

Recent Storage Landscape – Tape, HDD, NAND



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Data Storage trends for LTO Tape Media, NAND chips, and HDD drives from 2008-2021

- Data Methodology
- Highlights on \$/TB and EB shipments and Areal Density
- Technology Outlook
- Summary

	Yearly Change 2015-2020			2020		
	NAND	HDD	LTO MEDIA	NAND	HDD	LTO MEDIA
Bit Shipments (EB)	39%	16%	6%	439	1190	43
Cost/Bit (\$/TB)	-20%	-18%	-14%	129	18.8	8.4
Revenue (\$B)	12%	-5%	-7%	56.7	22.4	0.36
Areal Density (Gb/in2)	25%	6%	15%	4700	1300	8.5 ('20) 12 ('21)

DATA METHODOLOGY

- Data for 2019 to 2021 added to the previous study: *R. Fontana, G. Decad AIP Advances 8 (5) 056506 (2018) and our Library of Congress 2019 presentation*
- Data obtained from publicly available sources, e.g. Quarterly Financial Reports, www.TrendFocus.com, Investor Presentations, www.LTO.org,
- Landscape parameters are relevant to the entire product space for each technology
 - TAPE: **Only** the spectrum of all LTO media generations with no differentiation
 - HDD: All hard disk drives with no differentiation for capacity, disk diameter, platter number
 - NAND: All chip shipments (not SSD products) with no differentiation for bits/cell, planar or 3D design, or capacity
- Data qualifiers
 - Cost/Bit is determined as **Total Revenue / Total Bits Shipped** and is not representative of any single product
 - Areal Density is determined as the “best” or “highest” value in a shipped product, i.e. for LTO Tape Media, it is the areal density for LTO9 even though LTO2-LTO7 media is also shipped as product
 - Revenue is the total revenue for all products
- Tape data issues – LTO Media Only
 - The LTO Consortium published bit shipment information for 2018 and 2019 does not include LTO-7 Type M units .
 - Data is for media only and does not include contributions from drive sales, library sales, or TS11XX, Oracle, SpectraLogic
 - Media cost/bit is based on web-based pricing at www.tape4backup.com so the cost/bit is likely lower than these data
- Comparison realities
 - The ideal comparison would be an HDD with a given capacity to an SSD of a given capacity to an LTO drive with n tapes
 - The reality is that this landscape compares HDD drives with NAND chips with LTO cartridges

Storage Landscape History – 2008 – 2021

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
<u>HDD</u>														
Units (HDD millions)	540	557	652	620	577	551	564	470	425	406	374	315	268	258
Bits Shipped (EB)	125	200	330	335	380	470	549	565	693	780	938	1034	1190	1418
Areal Density (Gb/in ²)	380	530	635	750	750	900	900	1000	1100	1200	1200	1300 (?)	1300 ³	
Revenue (\$B)	34.0	34.0	33.0	33.5	37.5	33.4	33.4	28.3	26.8	26.1	26.4	23.3	22.4	28
\$/TB Shipped	272	170	100	100	100	71	61	51	39	33	28	22.5	18.8	19.7
<u>NAND</u>														
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	19.7	20.6	
Bits Shipped (EB)	3	5.43	10.46	18.60	28	39	62.50	83	120	175	250	338	439	598
Areal Density (Gb/in ²)	200	280	330	550	550	850	1200	1500	2000	2500	3000	3800 (?)	4700 ⁴ (?)	
Revenue (\$B)	10.1	12.1	18.5	21.5	22.0	24.0	32.2	33.2	38.7	56.5	63.2	46.0	56.7	68.6
\$/TB Shipped	3333	2230	1770	1160	780	615	515	401	320	320	252	136	129	115
<u>LTO TAPE MEDIA</u>														
	LTO4		LTO5		LTO6			LTO7		LTO8				LTO9
Units (cart millions)	27.1	24.3	25.0	24.3	23.4	21.6	22.2	19.4	19.4	18.0	12.7 ²	11.9 ²	8.6 ⁵	
Bits Shipped (EB)	11.05	11.96	15.34	18.42	20.68	24.27	30.10	33.02	40.32	44.85	40 ²	46 ²	42.5 ⁵	
Areal Density (Gb/in ²)	0.9	0.9	1.2	1.2	2.1	2.1	2.1	4.1	4.1	8.5	8.5	8.5	8.5	12
Revenue (\$B) ¹	1	0.70	0.70	0.70	0.62	0.54	0.50	0.59	0.65	0.66	0.43	0.48	0.36	
\$/TB Shipped	90.50	58.50	45.60	38	30	22.20	16.60	17.70	16.20	14.70	10.70	10.40	8.40	

