
A Ten Year (2008-2017) Storage Landscape -- \$/GB and Exabytes LTO Tape Media, HDD, NAND



A Ten Year (2008-2017) Storage Landscape: LTO Tape Media, HDD, NAND \$/GB and Exabytes



- Topics
 - General Observations
 - \$/GB Trends
 - Revenue Trends
 - Exabyte Production
 - Manufacturing Realities
 - The Future

- Key Points
 - Reality check for annual \$/GB reductions and annual Exabyte production increases
 - Provide a perspective on future capabilities on Exabyte production
 - Gain a perspective of “large numbers” associated with storage technologies

2016-2017 % CHANGE	EB	REVENUE	\$/GB
LTO TAPE MEDIA	11%	1%	-9%
HDD	13%	-3%	-15%
NAND	45%	45%	0%
TOTAL	17%	26%	NA

10 Year Storage Landscape



	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
HDD										
Units (HDD millions)	540	557	652	620	577	551	564	470	425	406
PB Shipped (PB)	125000	200000	330000	335000	380000	470000	549000	565000	693000	780000
Areal Density (Gb/in ²)	380	530	635	750	750	900	900	1000	1100	1200
Revenue (\$B)	34.0	34.0	33.0	33.5	37.5	33.4	33.4	28.3	26.8	26.1
\$/GB Shipped	0.272	0.170	0.100	0.100	0.100	0.071	0.061	0.051	0.039	0.033
NAND										
Wafers (12"-millions)	7.3	8.3	9.7	11.3	12.1	13.7	14.8	15.9	17.0	18.1
PB Shipped (PB)	3000	5430	10464	18600	28000	39000	62500	83000	120000	175000
Areal Density (Gb/in ²)	200	280	330	550	550	850	1200	1500	2000	2500
Revenue (\$B)	10.1	12.1	18.5	21.5	22.0	24.0	32.2	33.2	38.7	56.5
\$/GB Shipped	3.33	2.23	1.77	1.16	0.78	0.615	0.515	0.401	0.320	0.320
LTO TAPE MEDIA										
Units (Cart millions)	27.1	24.3	25.0	24.3	23.4	21.6	22.2	19.4	19.4	18.0
PB Shipped (PB)	11050	11960	15340	18420	20680	24270	30100	33020	40320	44850
Areal Density (Gb/in ²)	0.9	0.9	1.2	1.2	2.1	2.1	2.1	4.1	4.1	8.0
Revenue (\$B) [SCCG]	1.0	0.7	0.7	0.7	0.62	0.54	0.50			
Revenue (\$B) [LTO.org]								0.59	0.65	0.66
\$/GB Shipped	0.0905	0.0585	0.0456	0.0380	0.0300	0.0222	0.0166	0.0177	0.0162	0.0147

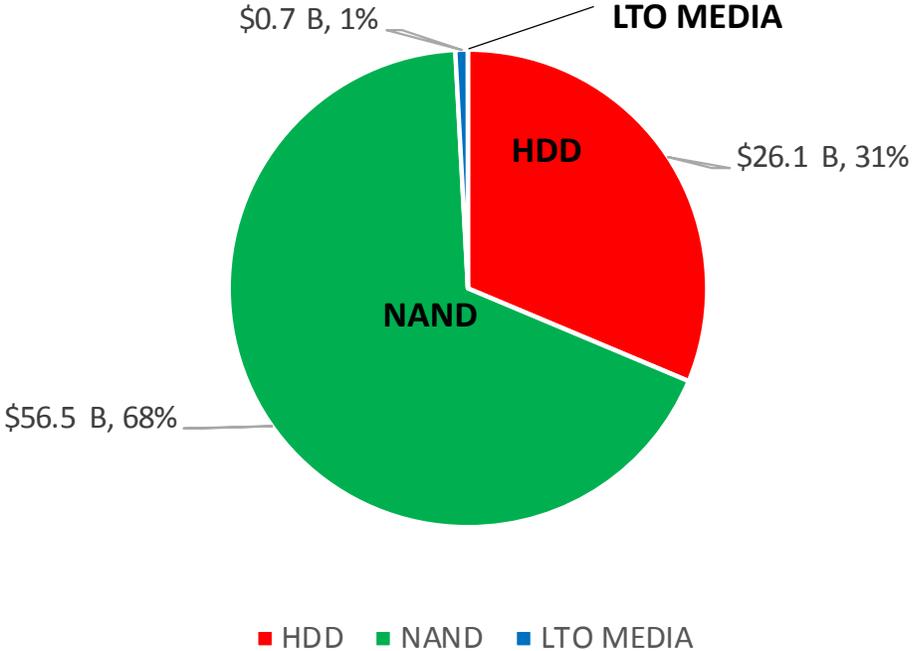
*R. Fontana, G. Decad
AIP Advances
Volume 8, Issue 5,
056506 (2018) with 2017
data added*

Major Observations (2017)

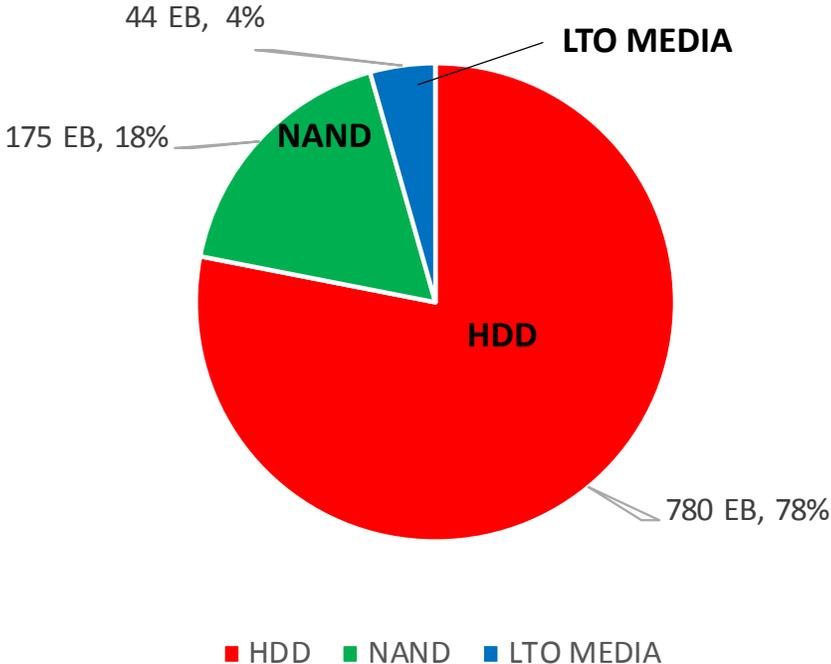


- **NAND vs HDD**
 - NAND revenue exceeds HDD revenue by 2.2X (\$56.5 B vs. \$26.1 B)
 - HDD EB shipments exceeds NAND EB shipments by 4.5X (780 EB vs 175 EB)

