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The 2018 Storage Landscape – An 11 Year Perspective (2008-2019)
LTO Tape Media, HDD, NAND

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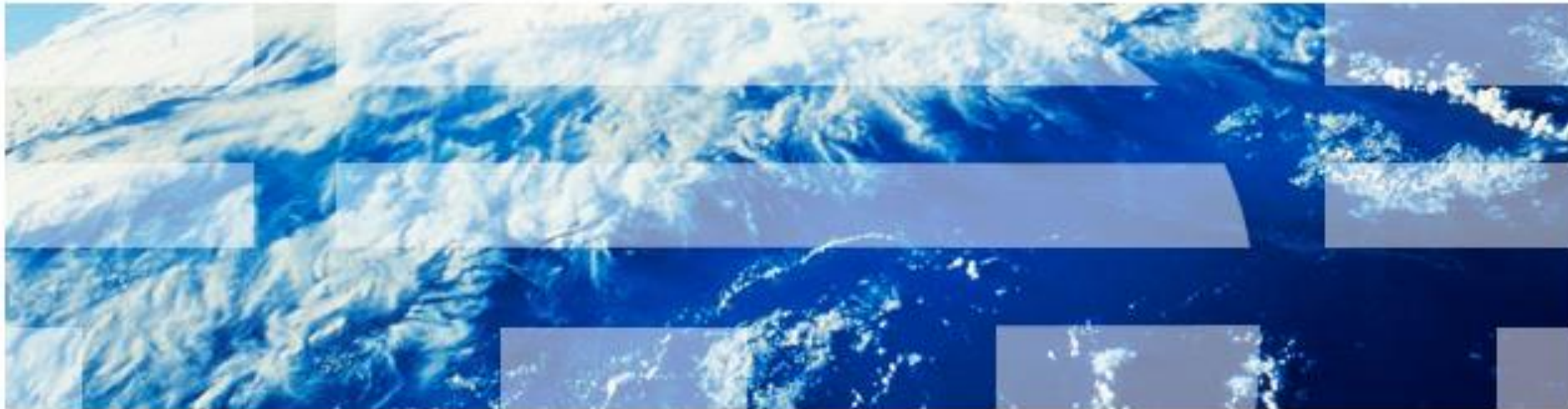
- LTO 2018 data is not available

- NAND with 20% of manufactured EB represents 70% of storage bit revenue!

- NAND resumed $/GB decreases after correcting for supply shortage in 2017

- HDD revenue was stable

- Total manufactured storage increased by 23% in 2018 not the 40% increase associated with data creation

- Increase in NAND areal density with introduction of 4 bit per cell devices.

EXABYTES	2017	2018	% Change
LTO Media	44	44	0
HDD	780	938	20%
NAND	175	250	43%
TOTAL	999	1232	23%

$/GB	2017	2018	% Change
LTO Media	$0.0147/GB	0.0100/GB	32%
HDD	$0.033/GB	$0.028/GB	16%
NAND	$0.320/GB	$0.252/GB	21%

REVENUE	2017	2018	% Change
LTO Media	$0.66B	$0.44B	-32%
HDD	$26.1B	$26.4B	1.1%
NAND	$56.5B	$63.2B	11.9%
TOTAL	$83.3B	$90.1B	8.2%

Areal Density	2017	2018	% Change
LTO Media	8 Gb/in^2	8 Gb/in^2	0%
HDD	1200 Gb/in^2	1200 Gb/in^2 (?)	0% (?)
NAND	2500 Gb/in^2	3000 Gb/in^2 (?)	25% (?)

2018 Storage Landscape – Data Strategy

- LTO data only includes media shipments. No public data is available on drive shipments and costs

- LTO media 2018 data is not available from lto.org
    - ➜ Used 2017 EB data for 2019 EB data
    - ➜ Used 2018 Web cartridge prices to determine $/GB assuming equal split between LTO6 and LTO7 cartridges
    - ➜ Areal density remains constant since LTO8 is on a 2 year product cycle

- $/GB is a blended average, i.e. (Total Revenue) / (Total EB Manufactured)

- Data is obtained from publically available sources
    - LTO.org
    - SemiconductorResearch.com
    - Western Digital and Seagate quarterly financial reports
    - Micron Technology quarterly financial reports
    - Samsung investor presentations

- WD financial data for HDD is now being merged with NAND data so differentiating NAND EB data and HDD EB data requires more data mining
    - Starting in 1Q18, WD reported total EB (HDD+NAND) shipped and % increase in HDD EB shipped and NAND EB
    - EB data extracted using 4Q 2017 data as a base line

- Toshiba HDD data had been inferred from TAM (total available market data, i.e. number of drives sold) from WD. WD no longer reports TAM. Critical assumption – Toshiba TAM ~ 20%

