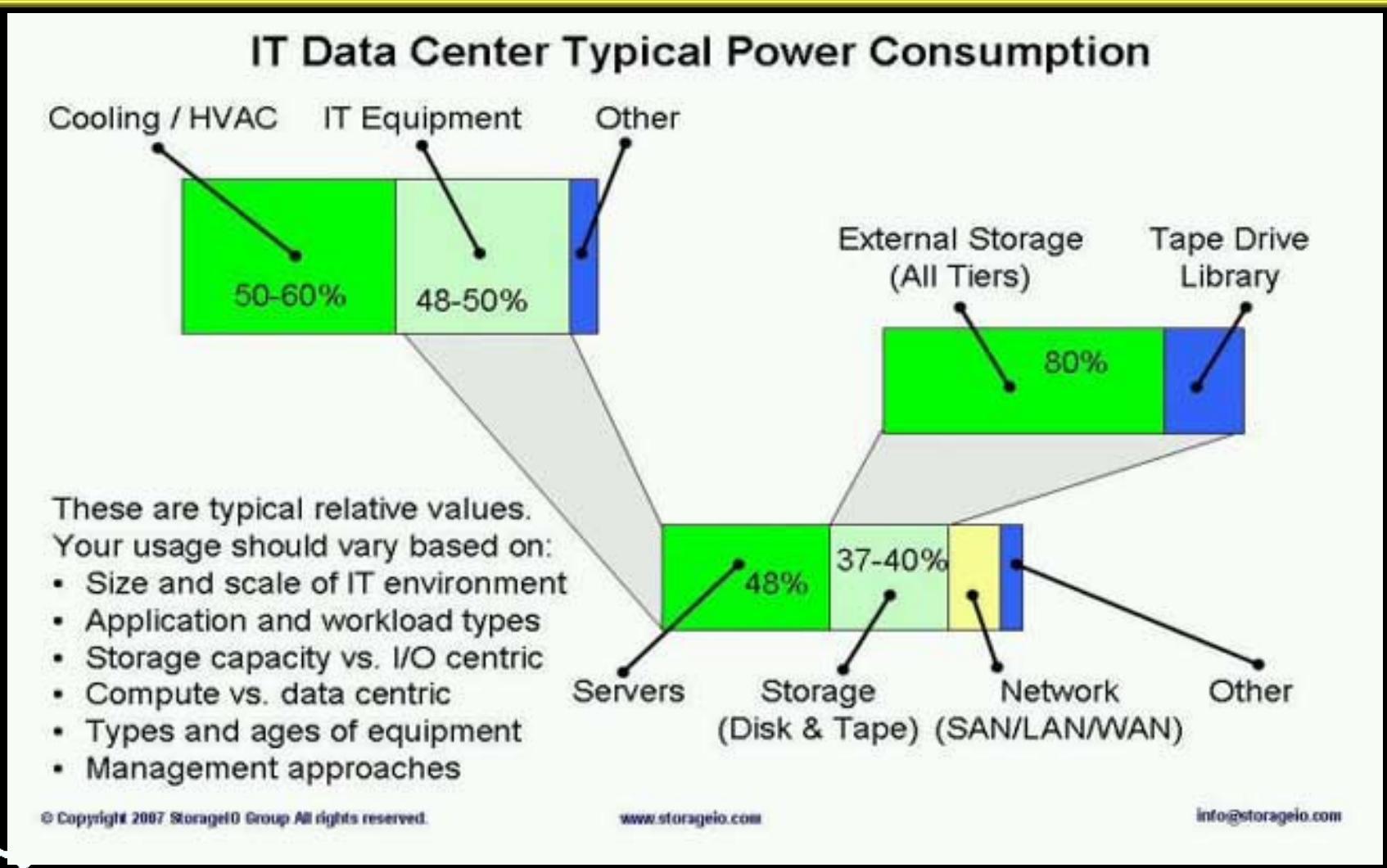
Source: http://www.websiteoptimization.com/bw/0711/

Tape Expects to Keep Up its $/GB Advantage



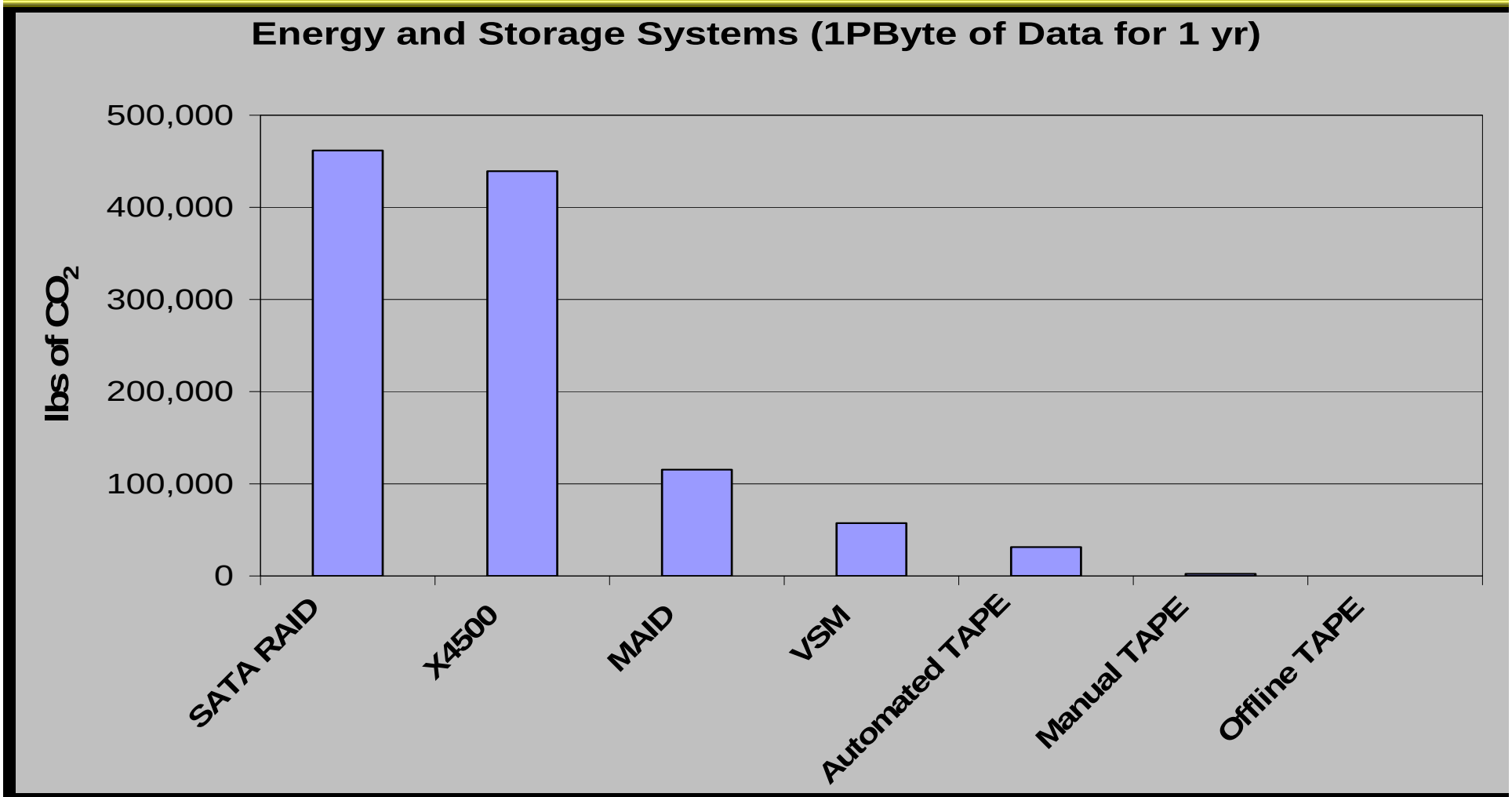
Source: Modeling by B. Johns, IBM

Energy Costs are a Growing Concern



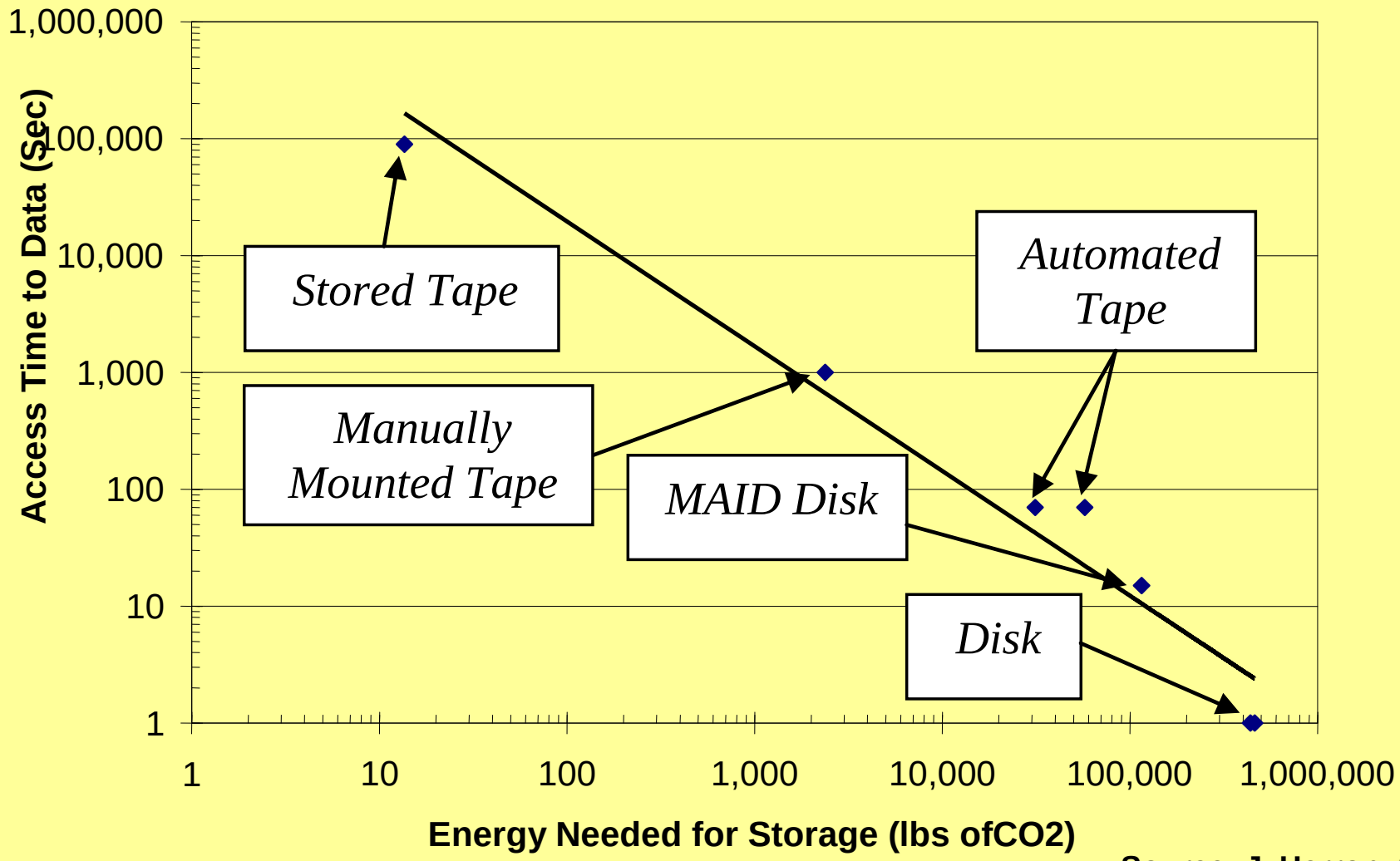
Source: http://www.enterprisestorageforum.com/management/features/article.php/3678671