2017 Storage Component Revenue



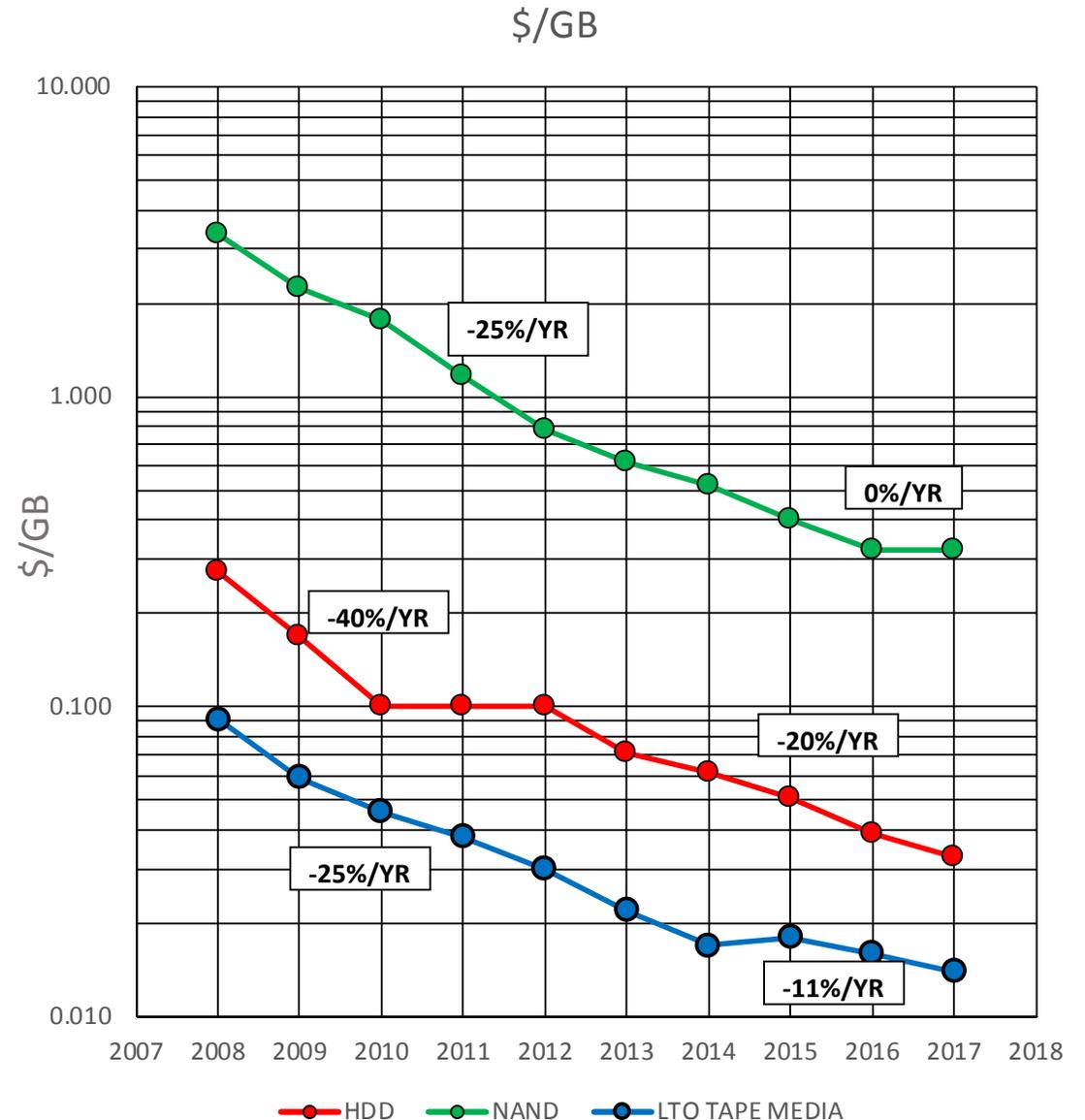
2017 EB Shipments



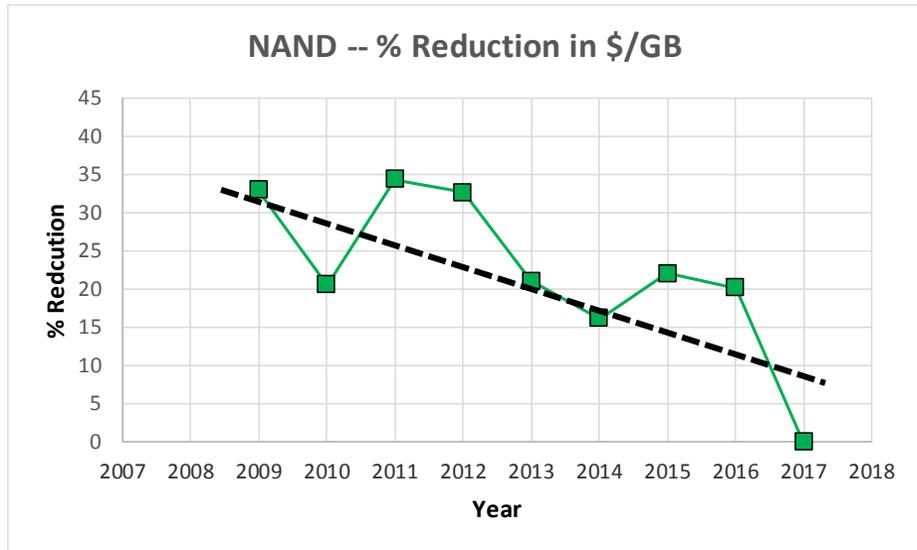
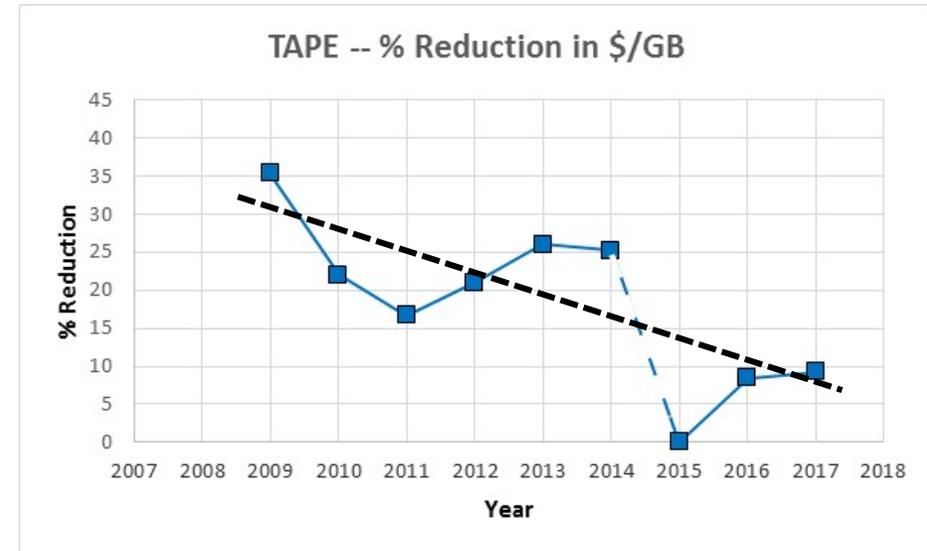
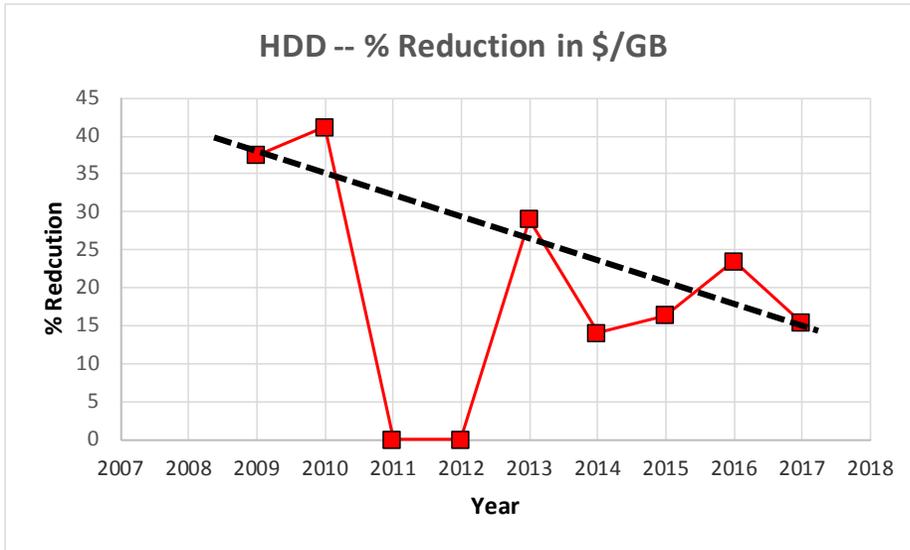
\$/GB – A Geometric Environment



- \$/GB show geometric trends: $C_N = C_0 \times (1 - \alpha)^N$
- NAND: First time in 10 years that \$/GB deviated from 25%/YR decrease but now at **“0%/YR”** (supply-demand imbalance)