The 2018 Storage Landscape

|	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
HDD											
Units (HDD millions)	540	557	652	620	577	551	564	470	425	406	374
PB Shipped (PB)	125000	200000	330000	335000	380000	470000	549000	565000	693000	780000	938000
Areal Density (Gb/in^2)	380	530	635	750	750	900	900	1000	1100	1200	1200 (?)
Revenue ($B)	34.0	34.0	33.0	33.5	37.5	33.4	33.4	28.3	26.8	26.1	26.4
$/GB Shipped	0.272	0.170	0.100	0.100	0.100	0.071	0.061	0.051	0.039	0.033	0.028
NAND											
Wafers (12"-millions)	7.3	8.3	9.7	11.3	12.1	13.7	14.8	15.9	17.0	18.1	18.9
PB Shipped (PB)	3000	5430	10464	18600	28000	39000	62500	83000	120000	175000	250000
Areal Density (Gb/in^2)	200	280	330	550	550	850	1200	1500	2000	2500	3000 (?)
Revenue ($B)	10.1	12.1	18.5	21.5	22.0	24.0	32.2	33.2	38.7	56.5	63.2
$/GB Shipped	3.33	2.23	1.77	1.16	0.78	0.615	0.515	0.401	0.320	0.320	0.252
LTO TAPE MEDIA											
Units (Cart millions)	27.1	24.3	25.0	24.3	23.4	21.6	22.2	19.4	19.4	18.0	
PB Shipped (PB)	11050	11960	15340	18420	20680	24270	30100	33020	40320	44850	44850
Areal Density (Gb/in^2)	0.9	0.9	1.2	1.2	2.1	2.1	2.1	4.1	4.1	8.0	8.0
Revenue ($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	0.44
$/GB Shipped	0.0905	0.0585	0.0456	0.0380	0.0300	0.0222	0.0166	0.0177	0.0162	0.0147	0.0098

Exabyte History

- Contrarian Observation: Total manufactured bits of storage (HDD, NAND, LTO Tape) growth rate is ~20%/yr and not the perceived growth rate of information creation of 40%/yr.

- Inflections in growth rate for manufactured bits of storage
    - 2008-2010   60%   HDD "golden technology years", tunnel valve, perpendicular recording, areal density increases
    - 2010-2112   9%/yr   HDD production issues (natural disasters)
    - 2012-2015   17%/yr   HDD transition from appliances to enterprise, NAND growth in phone and PC
    - 2015-2018   22%/yr   HDD enterprise applications, NAND continued exponential growth

TOTAL MANUFACTURED EXABYTES
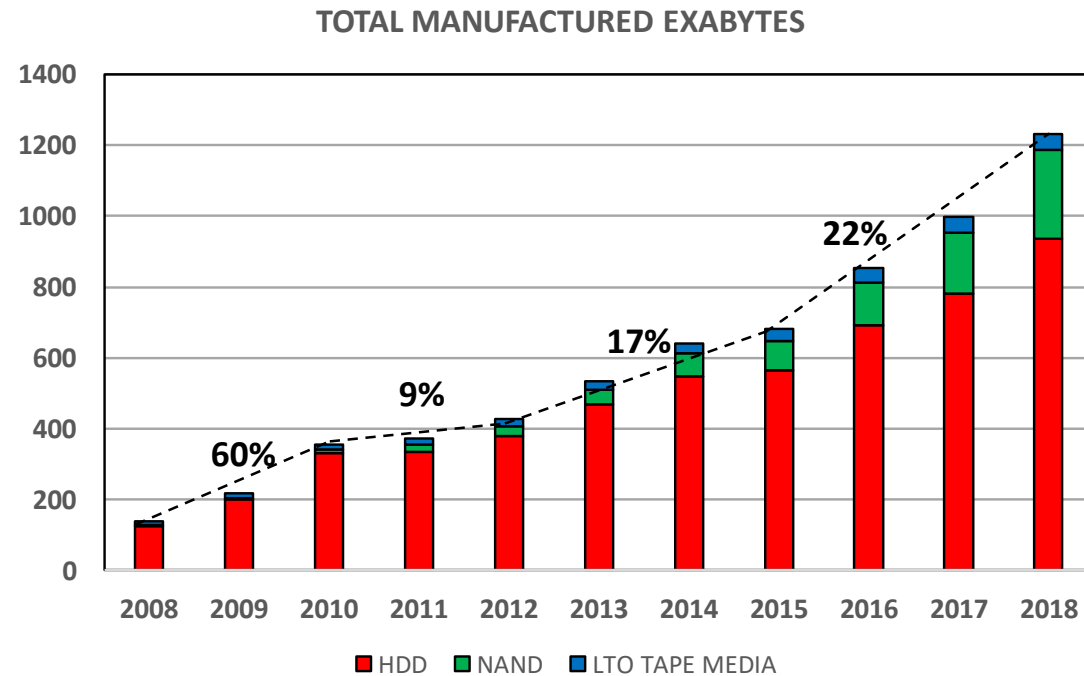
Exabyte History – Linear or Geometric