Tape Uses Much Less Energy Than Disk



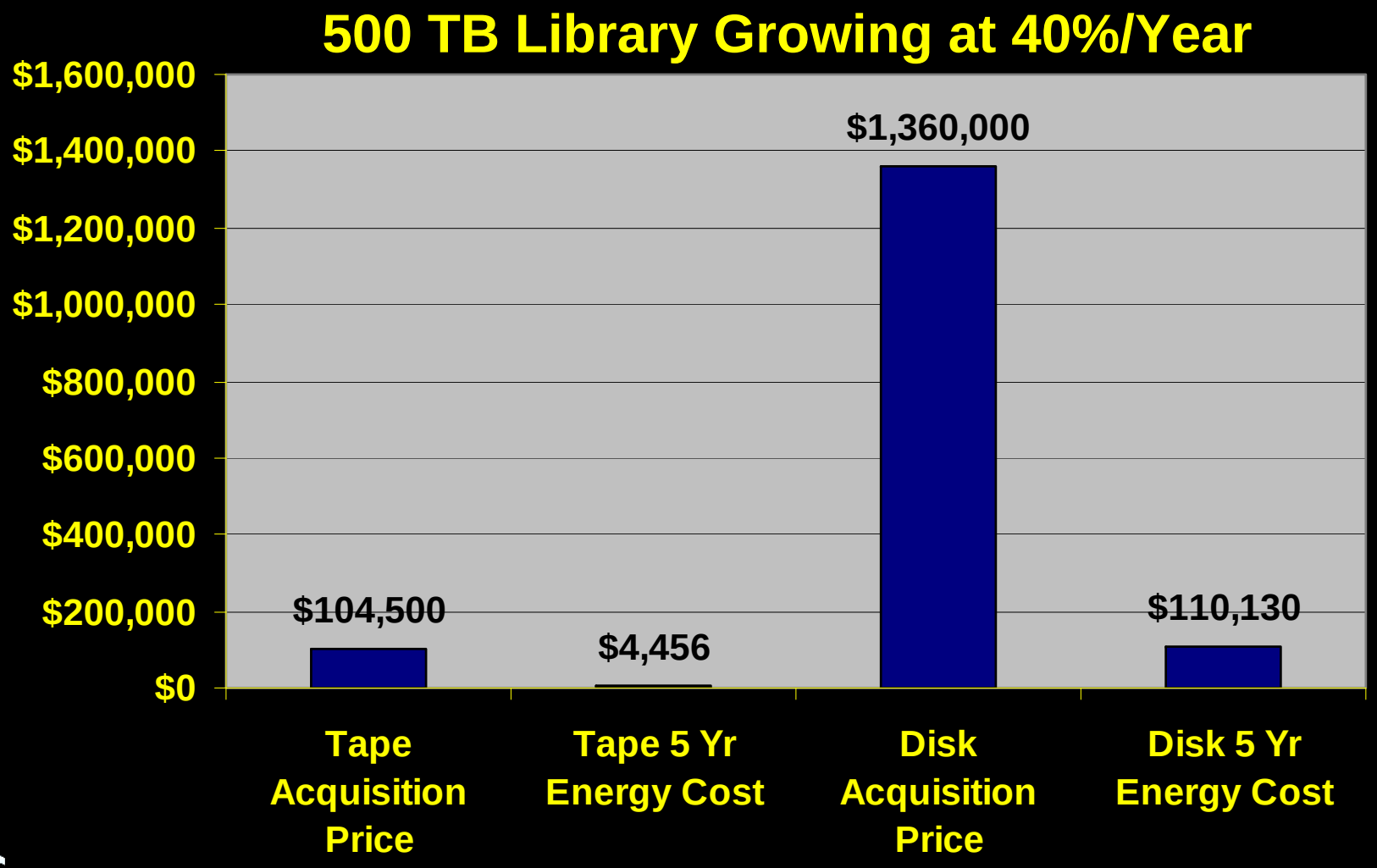
Source: R. Dee, Sun Microsystems, INSIC AST Symposium, July 2007