- HDD: \$/GB sustains 20%/YR decrease for 5 consecutive years but 2011-2012 supply line issues ended the earlier 40%/YR decreases and annual revenue continues to decrease
- TAPE: \$/GB decreases for last 3 years of 10%/YR are less than historical values of 25%/YR. Possible source supply issue for BaFe media.



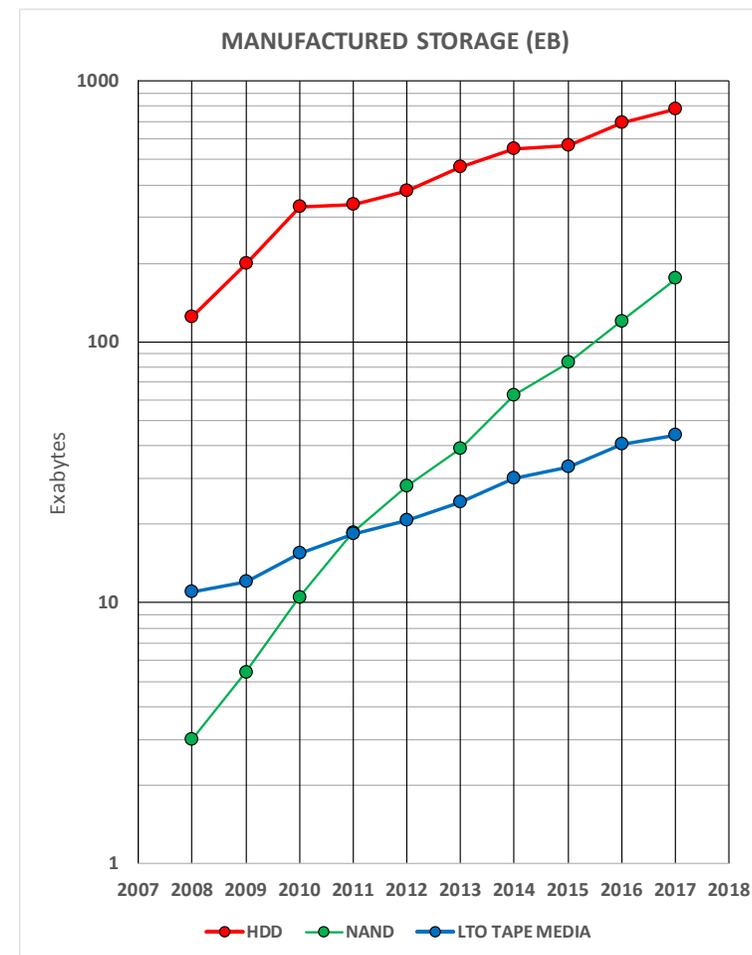
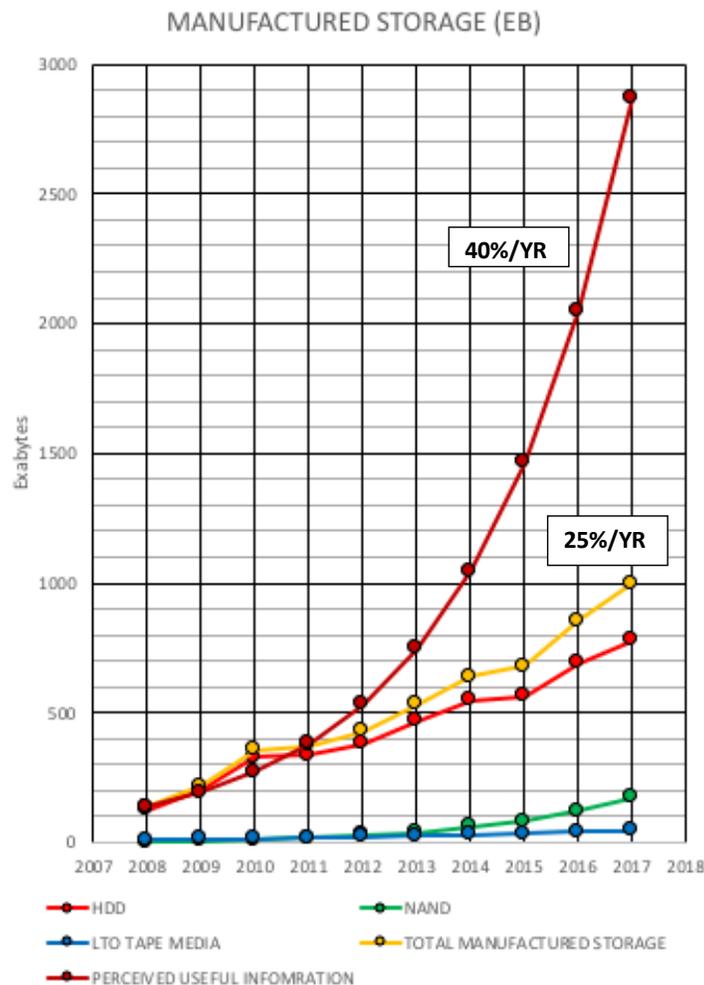
- Annual percentage of \$/GB reductions is decreasing