- Tape and HDD EB growth has a more linear characteristic

- NAND continues on a geometric growth pattern
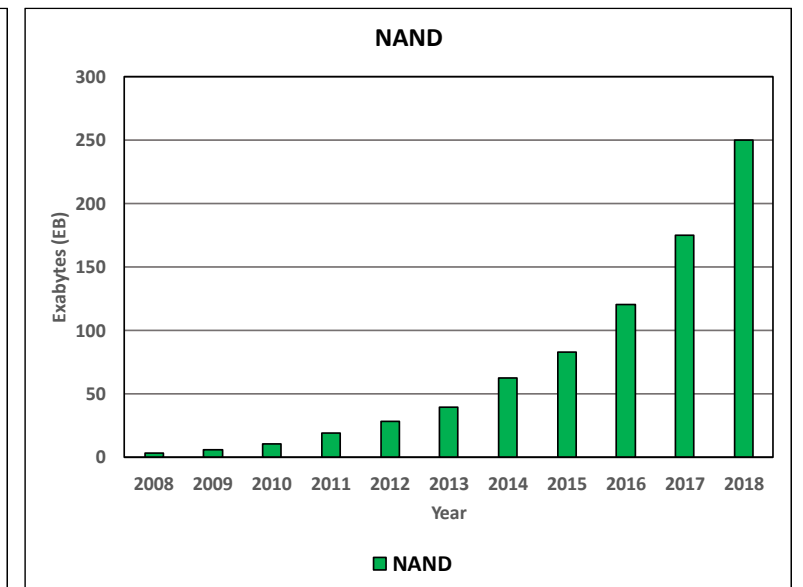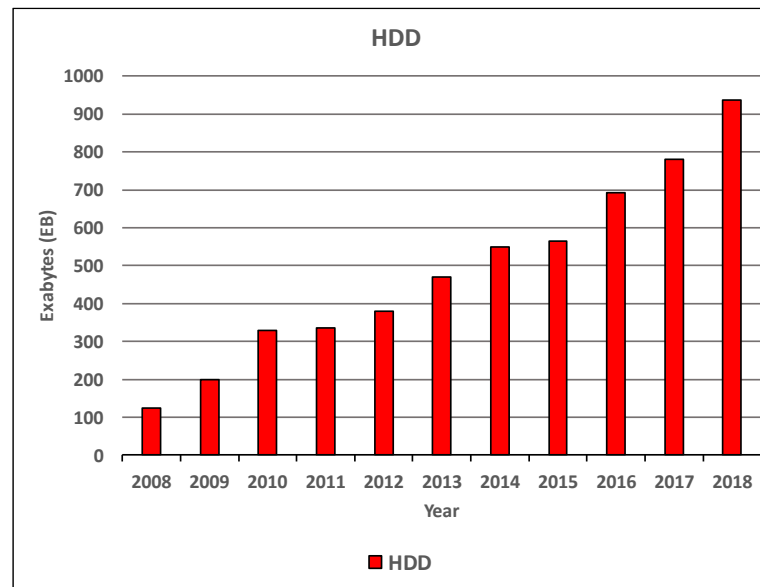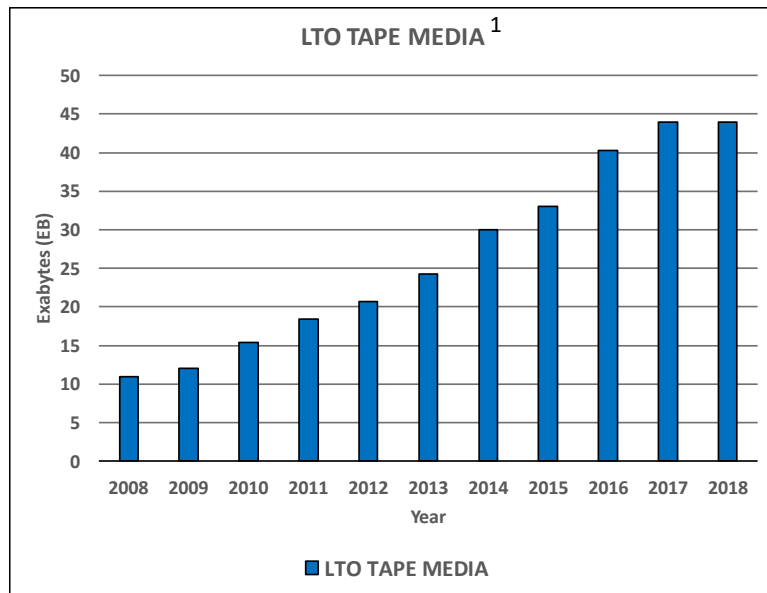