Energy Consumption Varies with Access Time



Source: J. Herron, Sun

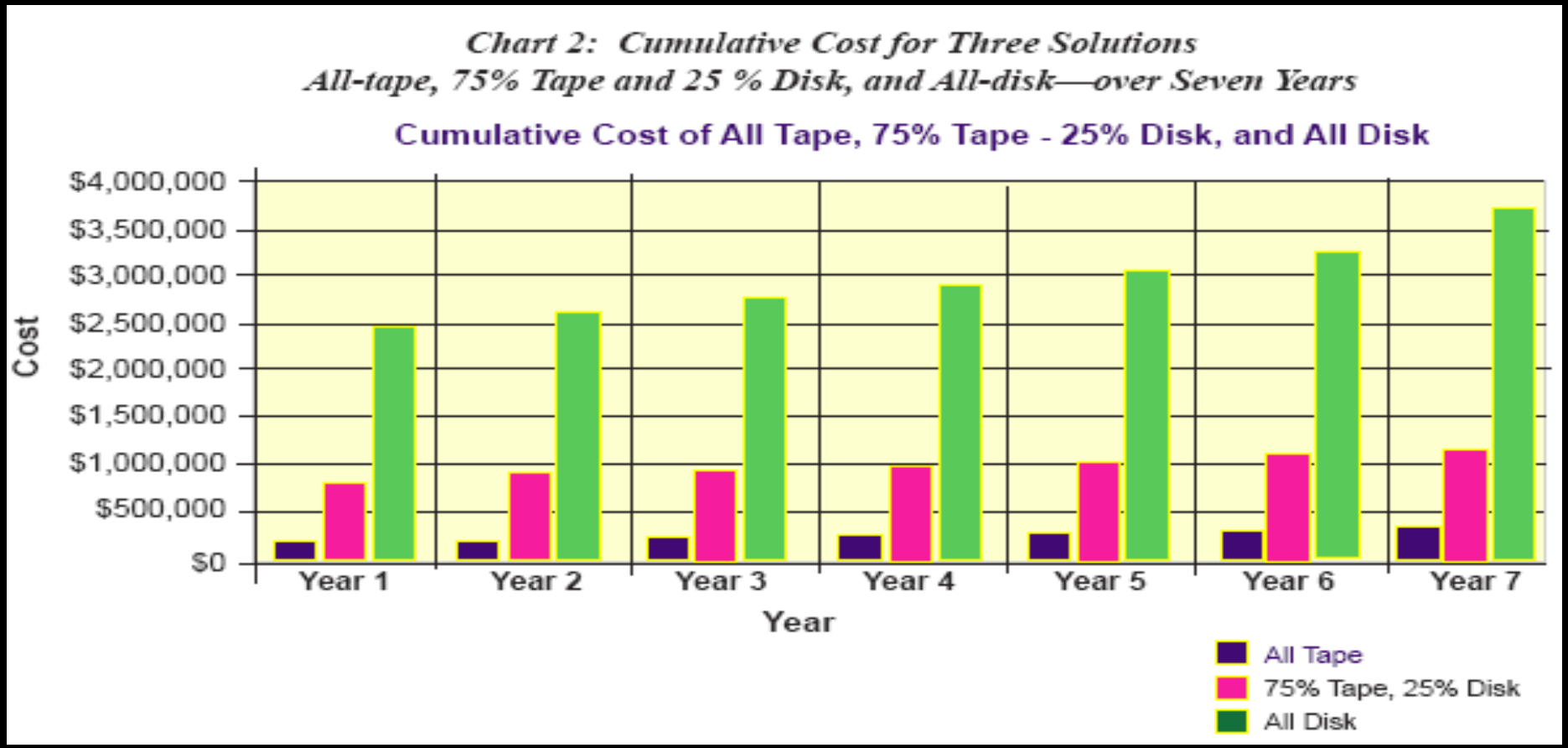
Tape vs. Disk Five Year Energy Cost



Source: Modeling by B. Johns, IBM

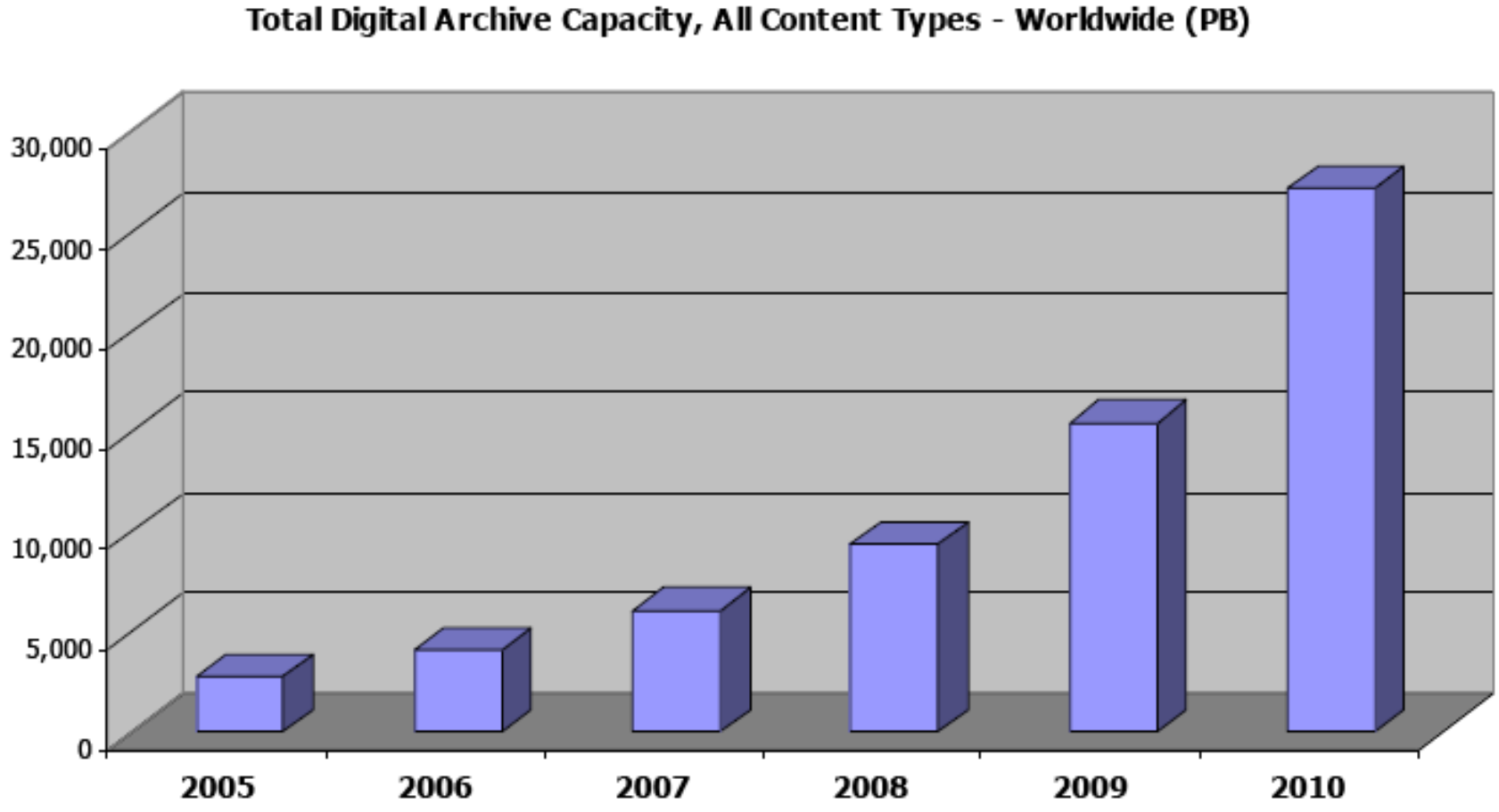
Another Analysis of Tape vs. Disk Costs

125 TB Library Growing 20%/Year



Source: Data Mobility Group White Paper, October 2005
http://www-03.ibm.com/industries/media/doc/content/bin/DMG_tape_disk.pdf?g_type=pspot

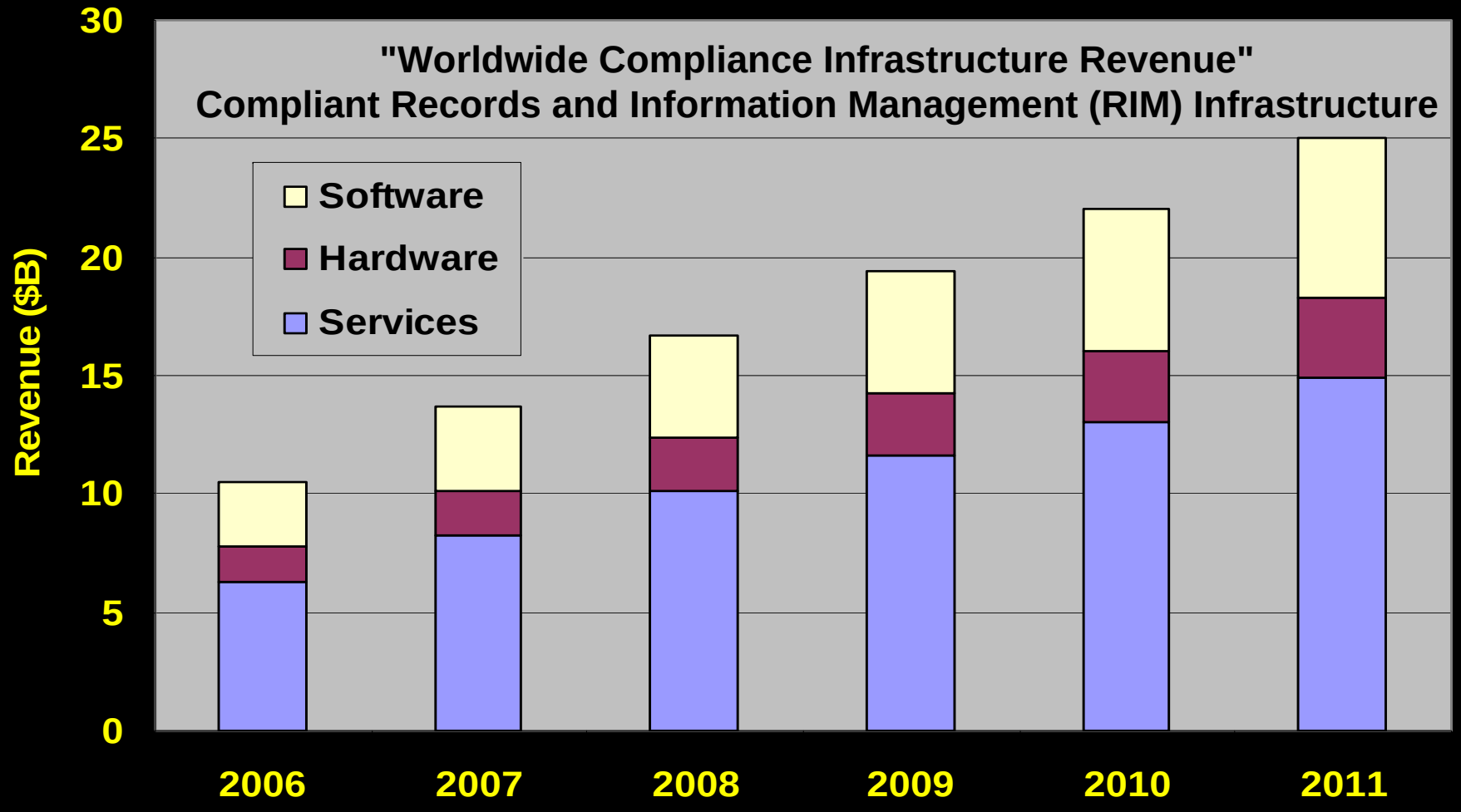
Rapidly Growing Demand for Archival Storage



Source: ESG Research Report: Digital Archiving: End-User Survey and Market Forecast 2006 - 2010, 2007

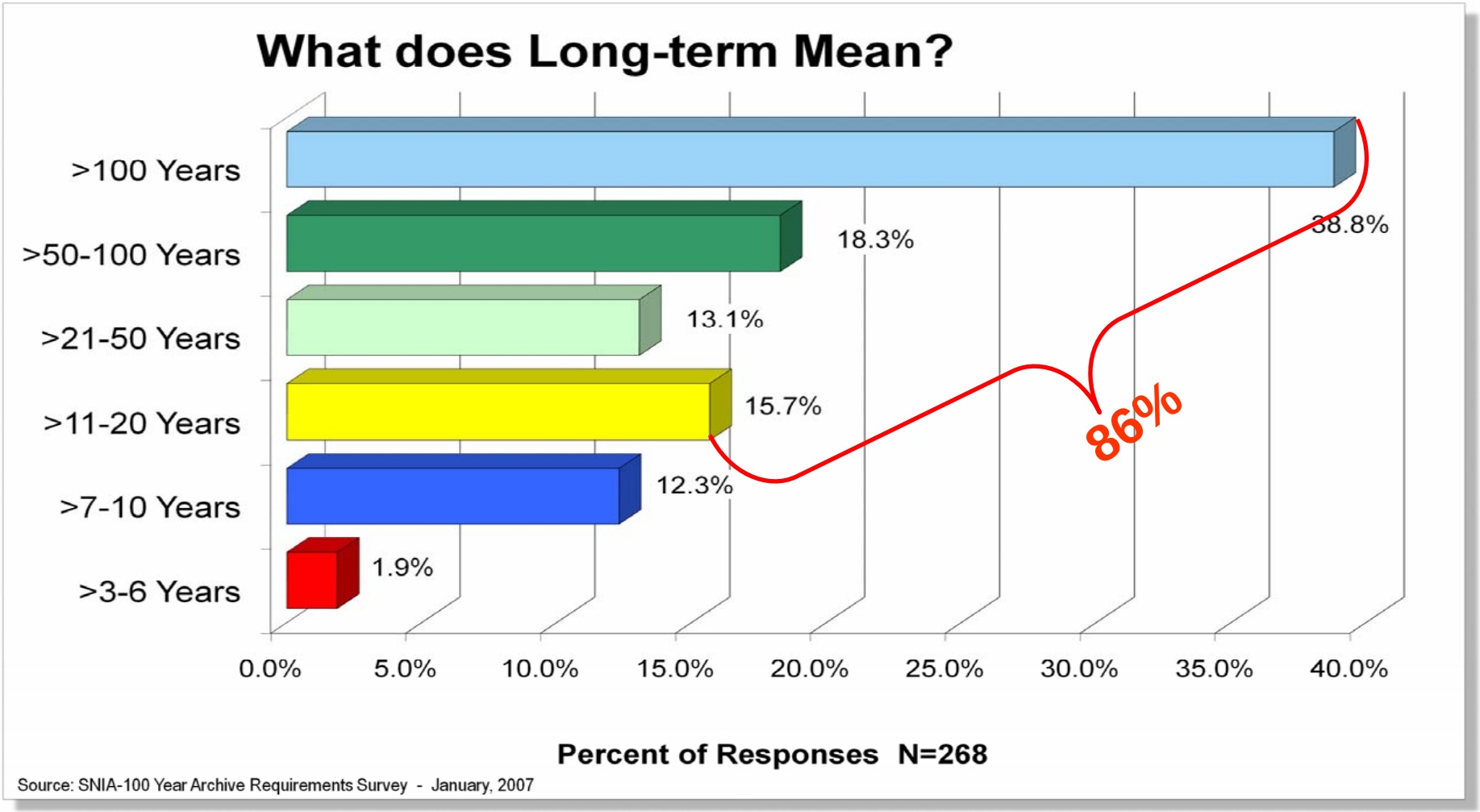
Source: http://www.enterprisestrategygroup.com/ESGPublications/ReportDetail.asp?ReportID=591