\$/GB Reductions are Slowing
Smaller bit cells are more costly on a per area basis

Manufactured PB History

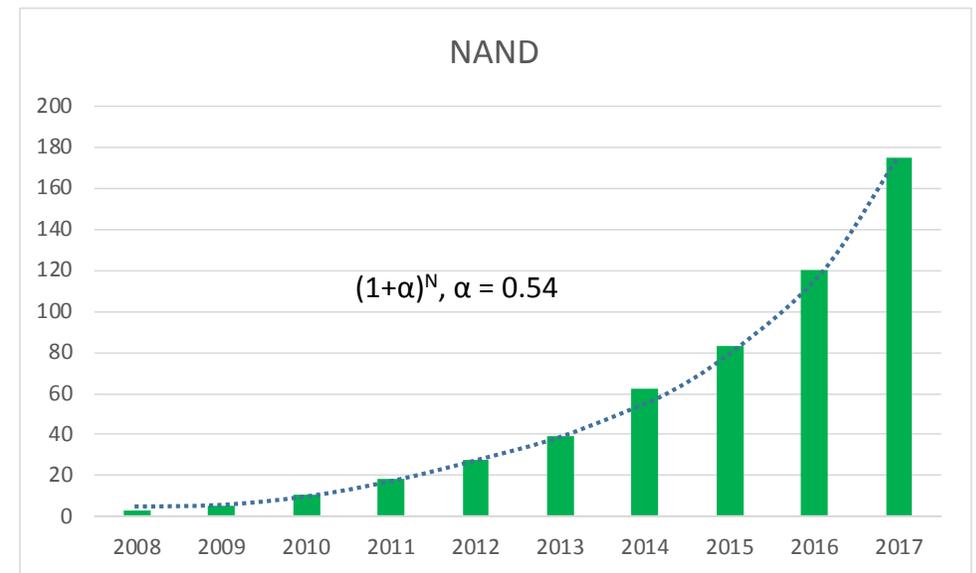
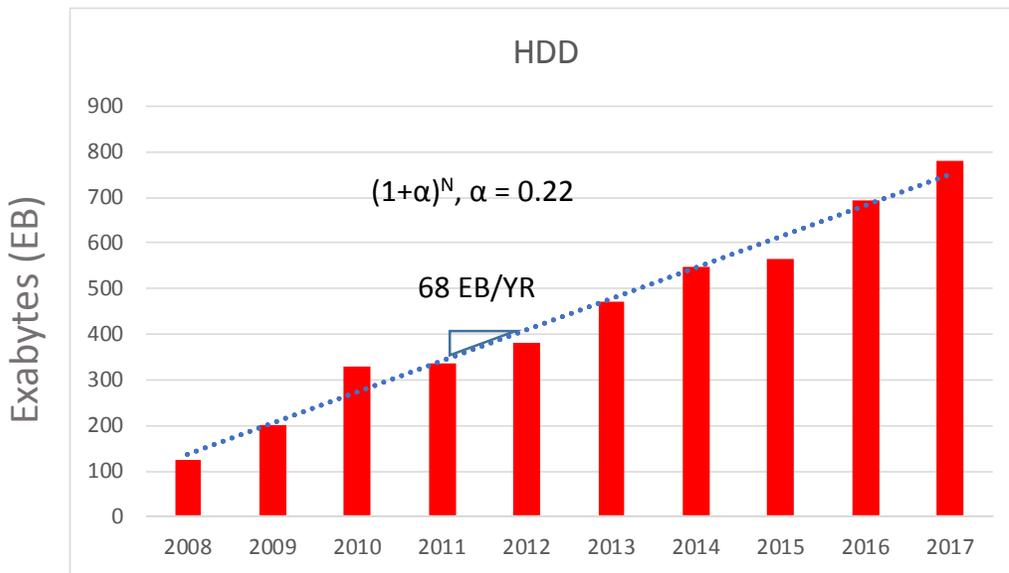
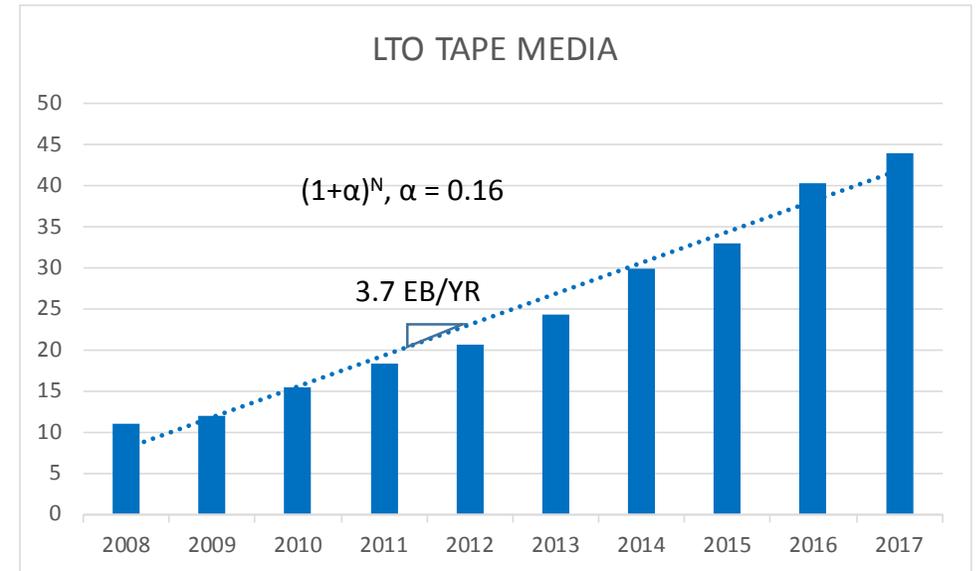
- Manufactured storage, i.e. EB, does not follow a geometric growth pattern
- HDD and NAND have consumer components that sustain growth with LTO Tape deals exclusively with client based applications
- Growth on an annual percentage basis is slowing with about 90EB being added annually



