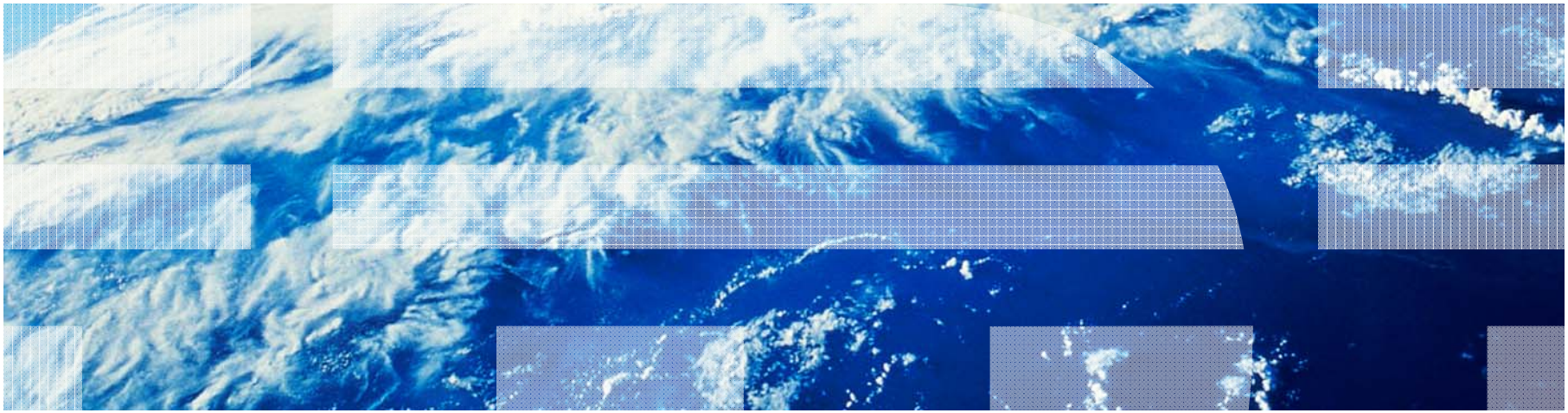
Robert Fontana – Research Scientist, IBM systems and Technology Group

20 September 2012

How to store stuff at specified sizes and specified dates in the future?

Memory Landscape for TAPE, HDD, NAND Flash

- Industry Size
- Areal Density
- Volumetric Measures
- Options



PB Shipments -- TAPE, NAND, HDD -- Product Space

	YE2008	YE2009	YE2010	YE2011
HDD				
Units (HDDs millions)	540	557	652	620
PB Shipped (PB)	125000	200000	330000	335000
Areal Density (Gb/in²)	380	530	635	750
Revenue ($ billions)	34.0	34.0	33.0	33.5
$/GB Shipped	0.272	0.170	0.100	0.100
NAND				
Units (2GBs millions)	1500	2715	5232	9326
PB Shipped (PB)	3000	5430	10464	18600
Areal Density (Gb/in²)	200	280	330	550
Revenue ($ billions)	10.0	12.1	18.5	21.5
$/GB Shipped	3.33	2.23	1.77	1.16
LTO TAPE				
Units (Cart. Millions)	20	24	23	25
PB Shipped (PB)	10400	12165	15300	17800
Areal Density (Gb/in²)	0.9	0.9	1.2	1.2
Revenue ($ billions)	1.0	0.7	0.7	0.7
$/GB Shipped	0.093	0.061	0.046	0.038

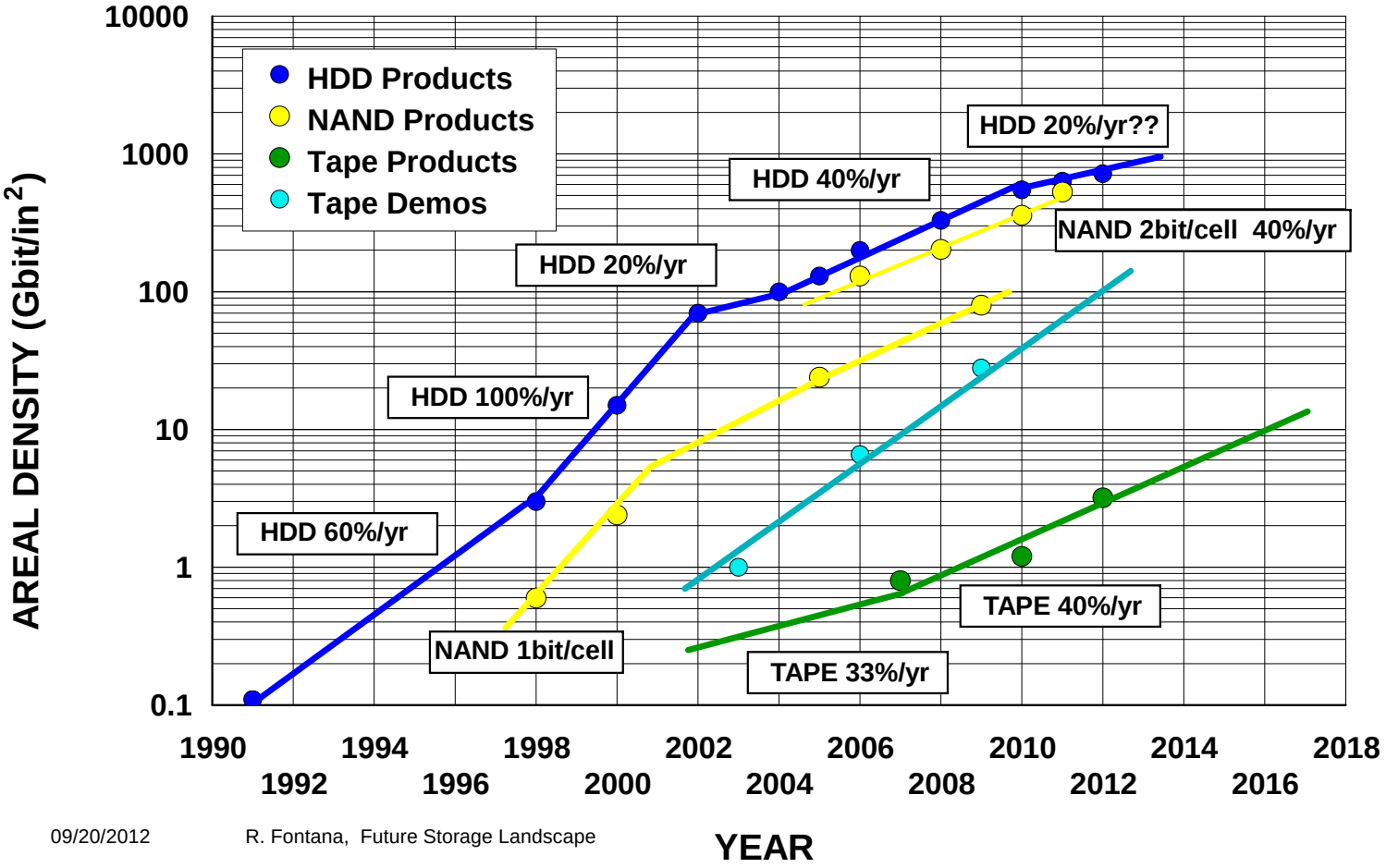
{ Large Consumer Base
Supply Issues
Consolidation
Stable Prices in 2010,2011
Archive and Enterprise PB
~ **50,000 PB** in 2012