Regulation Helps Drive Archival Demand



Source: IDC, "Worldwide Compliance Infrastructure 2007-2011 Forecast: Compliant Information Infrastructure, Data Privacy, and IT Risk and Compliance Management Underpin Spending," Doc # 209257, November 2007

Archival May Mean VERY Long Term!
(especially relative to hardware/software cycles longevity)



Source: http://www.snia.org/forums/dmf/programs/ltacsi/100_year/100YrATF_Archive-Requirements-Survey_20070619.pdf

Tape Dominates Enterprise Archive

Each silo:

1987 1 TB

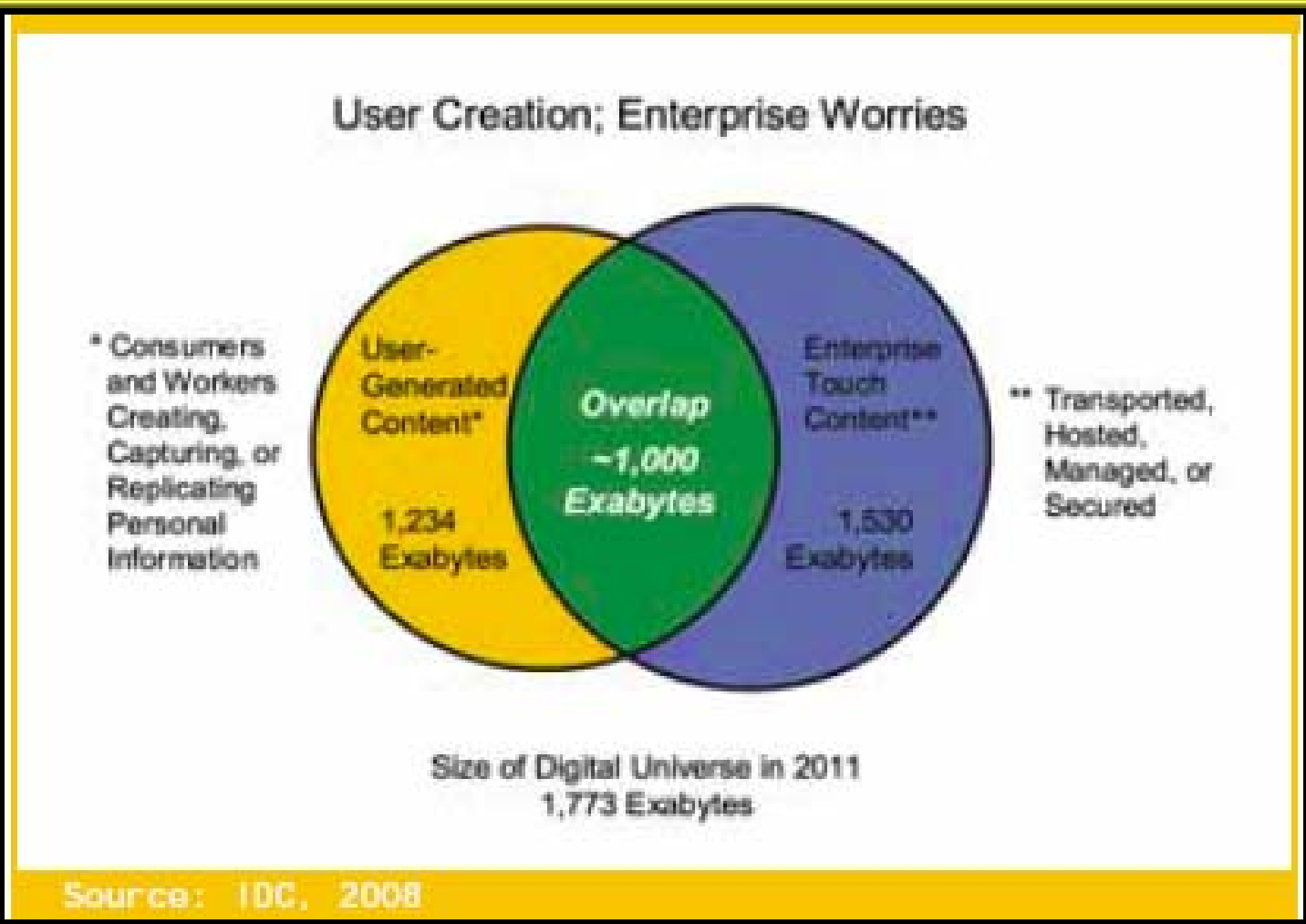
2002 1 PB

2007 6 PB

2017 ≥100 PB

Source: R. Dee, Sun Microsystems
INSIC AST Symposium, July 2007

70% is Individually Created, but…
86% is Handled by Enterprises



IDC White Paper, "The Diverse and Exploding Digital Universe," Sponsored by EMC, March 2008
http://www.emc.com/collateral/analyst-reports/diverse-exploding-digital-universe.pdf

