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

<table>
<thead>
<tr>
<th></th>
<th>YE2008</th>
<th>YE2009</th>
<th>YE2010</th>
<th>YE2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>HDD</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Units (HDDs millions)</td>
<td>540</td>
<td>557</td>
<td>652</td>
<td>620</td>
</tr>
<tr>
<td>PB Shipped (PB)</td>
<td>125000</td>
<td>200000</td>
<td>330000</td>
<td>335000</td>
</tr>
<tr>
<td>Areal Density (Gb/in²)</td>
<td>380</td>
<td>530</td>
<td>635</td>
<td>750</td>
</tr>
<tr>
<td>Revenue ($ billions)</td>
<td>34.0</td>
<td>34.0</td>
<td>33.0</td>
<td>33.5</td>
</tr>
<tr>
<td>$/GB Shipped</td>
<td>0.272</td>
<td>0.170</td>
<td>0.100</td>
<td>0.100</td>
</tr>
</tbody>
</table>

| 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

![Graph showing areal density trends for HDD, NAND, and TAPE from 1990 to 2018.](image)
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