1. 2008-2014 data from Santa Clara Consulting Group. 2015-2019 data from LTO.org EB data and web-based pricing information

2. EB shipment data does not include LTO-7 Type M shipments. Unit shipment data does not include LTO-7 Type M shipments

Fontana/Decad/Lauhoff 3/2022

3. HDD areal density from Seagate 2.5" SMR drive. 3.5" areal density ~ 10% lower

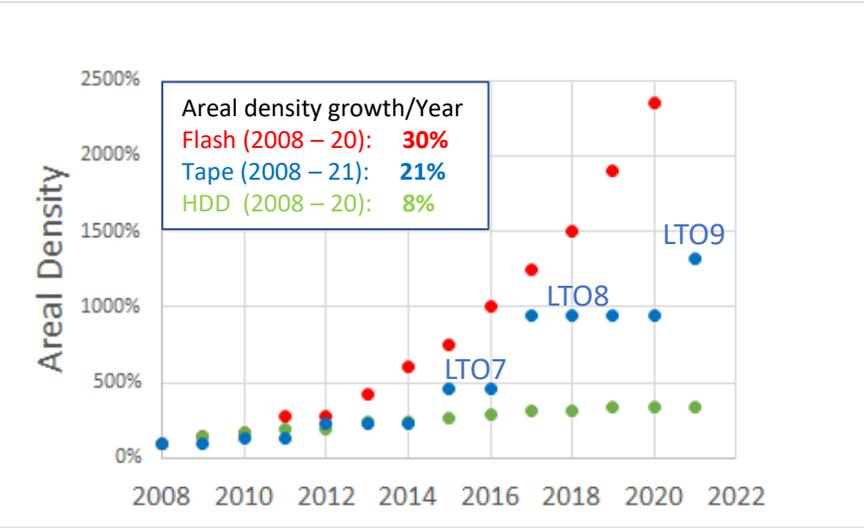
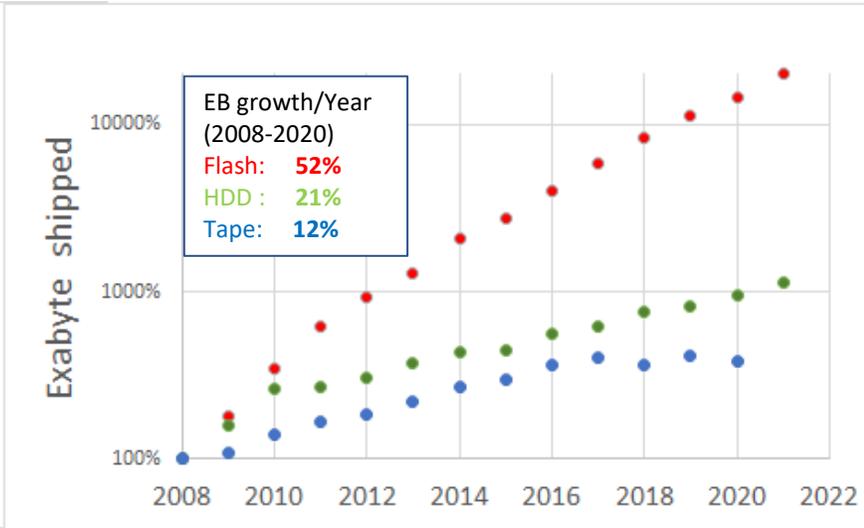
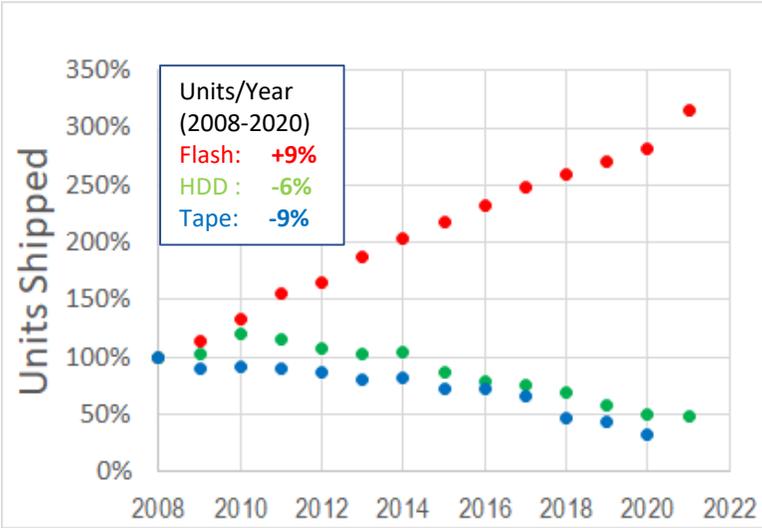
4. NAND areal density uncertainty due to layer number varying from 96 to 128