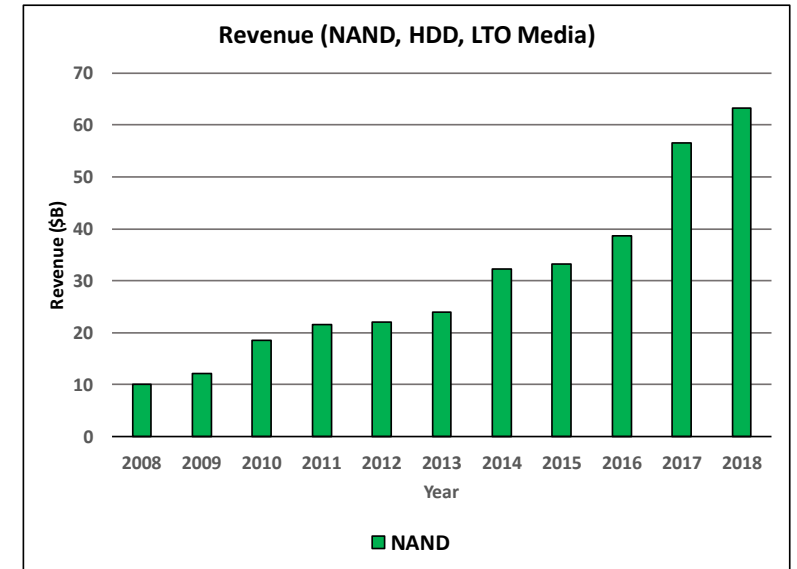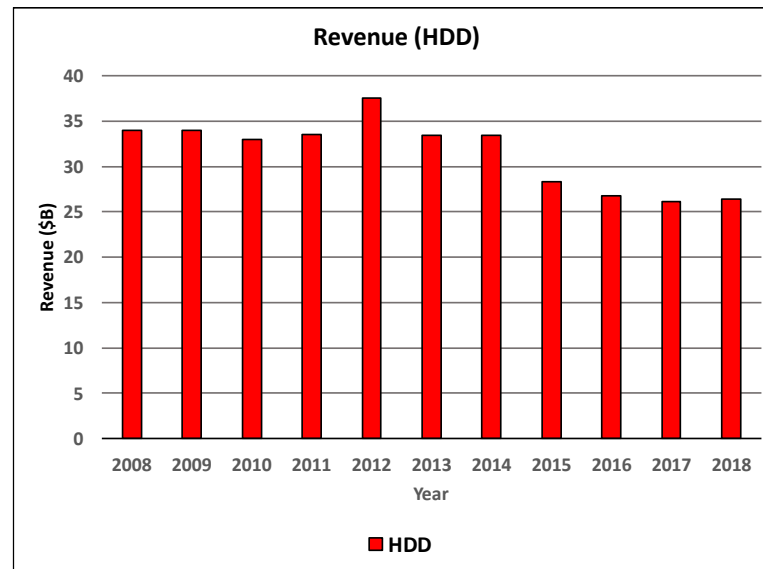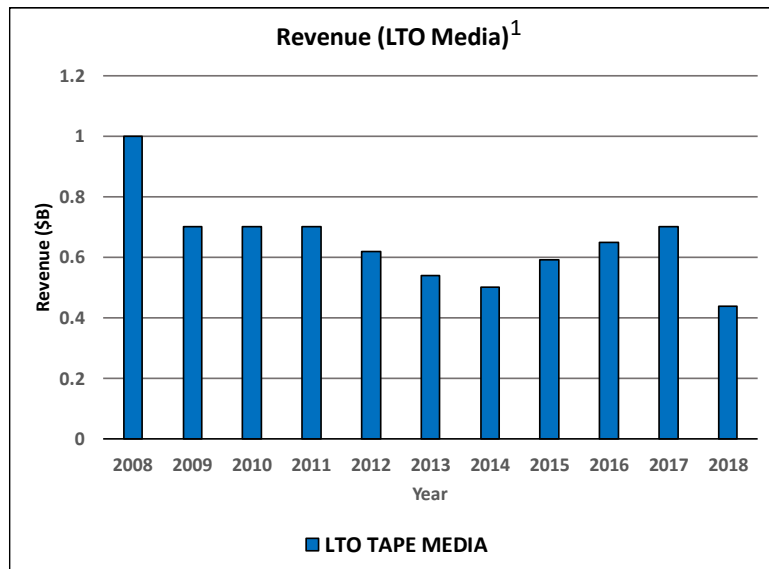1. 2018 LTO Tape data unavailable,
   2017 data used for 2018 data