1 TB Tape is Here!

Sun microsystems

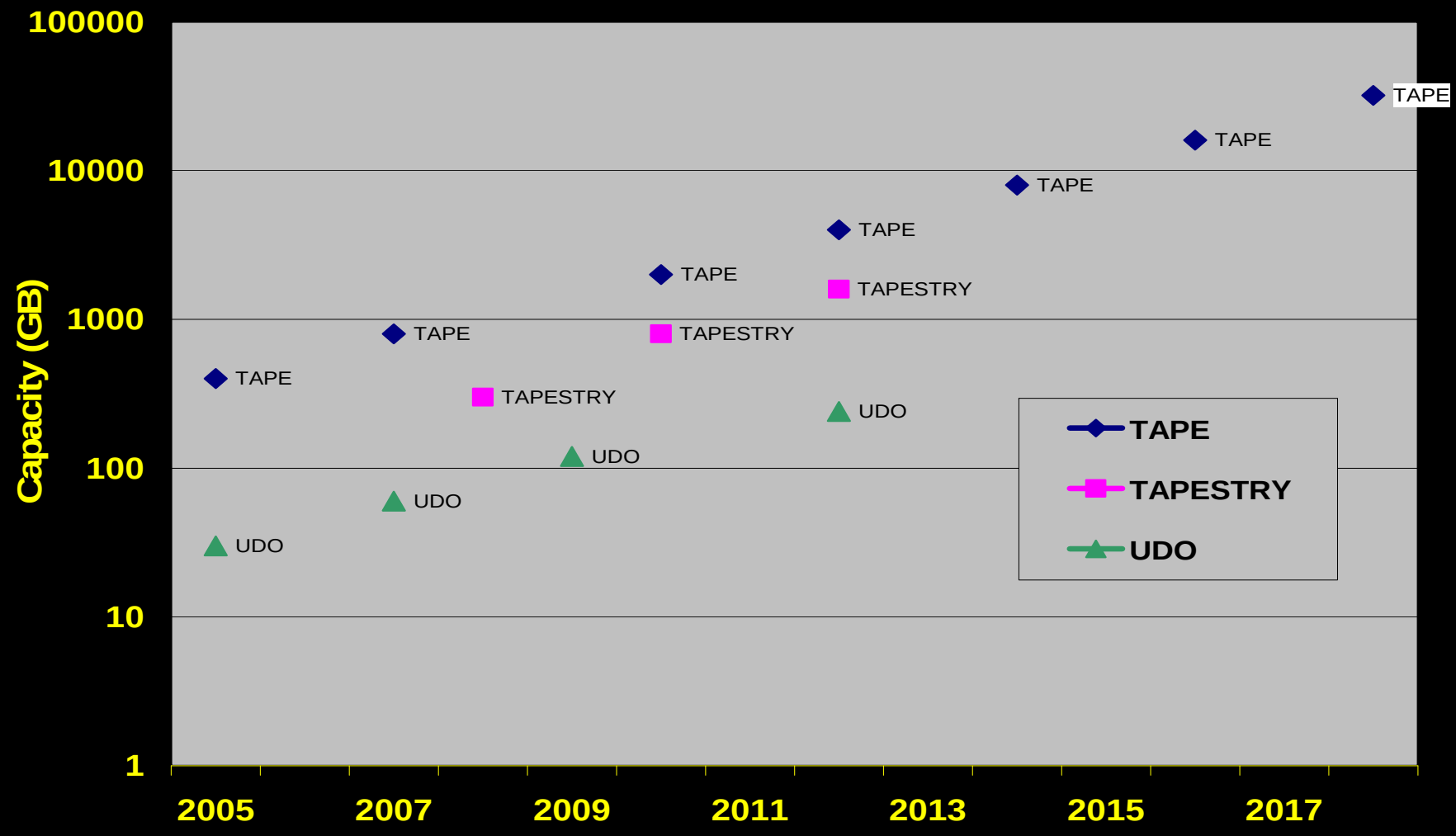
T10000B
120 MB/s

IBM

TS1130
160 MB/s

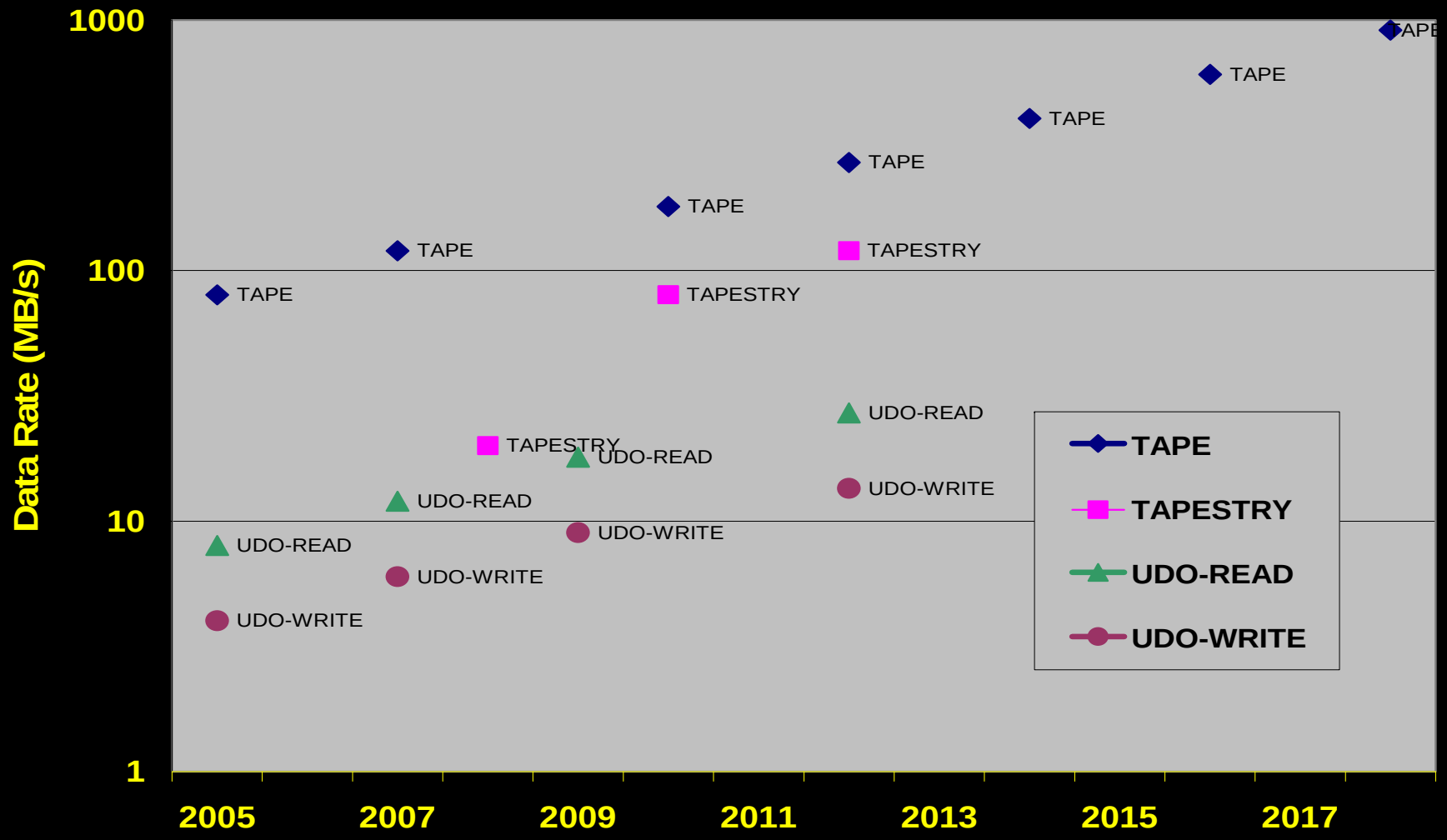
INSIC

Capacity Roadmap Comparison

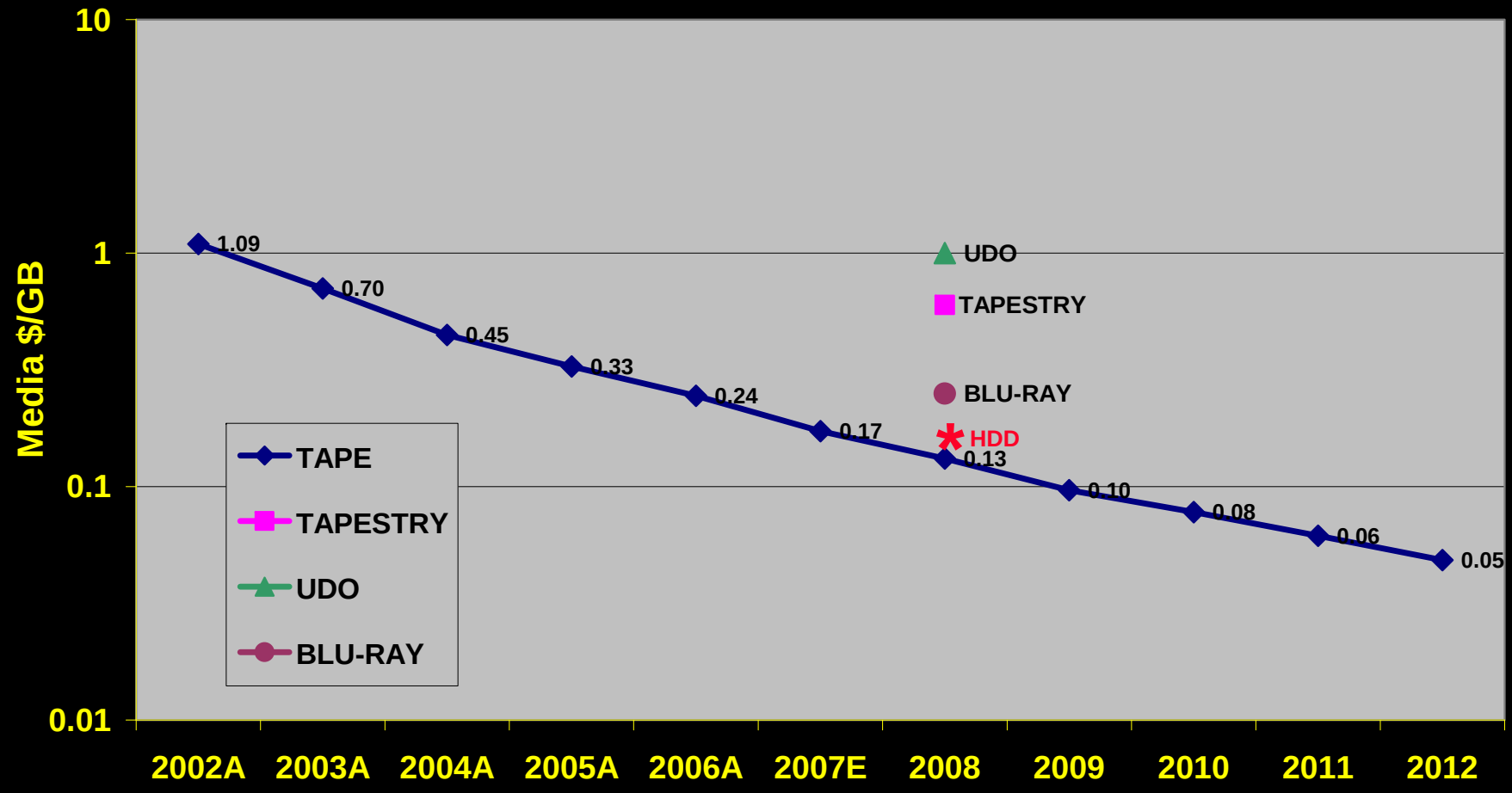


Source: INSIC Optical and Tape Roadmaps

Data Rate Roadmap Comparison



Media Cost is Critical for Archive



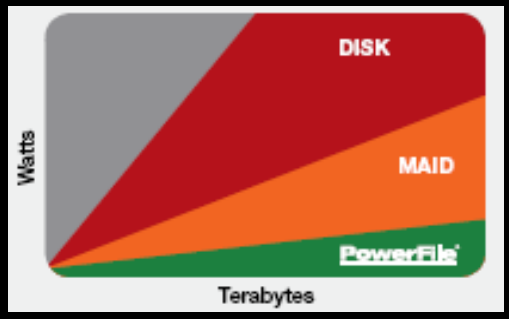
Source: Industry market research & Imation estimates; online product offerings

PowerFile Hybrid Archive

Active Archive Appliance™

combines up to 34 TB of fast, disk-based cache with up to 240 TB of Blu-ray based archive storage

capacity optimization software uses adaptive inline data reduction with intelligent algorithm selection for up to 7X reduction of data



Green Technology

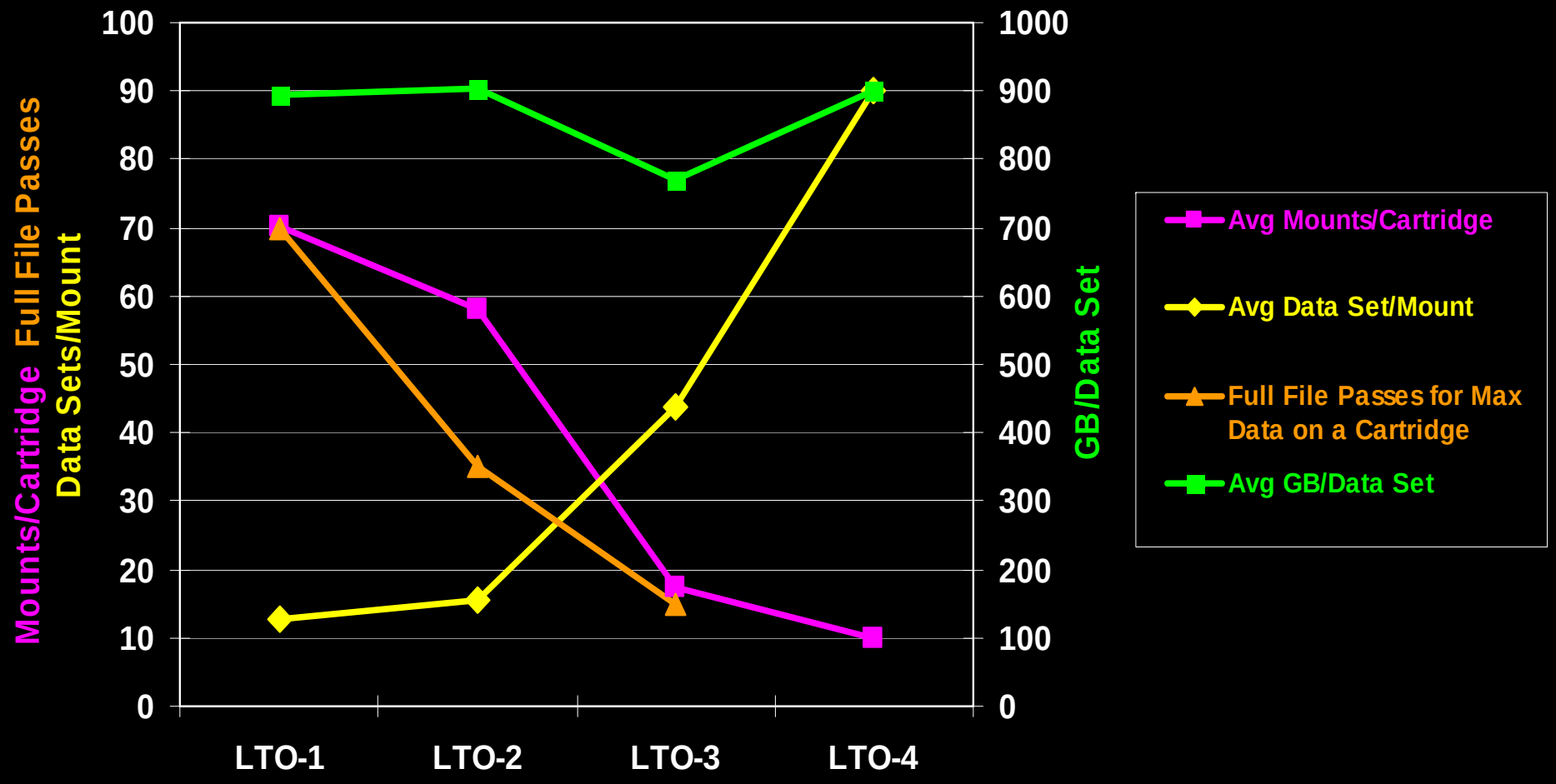
By delivering up to 350TB per Kilowatt and consuming less than 300 Watts per standard 42U rack, PowerFile uses only 5% of the power of disk-based solutions and 25% of MAID solutions making it easily the most energy efficient online storage system in the industry.