5. LTO Consortium Data published in 3Q 2021

Product Unit shipments

Capacity shipments

Areal Density

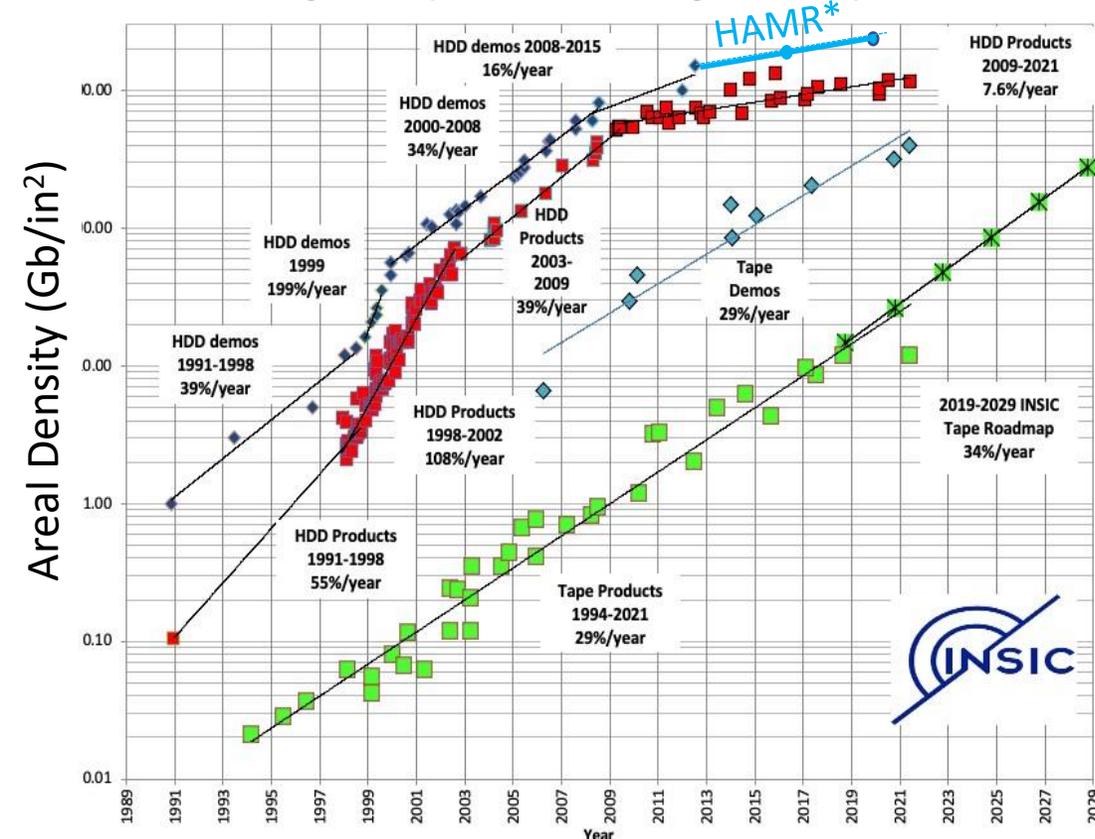


	Unit shipments	Exabyte	Areal Density
NAND Flash	Strong Growth	Strong Growth	Strong Growth
HDD	decrease	Increase	Very small
LTO Tape	decrease	Smaller	Larger than HDD