- NAND revenue exceeds HDD revenue in 2015

- HDD revenue declining or stable

- LTO Media revenue, ~ $0.5B, is small in comparison to HDD and NAND. No consumer base for LTO media and small EB volumes relative to HDD (5%) and NAND (18%)

- Annual revenue increases of $3.5B attributed solely to NAND growth and NAND premium on $/GB

Revenue (NAND, HDD, LTO Media)
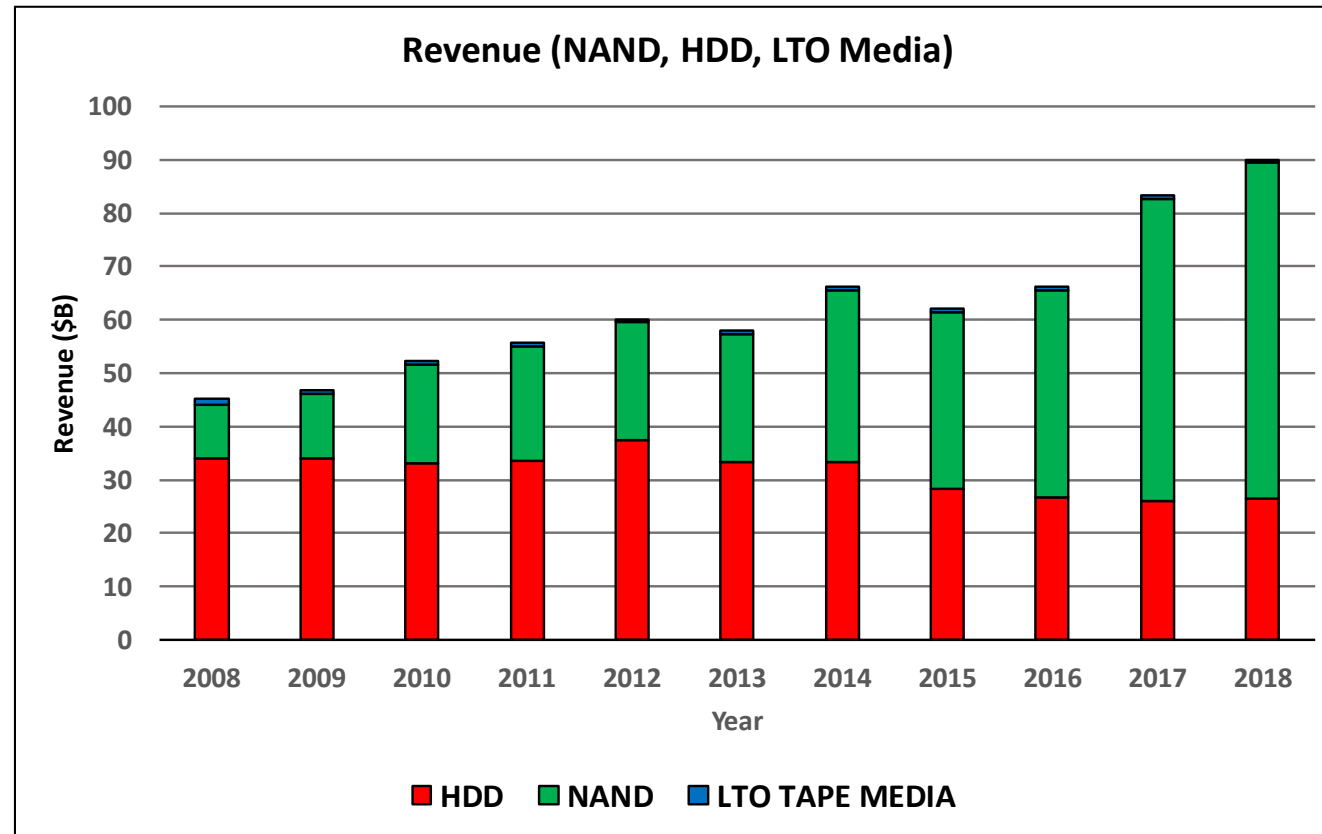
Revenue Observations

- NAND -- Dramatic revenue increase in 2017, less increase in 2018

- HDD – Revenue decreases beginning in 2013 (30% drop between 2012 and 2018) , now stable revenue with minimal growth (1%)

- LTO Media – 2018 revenue numbers not available but obvious impact due to media sourcing issues

1. 2018 LTO Tape data unavailable, revenue calculated using YE 2018 cartridge market prices with equal division between LTO7 and LT06 cartridges

$/GB

- Continued drop in $/GB for all storage types – classic exponential behavior with NAND resuming $/GB decreases in 2018 after recovering from supply constraints in 2017

- However, $/GB decreases are in the 19%/yr range and not the classical Moore's Law projection of 28%/yr associated with areal density doubling every 2 years

- LTO Note: 2018 data not available for EB shipments hence $/GB relies on YE2018 market prices for LTO6 and LTO7 cartridges with EB split equally between both cartridges.

