Trends

- Trend discussion to be published in Journal of Applied Physics, April 2015
- Today’s Environment

<table>
<thead>
<tr>
<th>Component</th>
<th>NAND SSD</th>
<th>HDD</th>
<th>LTO TAPE</th>
<th>ENT TAPE</th>
<th>OPTICAL BD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.5” drive</td>
<td>3.5” drive</td>
<td>LTO cartridge</td>
<td>Enterprise cartridge</td>
<td>12 disk cartridge</td>
</tr>
<tr>
<td>Volumetric Strategy</td>
<td>2 bits/cell</td>
<td>5 platters</td>
<td>840 m tape</td>
<td>840 m tape</td>
<td>3 layer disk</td>
</tr>
<tr>
<td>Capacity</td>
<td>1 TB</td>
<td>5 TB</td>
<td>2.5 TB</td>
<td>4 TB</td>
<td>1.2 TB</td>
</tr>
</tbody>
</table>

- Best Case Scenarios

<table>
<thead>
<tr>
<th>Component</th>
<th>AD Increase (2008-20013)</th>
<th>5 Year AD Increase (2019)</th>
<th>10 Year AD Increase (2014)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LTO TAPE</td>
<td>28%/yr</td>
<td>3.4X</td>
<td>11.8X</td>
</tr>
<tr>
<td>ENT TAPE</td>
<td>28%/yr</td>
<td>3.4X</td>
<td>11.8X</td>
</tr>
<tr>
<td>OPTICAL BD</td>
<td>12%/yr (18%/yr)</td>
<td>2.3X</td>
<td>5.2X</td>
</tr>
<tr>
<td>NAND</td>
<td>35%/yr</td>
<td>4.5X</td>
<td>20.1X</td>
</tr>
<tr>
<td>HDD</td>
<td>18%/yr</td>
<td>2.3X</td>
<td>5.2X</td>
</tr>
</tbody>
</table>
### 2015 Scenario

- **HDD**
  - No HAMR **yet**
  - More platters
  - “Duopoly” and technology

- **TAPE**
  - LTO7 will deliver on capacity target (6 TB) in the consortium roadmap

- **Optical BD**
  - Land and Groove recording and double sided disks?

- **NAND**
  - 2D 16 nm cells pervasive
  - Some 2D 13 nm cells
  - 3D multi-layer adopted by all NAND companies

### 2016, 2017, 2018 Scenario

- **HDD**
  - No HAMR **yet** (2017?)
  - More platters?
  - HDD companies and SSDs

- **TAPE**
  - LTO8 will deliver on capacity target (12 TB) in the consortium roadmap

- **Optical BD**
  - Land and Groove recording and double sides disks?

- **NAND**
  - 3D multi-layer pervasive
  - By 2018 (+4 Years from today) density goes up by a factor of $1.35^4 = 3X$ minimum
  - NAND investment for increased capacity?
### 2018 and Beyond

- **HDD**
  - Density plateaus at 2.0 Tbit/in\(^2\) to 2.5 Tbit/in\(^2\).

- **TAPE**
  - Thin film media

- **Optical BD**
  - Difficult transition to 300 - 500 GB platters

- **NAND -3D**
  - Will 80+ layer structures be feasible assuming 4 processing cycles of 20 layers each
  - Will cost issues close
  - Will PB shipments approach HDD

- **NAND replacing HDD (16 nm node)**
  - $3.5B NAND factory produces 2.5 EB
  - 100 EB requires 40 factories ($125B)