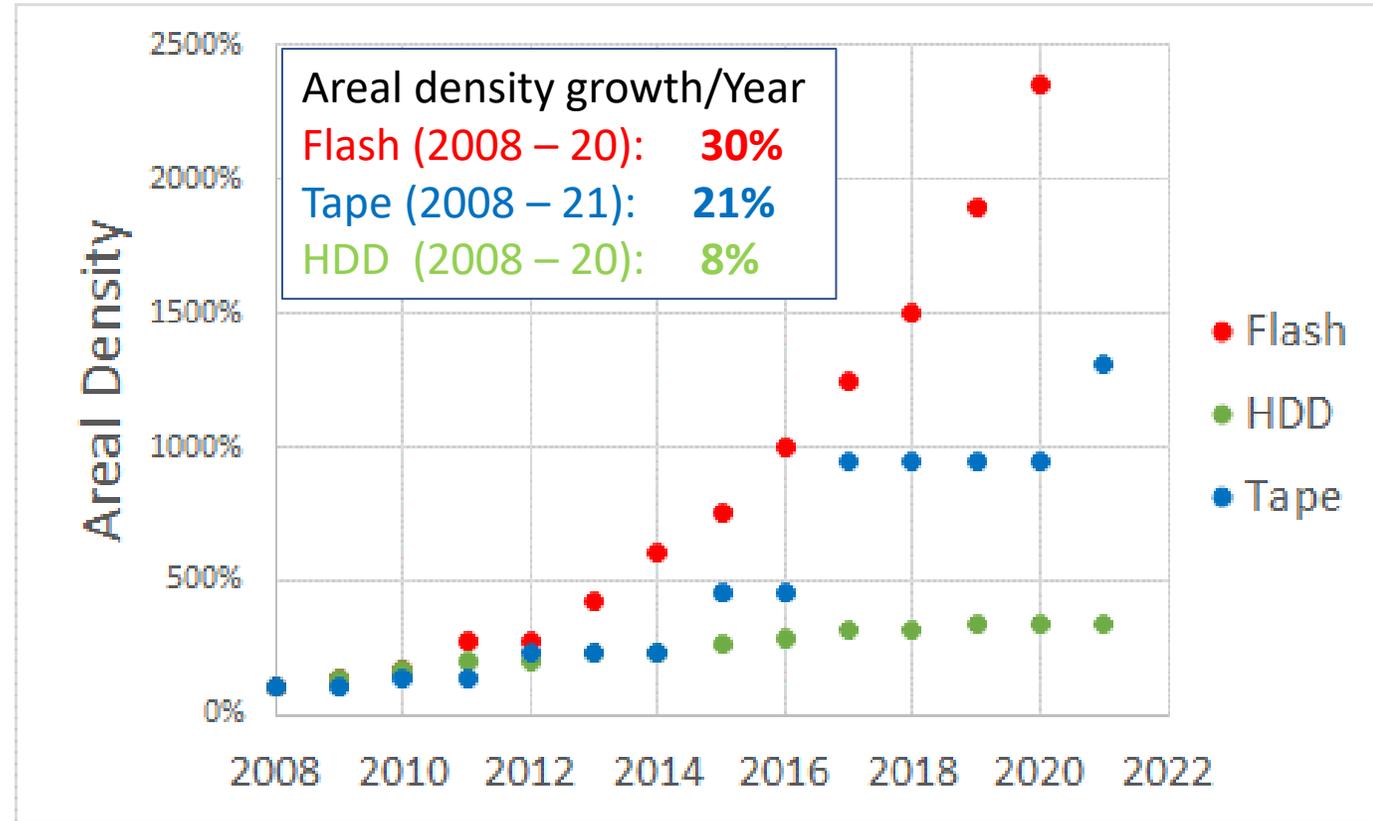
Tape is now re-entering a growth phase, as demand for archival storage, which mitigates climate change issues, grows in the cloud hyperscale storage facilities.