Geometric or Linear EB Growth for Memory Components

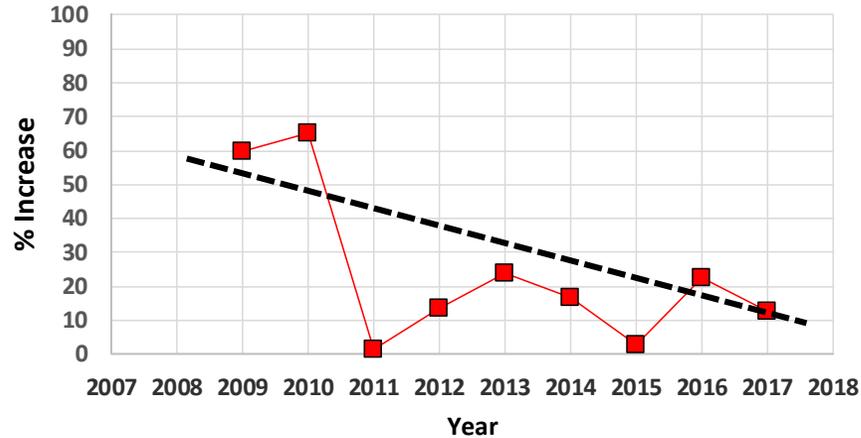


- Linear EB growth for HDD and TAPE (i.e. magnetics)
 - Only one or two competitors
 - Planar (2D) scaling becomes more difficult
 - Consumer market: erosion for HDD and not applicable for TAPE
- Geometric EB growth for NAND
 - Multiple competitors (4-5)
 - 3D scaling and bit/cell scaling
 - Consumer market (e.g. iphone)
- Growth: $(1+\alpha)^N \sim (1+ N\alpha)$ for small α