{ Large Consumer Base
Lithography Advances
Manufacturing Investment
Archive and Enterprise PB
~ **4,000 PB** in 2012

{ No Consumer Base
Archive and Enterprise PB
> **17,800 PB** in 2012

Storage Device Density Landscape – A History

- **Sustained increases in the areal density of a technology is a measure of technology robustness**
- **For HDD and NAND, annual areal density increases of 40%, the norm until 2010, have decreased to the 20% range (bit endurance issues)**
- **For TAPE, annual areal density continue at a 40% annual increase**



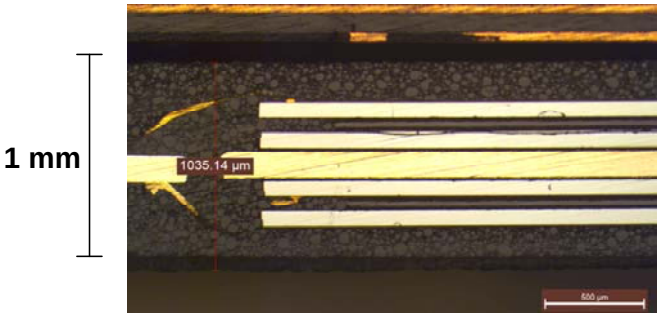
Volumetrics (Today) for HDD, NAND, TAPE

HDD (3 TB 3.5” Drive)

-- Areal Density	730 Gbit/in²
-- Media Density	2.4 Tb/in³
-- Component Density	126 GB/in³

NAND (0.5 TB 2.5” Form Factor Drive)

-- Areal Density	550 Gbit/in²
-- Media Density	6.7 Tb/in³
-- Component Density	121 GB/in³



TAPE (1.5 TB LTO5 Cartridge)

-- Areal Density	1.2 Gbit/in²
-- Media Density	0.7Tb/in³
-- Component Density	106 GB/in³

Volumetrics (Future)

- **HDD Scenario (20% per year density increase) – Add platters to reach HDD capacity points**
  - In 2012 the highest capacity 3.5” HDD platter is ~ 1 TB
  - An extra platter adds 1 disk ($3) and 2 heads ($6)
  - Changes in the 3.5” HDD form factor and/or closer disk spacing
  - An example
    - Today – 3 TB HDD with 3 platters
    - Next Year – 5 TB HDD with 4 platters and 20% areal density increase
- **NAND Scenario (a minimum of 20% per year density increase) – More chips per package, new SSD form factors**
  - In 2012 the highest capacity NAND chip for 2 bits per cell is 8 GB. The next logical chip size of 16 GB would require 16 nm lithography for 2 bits per cell or today’s lithography at 3 bits per cell but with significant endurance loss
  - Apple uses a “gum stick” form factor for SSDs in the MacBook Air with 2x to 3x density improvement
  - There is an ongoing package revolution allowing for more chips per package
- **TAPE Scenario (a minimum of 40% per year density increases**)
  - Present LTO5 cartridge capacity is 1.5 TB
  - Match HDD capacity points with areal density
  - Increase tape length to exceed HDD capacity points (access time issues)

Summary

- HDD and NAND annual areal density increases slowing to ~ 20% with main limiter being cell size – lithography and thermal fluctuations
- TAPE annual areal density increases maintaining traditional roadmaps of ~ 40% with the possibility of greater density increases owing to large feature sizes
- HDD $/GB will not decrease at past historical rates (see 2011, 2010)
- NAND $/GB (chip) decreases will continue if 3 bit cell low endurance cycles are tolerated by the user
- TAPE $/GB (cartridge) decreases will continue at historical levels
- Presently (2011), TAPE, HDD, and NAND are volumetrically equivalent at the SSD, HDD, or cartridge level.
- **Future HDD, TAPE, and NAND components will stress volumetric improvements over area density improvements**
- **Future system adjustments**
  - **Accommodate lower endurance cycles in NAND**
  - **Accommodate shingled writing (almost like tape) in HDD for intermediate density improvements**