- The $/GB metric is the key differentiator for storage technologies – hence $/GB decreases are competitive with all technologies

$/GB (NAND, HDD, LTO Tape Media)
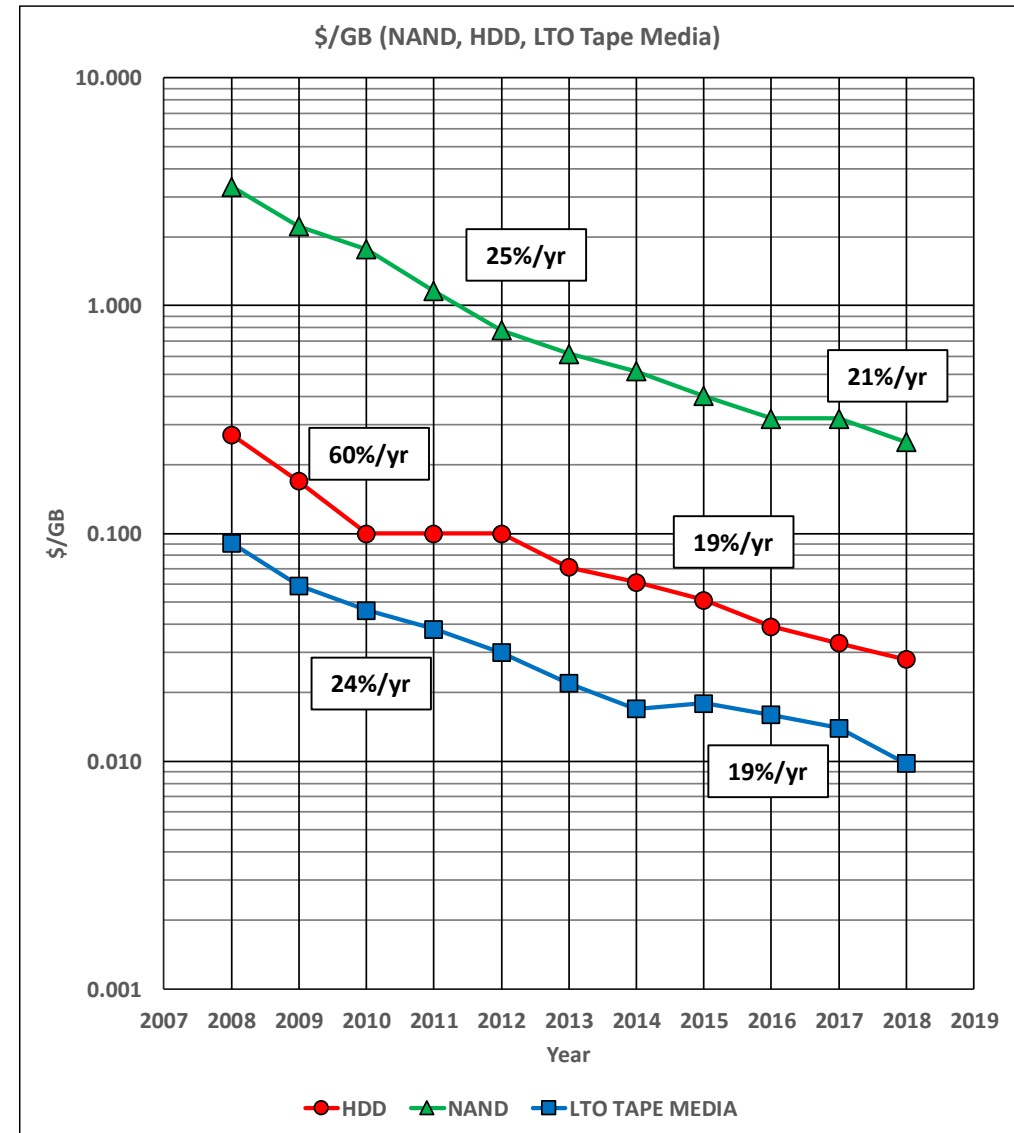
Areal Density

- NAND areal density has benefited by bit per cell transitions.
  - 2 bit/cell (4 levels) – 3 bits/cell (8 levels) ➜ 50% density increase
  - 3 bit/cell (8 levels) – 4 bits/cell (16 levels) ➜ 33% density increase
  - 5 bit per cell unlikely in near future

- Future NAND areal density from adding layers to structure, i.e. increasing today's 100 layers devices. There is speculation that 400 layer devices are possible but with tiering, i.e. processing 100 layers at a time

- HDD areal density is slowing with anticipation of improvements from HAMR and MAMR.

- LTO Tape areal density continues on a ~25% annual increase. Using enterprise tape benchmarks one could argue that annual areal density increases are in the 30% range

- Critical comments: If EB production increases exceed areal density increases then more factory space investment is required (capitalization) so $/GB decreases slow.