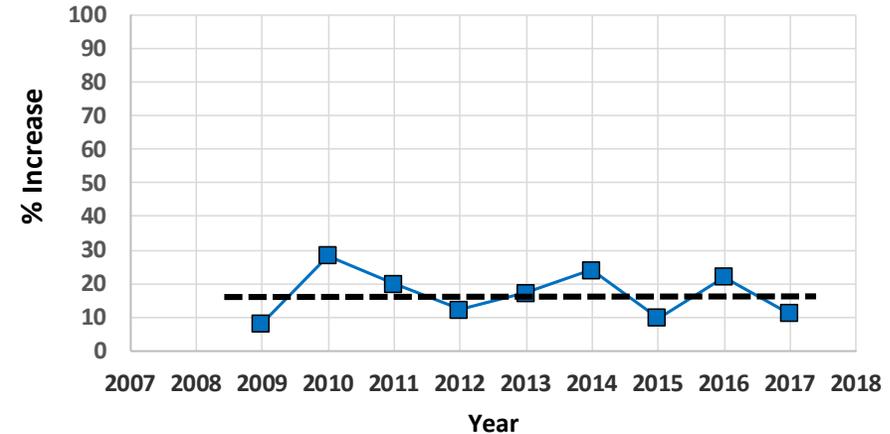


- Annual percentage of increases in manufactured PB is decreasing

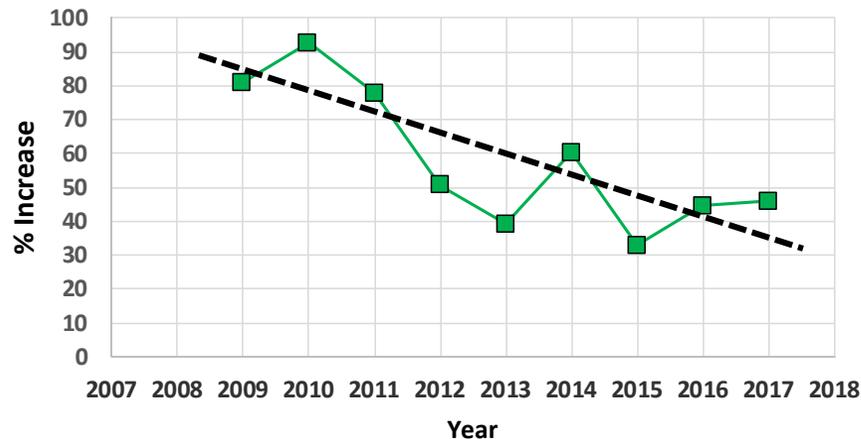
HDD -- % Increase in Manufactured PBs



TAPE -- % Increase in Manufactured PBs



NAND -- % Increase in Manufactured PBs

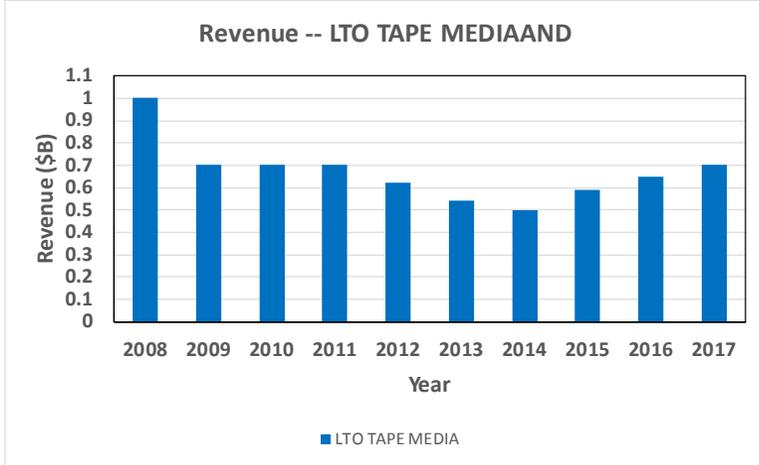
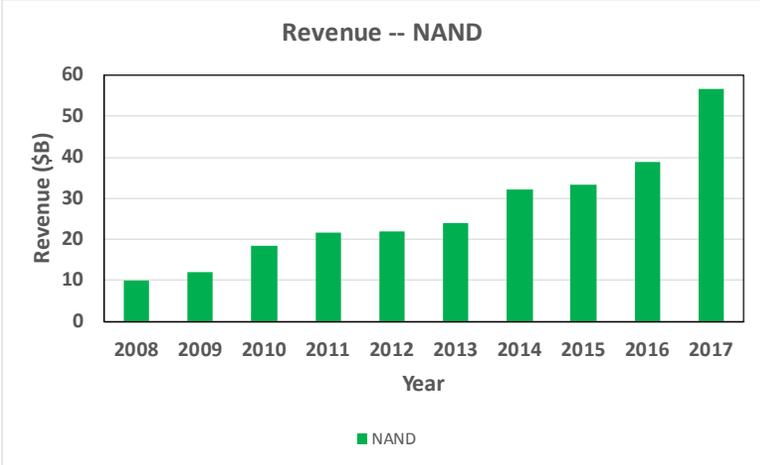
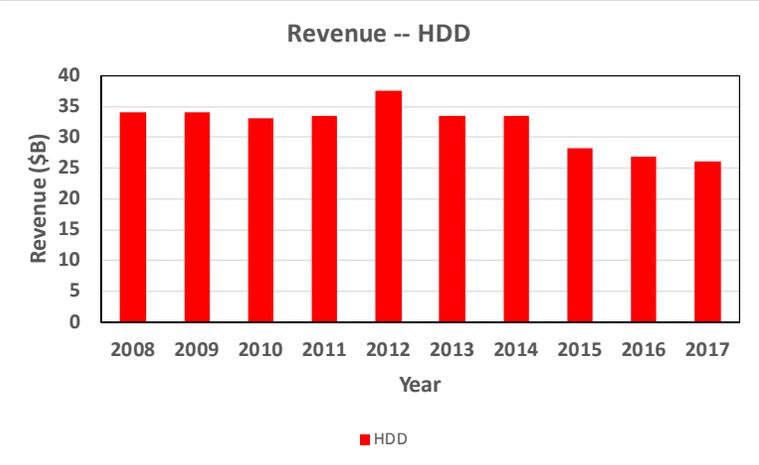
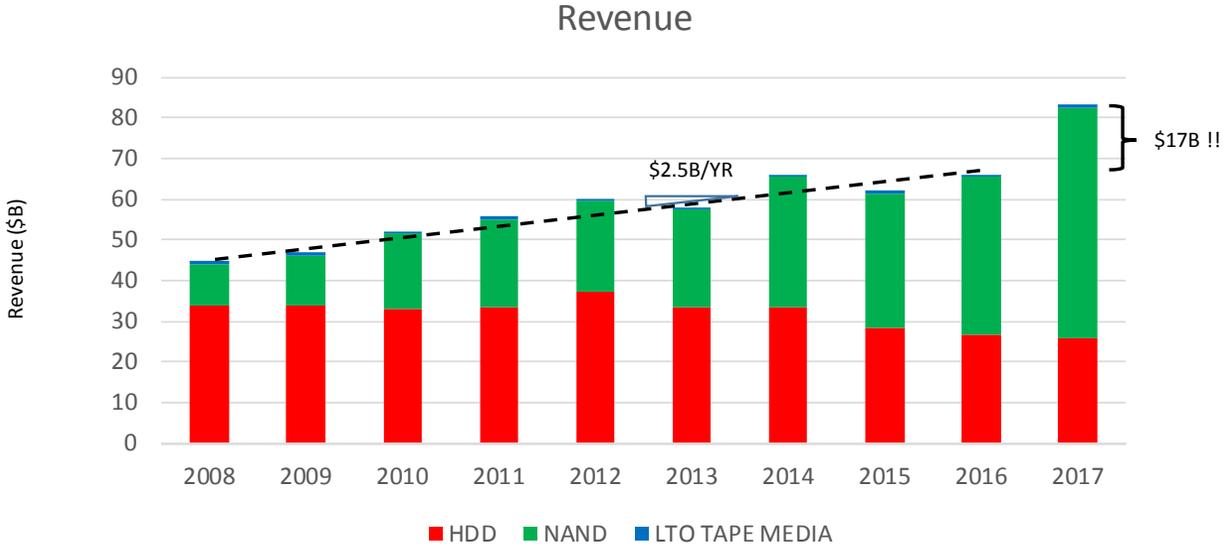


Annual EB Increases show reductions but with significant variability for the three technologies

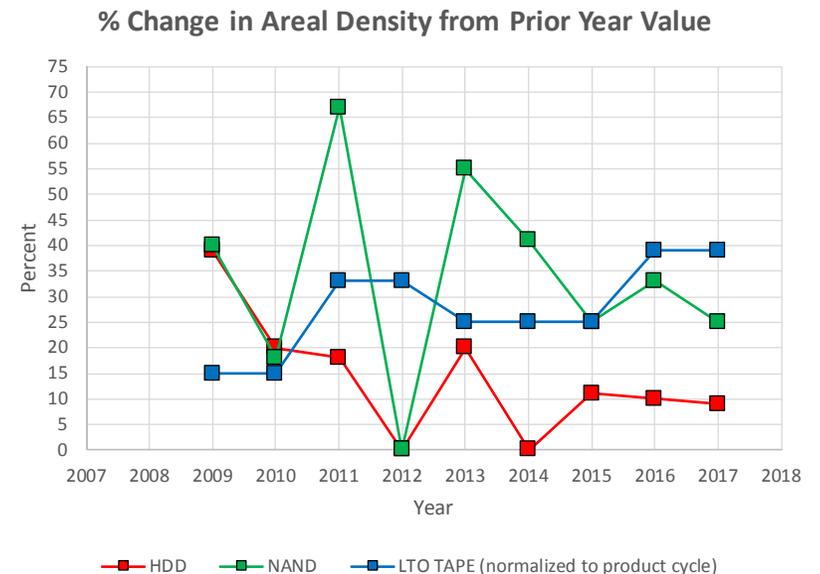
EB increases require investment in factory space and hence impact \$/GB metrics