Platform Longevity

The Active Archive Appliance leverages Blu-ray® disc technology to provide unmatched system longevity. PowerFile qualified "archive grade" media has a certified shelf life from the manufacturer of 50+ years. ?

http://www.powerfile.com/

Usage Modes May Differ for Archive vs. Backup



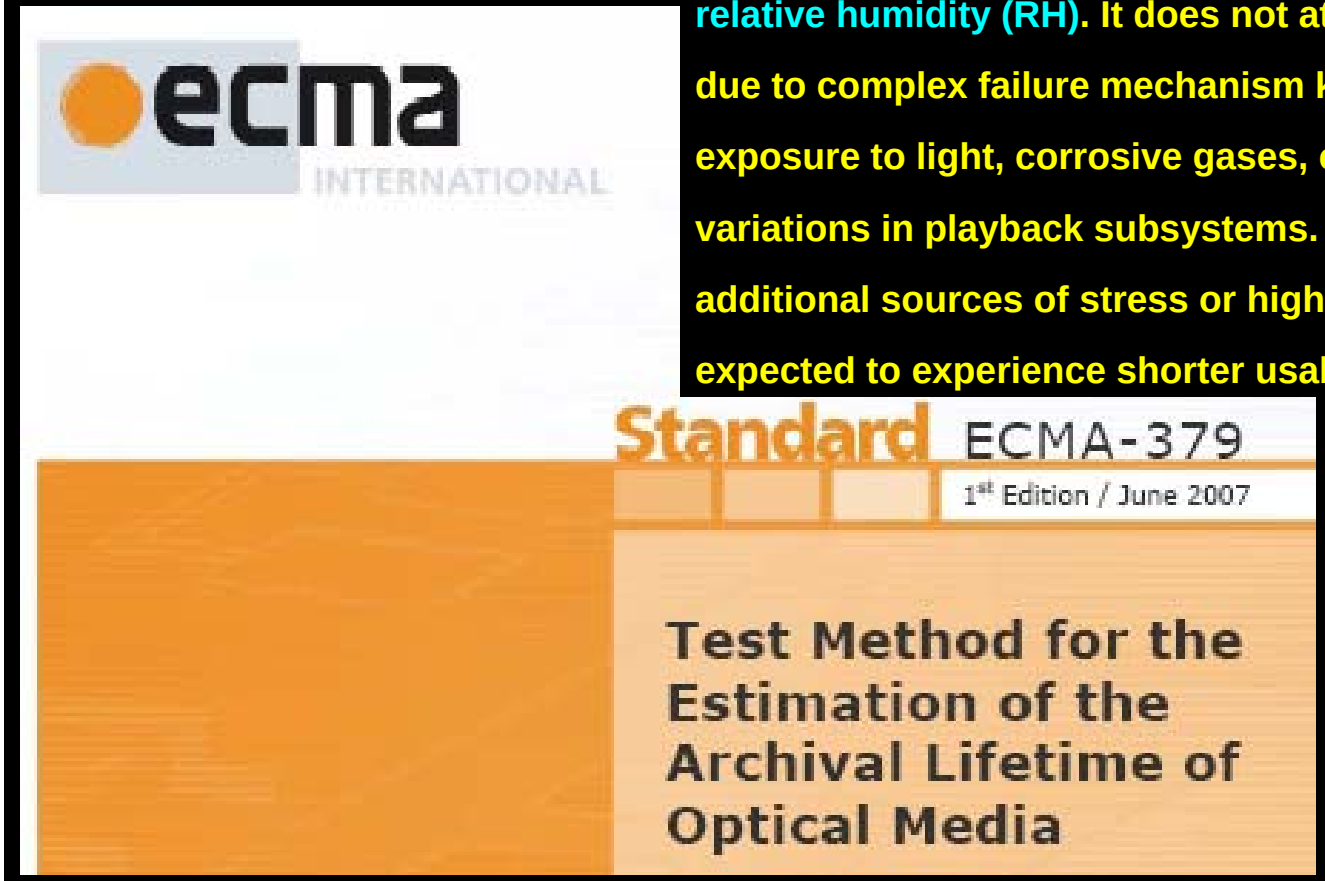
Source of Data: B. Findlay, Imation

Conclusions

- The primary threat to tape is disk
- Disk offers some unique capabilities for backup and will continue to gain share in that market
- But tape retains several inherent advantages for large installations and will not disappear
  - Lowest cost
  - Lowest energy
- The digital information explosion and increased regulatory requirements are driving strong growth in the market for archival storage
- Tape should seek to strengthen its already strong position in the large enterprise archival market by
  - Continuing to advance technology and reduce cost
  - Understanding the special properties required for archival storage
  - Developing complete purpose-built archival solutions

New Standard for Optical Disk Archival Test

The methodology includes only the effects of temperature (T) and relative humidity (RH). It does not attempt to model degradation due to complex failure mechanism kinetics, nor does it test for exposure to light, corrosive gases, contaminants, handling, and variations in playback subsystems. Disks exposed to these additional sources of stress or higher levels of T and RH are expected to experience shorter usable lifetimes.



Tape media would benefit from doing something similar!

ISO approved a similar standard in February 2008

Tape Archival Working Group (TAWoG)

TAWoG Group Formed August-September 2007

- Representatives named from all level 2 sponsors
- Collecting inputs on what paths the group should pursue
- Similar discussions in Japan seem not to have much momentum
- Possibilities:
  - Review and summarize existing documentation on tape archival properties (publish white paper?)
  - Research tape failure mechanisms
    - chemical, thermal (magnetic), mechanical
  - Assess scope of effort to develop a test standard
  - Define "standardized" test conditions for certifying archival grade tape media and shelf life
  - Set up an independent organization to conduct media testing
  - Share experiences and test results on tape longevity
  - Define "best practices" for using/storing "archive" tape
  - Deal with the broader problem of hardware/software obsolescence

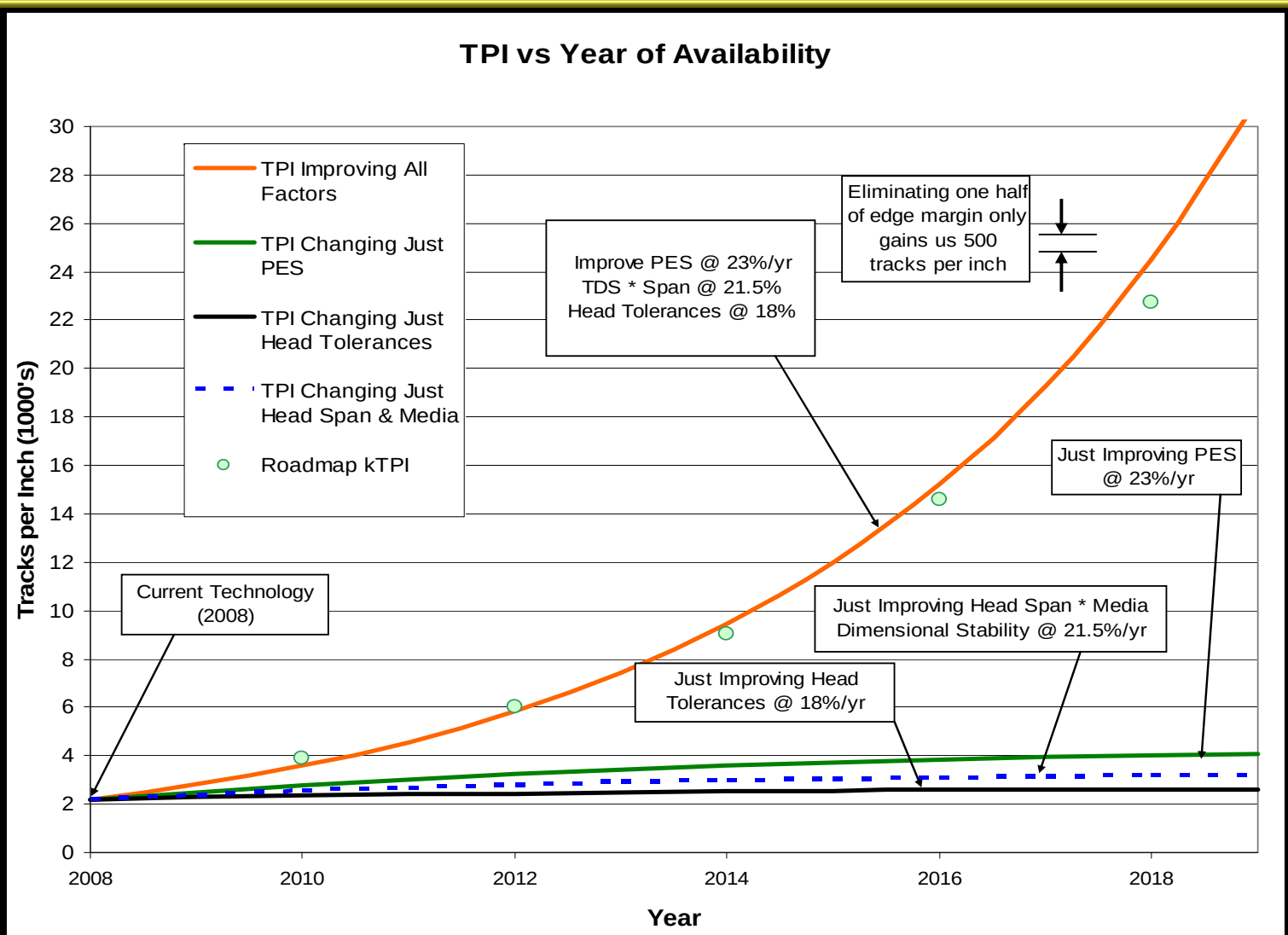
INSIC 2008 TAPE Roadmap
Technology Group Assumptions