Areal Density (NAND, HDD, LTO Tape Media)
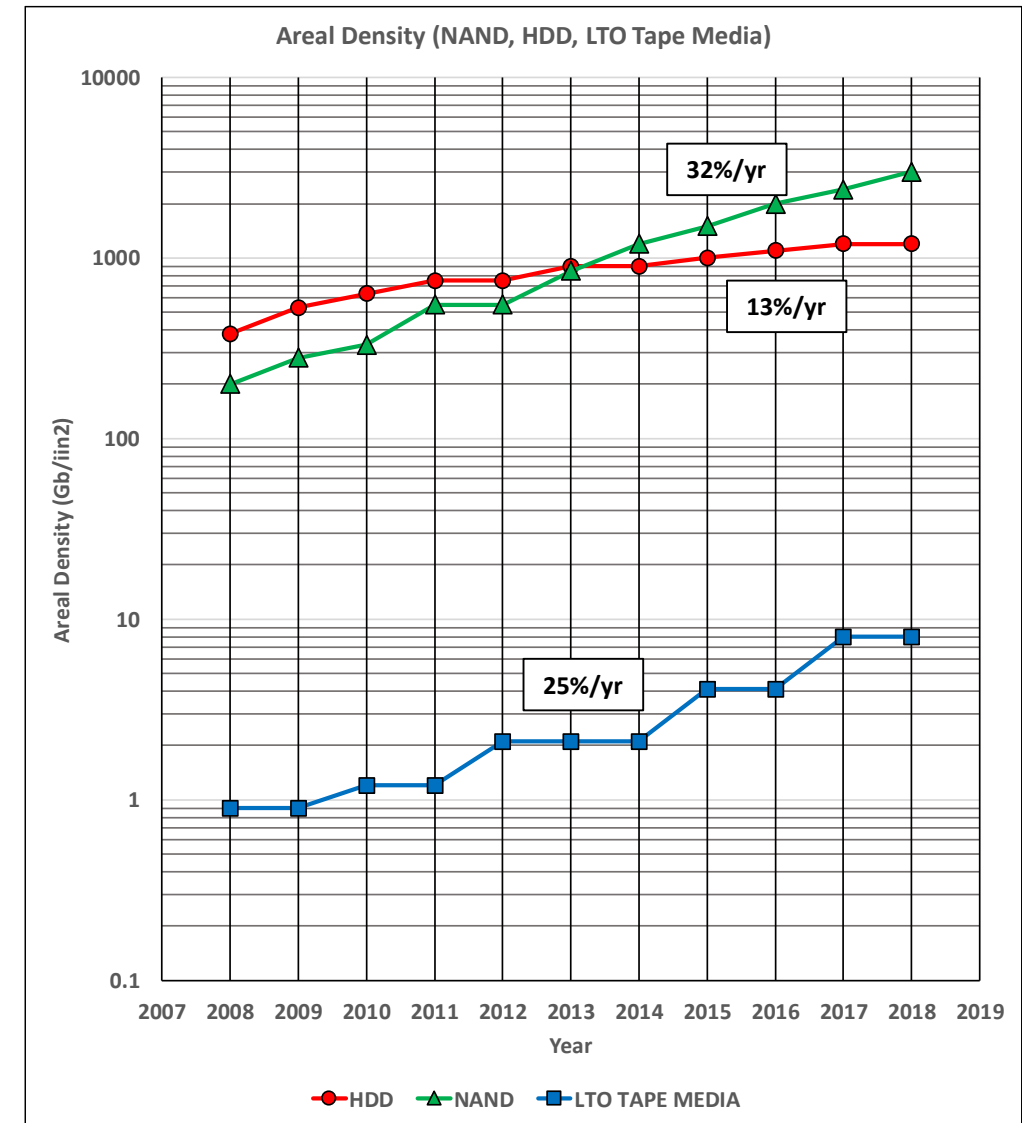
NAND Replacing HDD

- By YE 2026 (8 years) NAND EB will exceed HDD EB (7.6 years precisely) using YE 2018 data
  - NAND EB annual increase 43% staring with 250 EB, HDD annual increase 20% starting with 938 EB
  - NAND $/GB decrease annually by 20%, HDD $/GB decrease annually by 16%
  - $250 \times (1.43)^y = 938 \times (1.2)^y$ ➔ $y = 7.6$ years

- Implications

EXABYTES	2018	2026	Increase
NAND	250	4371	17.4X
HDD	938	4033	4.3X
LTO TAPE	44	116	4.2X
TOTAL	1232	8520	6.9X

REVENUE	2018	2026	Increase
NAND	$63.2B	$183.6B	2.9X
HDD	$26.4B	$28.2B	1.1X
LTO TAPE	$0.44B	$0.49B	1.1X
TOTAL	$90.0B	$211.8B	2.4X

$/GB	2018	2026	Decrease
NAND	$0.252/GB	$0.042/GB	0.167X
HDD	$0.028/GB	$0.007/GB	0.248X
LTO TAPE	$0.010/GB	$0.0024/GB	0.24X

- Issue: In 2026 is there demand for 7X more manufactured storage annually and is there sufficient value for this storage to spend $122B more annually (2.4X) for this storage.