Areal Density Growth

INSIC Magnetic Tape and HDD Storage Roadmap

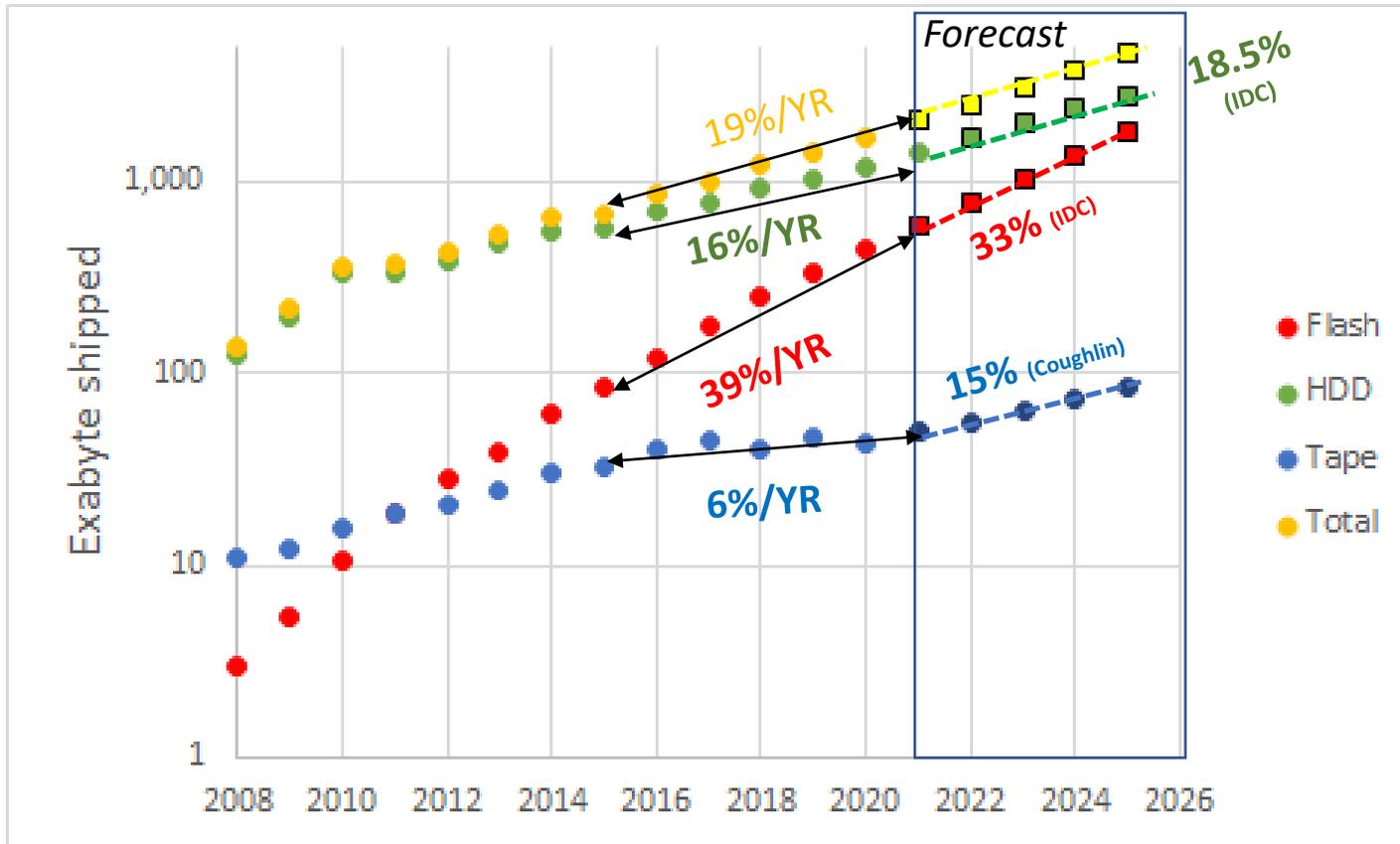


*Recent HDD Demo from 2021-Seagate-Analyst-Day added to INSIC chart



We believe that Tape is now re-entering a growth phase, as demand for archival storage, which mitigates climate change issues, grows in the cloud hyperscale storage facilities.