- Disk is the major competitive technology
- Disk will grow at ~40% per year
  - » Requires tape to grow capacity at least 40% per year
  - » Technology ➔ Cost per cartridge does not increase significantly with each generation
- The tape drive data rate growth is less than the expected interface (FC) data rate growth
- Number of r/w channels is a technology number not a product specification and should be viewed as an average of possible product implementations
- Media Life and Reliability need improvement with each generation

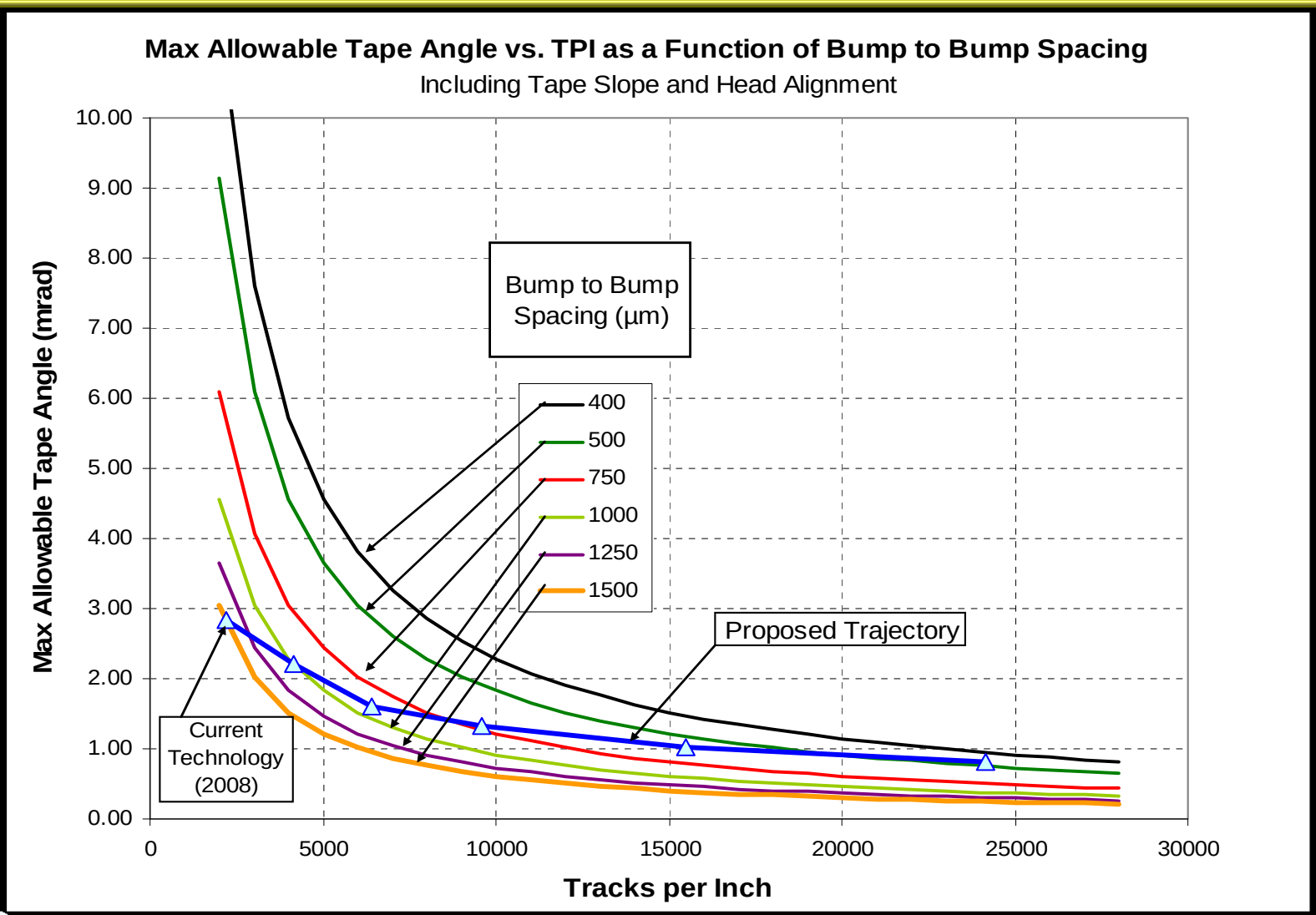
INSIC 2008 Tape Roadmap Parameters

Parameter	2007 LTO4	2010	2012	2014	2016	2018	Compared to 2005 roadmap yearly growth rate
Capacity (TB)*	0.8	2	4	8	16	32	41% per year
Data rate per channel MB/sec	7.5	8.9	10.6	12.6	14.9	17.8	17 % ⇨ 9% per year
Total data rate MB/sec	120	180	270	405	607	911	27% ⇨ 22.5% per year
FC roadmap MB/sec	400	800	1600	1600	3200	3200	
Number of channels	16	20	25	32	41	51	9.0% ⇨ 12.4% per year
Tape thickness (um)	6.6	6.00	5.90	5.40	5.30	5.00	-4% ⇨ -2.3% per year
Cust. usable tape length	740	814	828	904	921	977	6.1% defect reserve
Recordable tape length	788	867	882	963	981	1040	3.9% winding reserve
Tape length (meters)	820	902	917	1002	1021	1082	4% ⇨ 2.3% per year
Linear track density (TPI)	2209	4032	6426	9604	15490	24145	21% ⇨ 25% per year
Linear bit density (KBPI)	343	400	467	544	635	741	12% ⇨ 8% per year
Areal density (Gb/inch2)	0.76	1.61	3.00	5.23	9.83	17.88	36% ⇨ 35% per year
ECC formatting overhead	29%	26.39%	24.02%	21.86%	19.90%	18,11%	0% ⇨ -4.6% per year
Servo and layout overhead	18.00%	15.57%	13.46%	11.65%	10.07%	8.71%	0% ⇨ -7.0% per year
Tape speed (meters/sec)	6.3	6.1	6.1	6.0	6.0	5.9	5% ⇨ -0.4% per year
Number of passes to fill a tape	56	84	109	131	171	214	12.4% per year
Number of passes to EOL	14659	21825	28238	34133	44386	55631	260 Full file w/r for EOL
Time to fill a tape in minutes	111	185	247	329	439	585	15.5% per year

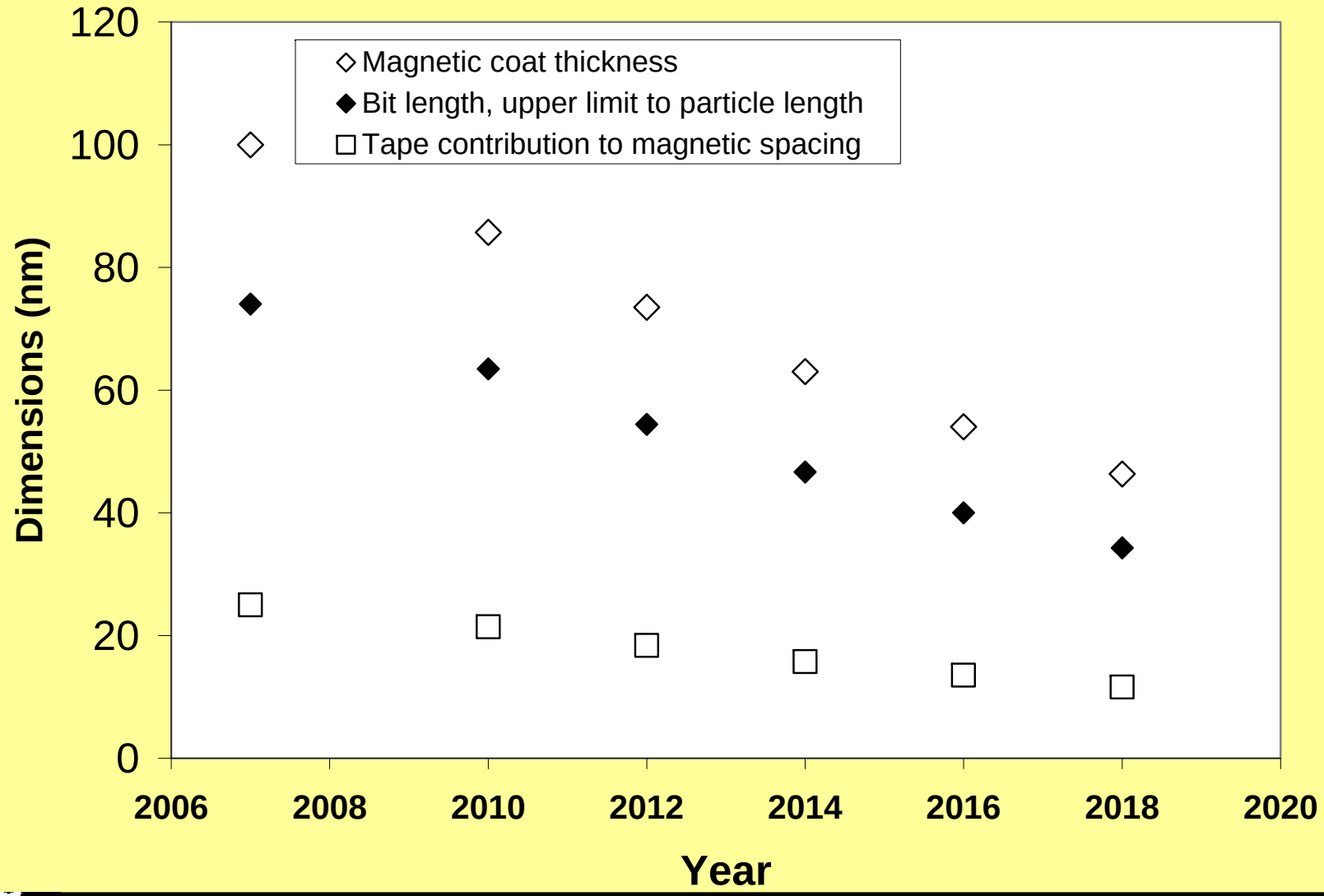
INSIC 2008 TAPE Roadmap
24 KTPI Requires Many Simultaneous Improvements