- Unknown: How much data is created annually and at what rate of increase?

- Unknown: How much important data is not being stored

- Unknown: How much of the non-stored data would clients desire to store and at what $/GB value

- NAND crossover with HDD in 2026 is aggressive since the bits per cell scaling is ending, i.e. 1 bit to 4 bit per cell in the last 10 years provided an effective 15%/yr areal density increase before moving to 3D cell structures.

- There is a storage gap == What is the value to the client to store this data.

MANUFACTURED EXABYTES -- HDD/NAND CROSSOVER IN 2026
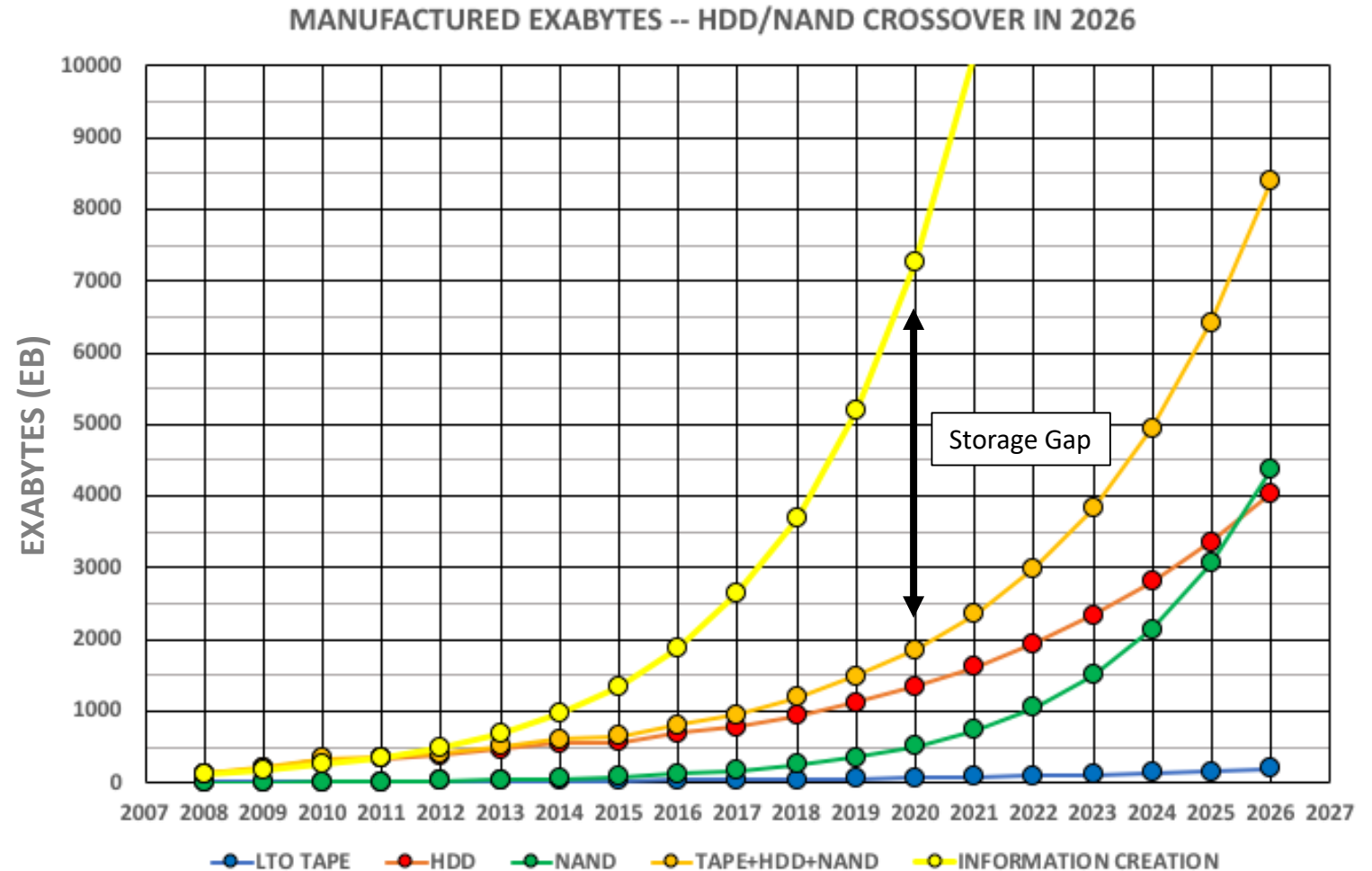
Key Point: HDD 75% of bits and 30% of revenue, NAND 20% of bits and 70% of revenue

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- Tape is coupled with HDD – Data placed on tape comes from data on HDD

- The ratio of LTO Tape EB shipped to HDD EB shipped has remained constant in the 5% to 6% range for the last 8 years.

- Tape provides an essential storage need in the Cloud

RATIO -- LTO TAPE EB to HDD EB