Manufactured Exabytes

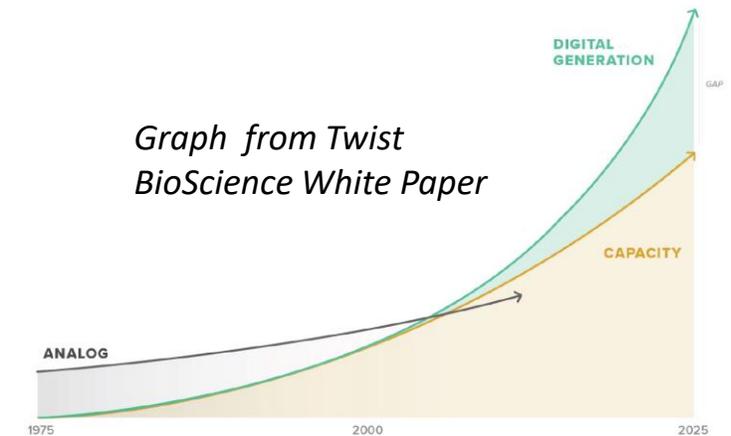


Data Growth larger than Capacity Growth

Data growth (2020- 25) *: **23%**

IDC, Worldwide DataSphere Forecast 2021

Installed capacity growth (2020-25): **19%**



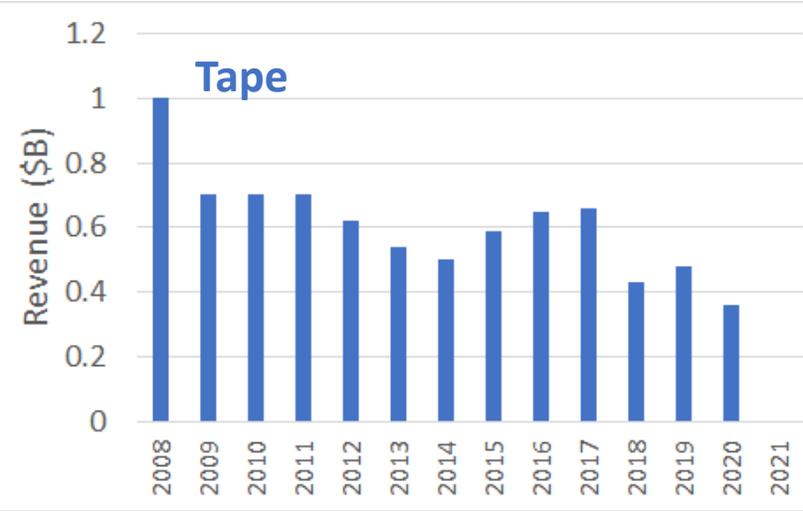
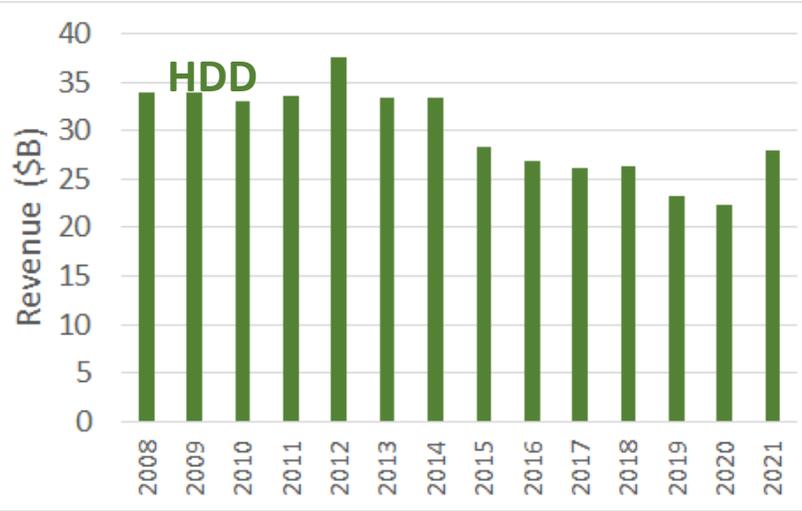