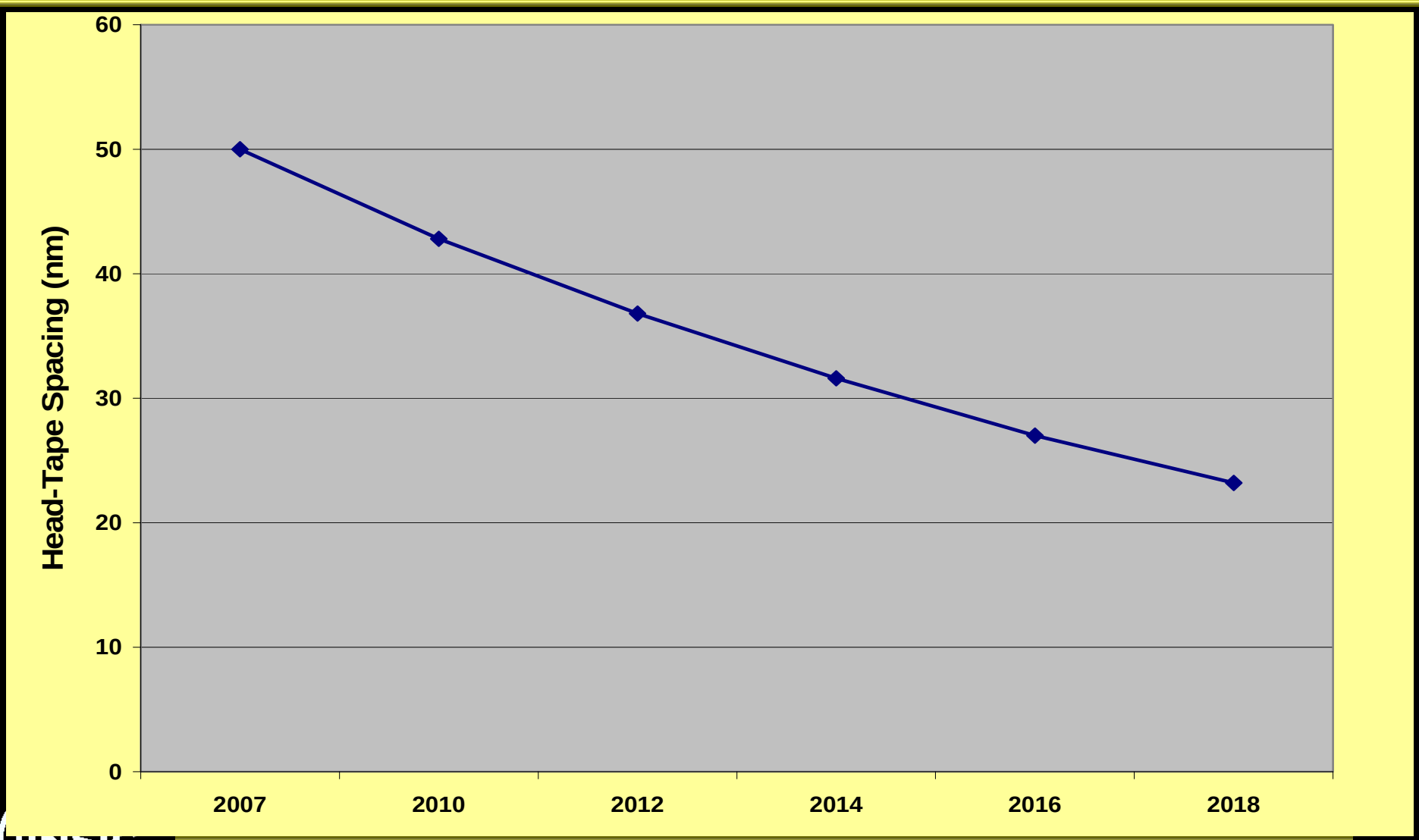
INSIC 2008 TAPE Roadmap
Critical Interaction Between Head & Transport



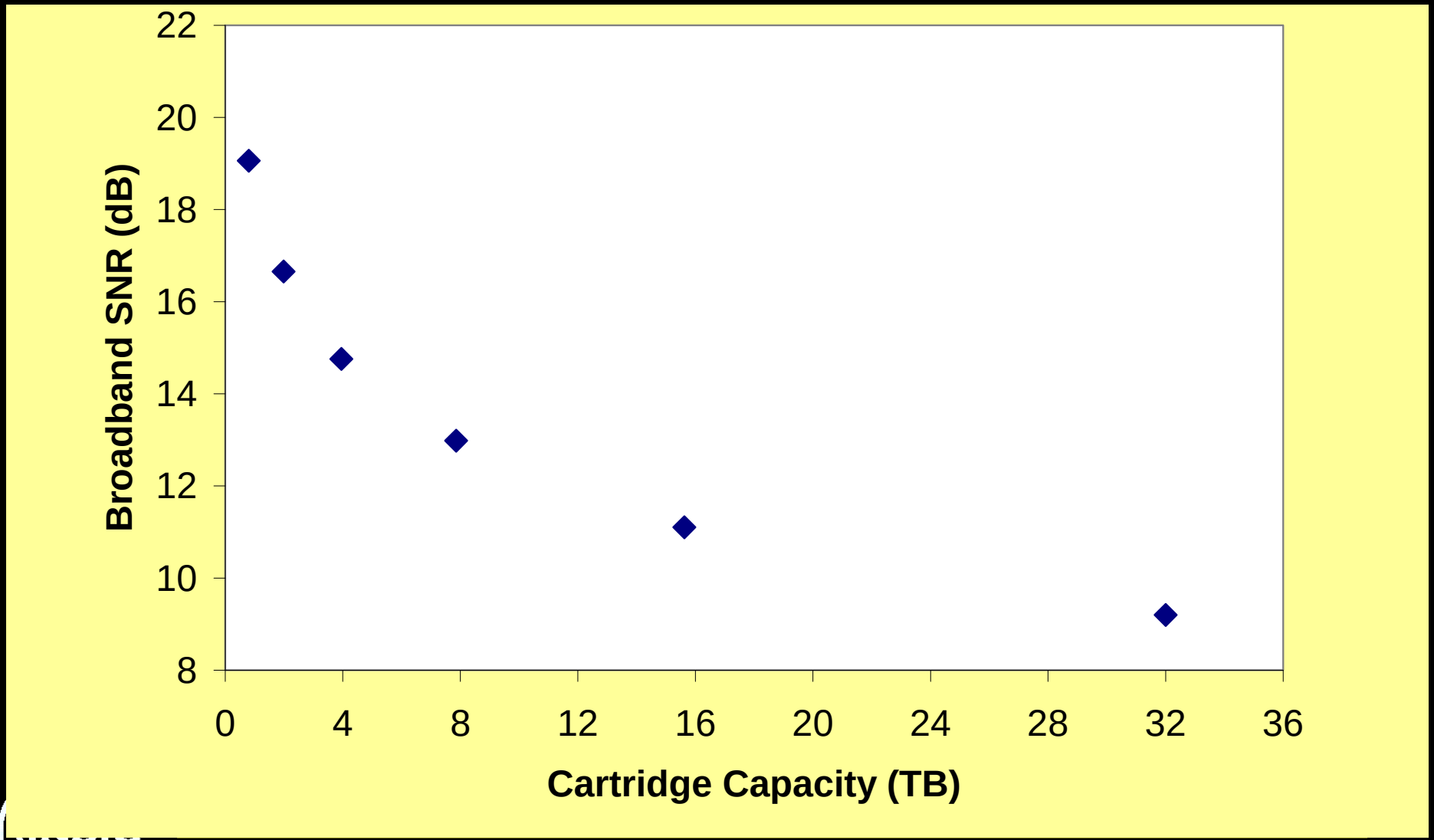
INSIC 2008 TAPE Roadmap
Critical Media Parameters



INSIC 2008 TAPE Roadmap
Head-Tape Spacing Will be Challenging



INSIC 2008 TAPE Roadmap
Signal-to- Noise Projections < 10 dB



INSIC 2008 TAPE Roadmap
Channel Must Handle Many Noise Sources

Noise Source	Description/Comments	Ranking	Seen in Disk
Media noise	Non-uniform size, orientation and distribution of magnetic particles in the media plus granularity of the recording medium -- finite number of particles per bit	1	Yes, much less
Head/tape separation increase	Large average head/tape separation	2	Yes, much less
Head/tape separation variation	Dynamic variations in head/tape spacing	2	Yes, much less
Media coating thickness variations	Impact to disk is radically different. Particulate media variation is much worse than thickness variation seen in sputtered disk media	3	Yes, limited
Head stain	Buildup on head that attenuates signal and causes head/tape separation; largely due to particulate media	3	Yes, much less
Pole tip recession	Wearing away of magnetic structure, similar in effect to head stain	3	Yes, much less
Thermal asperities	Head to tape contact causing the MR head to experience a DC shift due to heating or cooling; somewhat less in disk because of head flight	3	Yes, somewhat less
Short dropouts	Small areas on the media where the coating does not function as intended give rise to short dropouts in signal strength. Errors due to short dropouts are correctable by C1 ECC.	4	Yes
Long dropouts	Large areas on the media where the coating does not function as intended give rise to long dropouts in signal strength. Errors due to long dropouts require correction by C2 ECC and may be caused by media defects, debris, or scratches, etc.	4	No
Electrical noise	Electrical noise in preamp, printed circuit board assembly, cables, and connectors	5	Yes
Thermal noise	Noise introduced by the read head	5	Yes
Writer to writer crosstalk	Crosstalk from one writer into adjacent writers, or between write signals on the flex circuit	5	No
Writer to reader crosstalk	Crosstalk during read while write	5	No
Head clogs	Head becomes clogged and produces severely attentuated output	6	No
Barkhausen noise	Head noise arising from fluctuations of magnetic domain walls in the magneto-resistive (MR) sensor	6	Yes
Transition jitter	Non-stationary data-dependent noise associated with high-frequency issues during write equalization	7	No
Adjacent track crosstalk	Crosstalk due to reader approaching adjacent tracks; likely to increase with higher track density	7	Yes
Azimuth loss	Skew between head and tape causes azimuth error	7	No
Tape speed variations	Tape speed variation stresses timing recovery	8	No
Overwrite noise	Reading of old data that was not overwritten well due to write process variations and/or separation	9	Yes
Read head nonlinearities	MR heads saturate and/or operate in the nonlinear region	10	Yes
Azimuth loss due to media interchange	Interchange of media between drives with heads at different angles	11	No
Transition noise	Zigzag erasure does not exist in particulate media, but will be seen on conversion to sputtered or ME media; ranking will then move to 4 or 5	12	Yes

INSIC 2008 TAPE Roadmap
Key Technology Challenges

Heads
- Surface science and tribology of head/media materials and lubricants
- Head contour for low tape tension and high tape speed

Media
- Head-media integration and tribology of very smooth surfaces
- Fundamental understanding of system SNR requirements

Transport
- Alternative guiding technologies
- Azimuth compensation of tape expansion

Channel
- Development of noise decomposition and characterization tool
- Reverse concatenation of ECC (product codes) and modulation code

Questionnaire Results and Discussion