Revenue Details

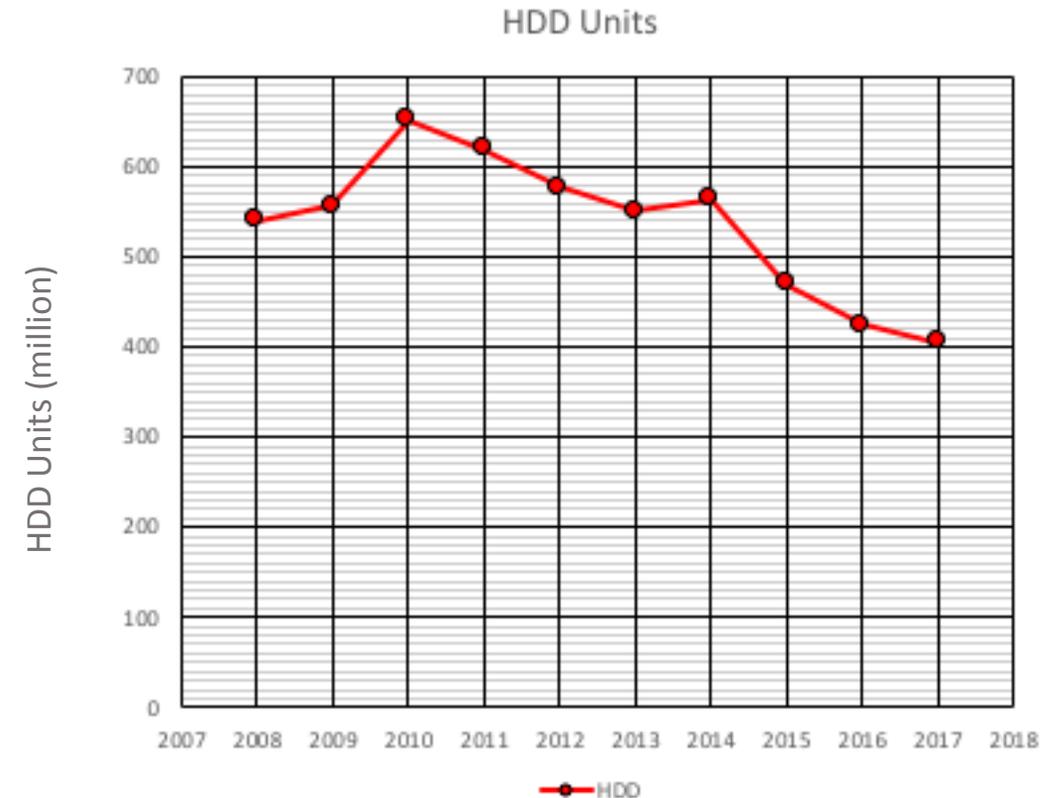
- Virtually all revenue growth in storage has come from NAND. Conjecture: High margin in cell phone units
- Question: How much annual added EB capacity for storage components can be supported in a revenue neutral environment



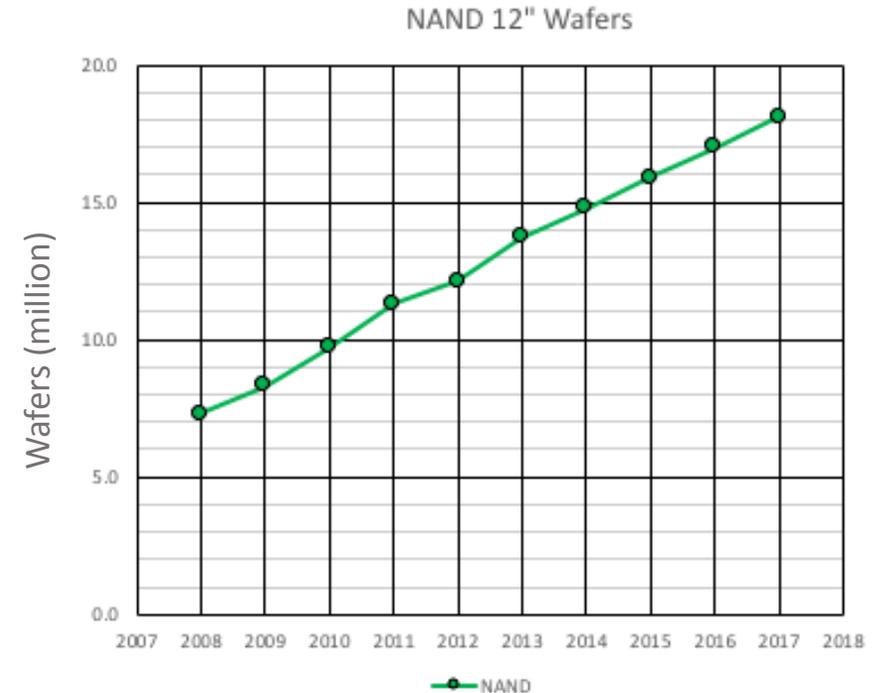
- Storage manufacturers have constraints on the maximum PB of storage that can be manufactured annually
- Storage manufactures increase PB production with a combination of two strategies
 - Capital Intensive: Increase factory space or the capability to manufacture more “square inches” of storage media, i.e. more tape, more disk surfaces, more silicon wafers, but at the same bit density.
 - Development Intensive: Increase the density of bits per square inch and build more memory bits on existing manufacturing capability
- The key to increasing future EB shipments with lower \$/GB is areal density growth. Without density growth, capital expenditures for factory space is required
 - HDD has low areal density increases ~ 10%
 - LTO Tape and NAND have ~ 3X higher areal density increases ~ 30%
- Semiconductor manufacturers have used the MSI (millions of square inches of processed silicon wafer surfaces) term to track manufacturing capacity. For storage this becomes
 - LTO TAPE: Number of cartridges manufactured
 - NAND: Number of 12” wafers processed
 - HDD: Number of HDD drives manufactured



- From 2010 to 2017 HDD unit shipments dropped by 32% but EB shipments increased by 2.4X (13%/yr)
- Net: Average drive increased in capacity by almost 3.7X (2.4/0.68) from 0.5TB to 1.9 TB
- How did HDD increase EB shipments from 2010 to 2017
 - Areal density increased 10%/yr
 - EB shipments increased 13%/yr
 - Shortfall in areal density compensated by increase in factory investments, i.e. space, of 3%/yr.
 - An estimate: In 7 years, factory MSI increased 23%
- Net: HDD unit shipments not a measure of MSI
- Surface area issues dominate HDD manufacturing
 - Disk surfaces since average number of platters per drive is increasing
 - Wafer surfaces for head fabrication since more platters per drive requires more heads per drive
 - **Comment: 8" head wafer has 50000 transducers. Typical factory with 100 wafer starts per day builds 1.8 B heads annually**



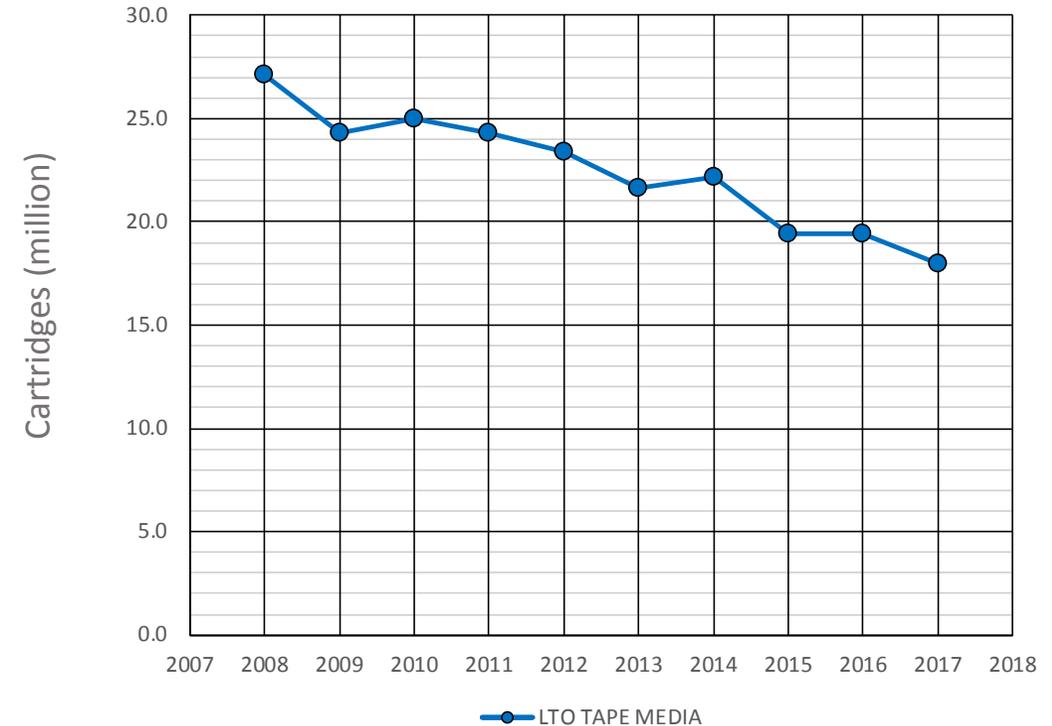
- **NAND historically increases wafer starts by ~1 M wafers each year**
- **Some numbers**
 - 18 M wafers → 175000 PB or 9.7 TB / wafer
 - 12" wafer yields ~ 400 121 mm²chips → average chip capacity ~ 24 GB or 194 Gbit
 - Best of breed chip capacity (3 bit/cell, 48-64 layers) is ~ 384 Gbit or 48 GB.
 - 7.2 B chips annually (~1.4 B smart phones built annually)
- **MSI Implication**
 - NAND could double EB shipments by moving all production to 3D designs, i.e. 350 EB or 44% of today's HDD EB shipments, with no increase in MSI (factories)
 - Reality: NAND product mix requires a variety of chip capacity designs
- **NAND Manufacturing Growth ~ 40%/yr with 6%/yr from MSI**
 - 1 M wafers → 9700 PB (minimum) → 6%
 - 34% areal density growth → 60000 PB → 34%
- **Factory Issues**
 - \$3B factory produces 1500 wafers daily or 500,000 annually
 - Adding 1 M wafers annually requires \$6B in factory capitalization annually





- MSI shipments dropped 7% in 2017. Over 10 years MSI has dropped by 4.5% annually while PB shipments have grown 17% annually
- **No consumer market**
- The LTO consortium reports that 2017 compressed bit shipments were 108442 PB, a 13% increase over 2016 compressed bit shipments. An estimate for native bit shipments is 45000 PB since the bulk of cartridge shipments are LTO6 and LTO7 with 2.5X compression.
- 18,000,000 LTO cartridges produced in 2017 implies an average cartridge capacity of 2.5 TB
 - LTO6 capacity 2.5 TB
 - LTO7 capacity 6.0 TB
 - LTO8 capacity 12.0 TB
- Maximum possible PB production (all cartridges LTO7) is 108,000 PB with no MSI increase
- Maximum possible PB production (all cartridges LTO8) is 216,000 PB with no MSI increase

LTO Cartridges



- \$/GB Observations
 - 10% to 15% Annual Decreases are the NORM
- EB Observations
 - 10% to 15% Increases are the NORM for magnetic technologies: HDD and LTO TAPE MEDIA
 - 40% Increases have been sustained by NAND for 4 years but 3D layer realities will limit further density increase
 - Overall EB growth has a “linear” characteristic
- Revenue Observations
 - Little or no growth in LTO MEDIA and HDD (obviously there is profit in these businesses)
 - Significant growth in NAND due to under supply environment and large consumer based demand (cell phones)
- Manufacturing Observations
 - EB capacity growth for TAPE and NAND can be achieved by moving product mix to higher areal density design points
 - EB capacity growth for HDD is more dependent on increasing manufacturing space since density enhancements are lagging
- NET
 - **EB increases of 40% annually for all total manufactured storage are unlikely. HDD EB dependent on MSI rather than density**
 - **\$/GB reductions will be substantially less than 10 year averages meaning future storage will become more valuable**

- All Storage

- Revenue: \$82.3 B
- EB 1000 EB
- <\$>/GB> \$0.082/GB

- LTO Tape Media

- Revenue: \$0.7 B
- EB 45 EB
- <\$>/GB> \$0.015/GB

- HDD

- Revenue: \$26.1 B
- EB 700 EB
- <\$>/GB> \$0.033/GB

- NAND

- Revenue: \$56.5 B
- EB 175 EB
- <\$>/GB> \$0.320/GB

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