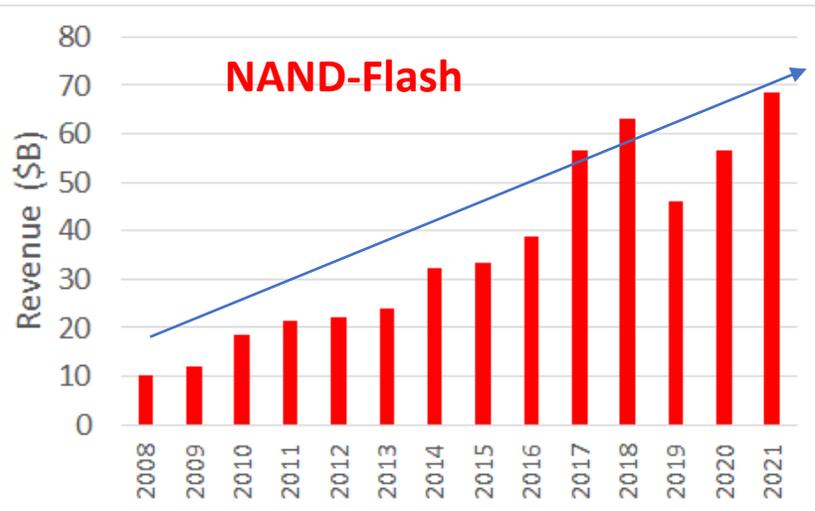
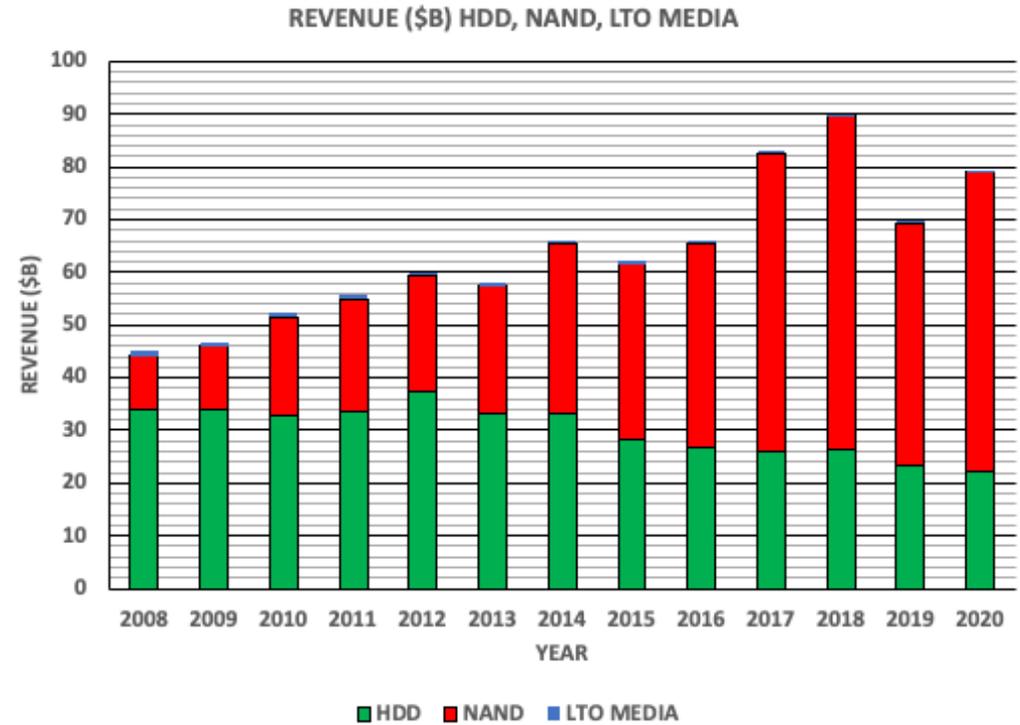
- NAND Flash is approaching HDD quickly

2019: 27%
2020: 37%
2025: 67%

- LTO Media shipments were impacted by Sony/Fuji intellectual property issues in 2020; The launch of LTO9 in 2021 expect to create additional demand

Revenue Trends

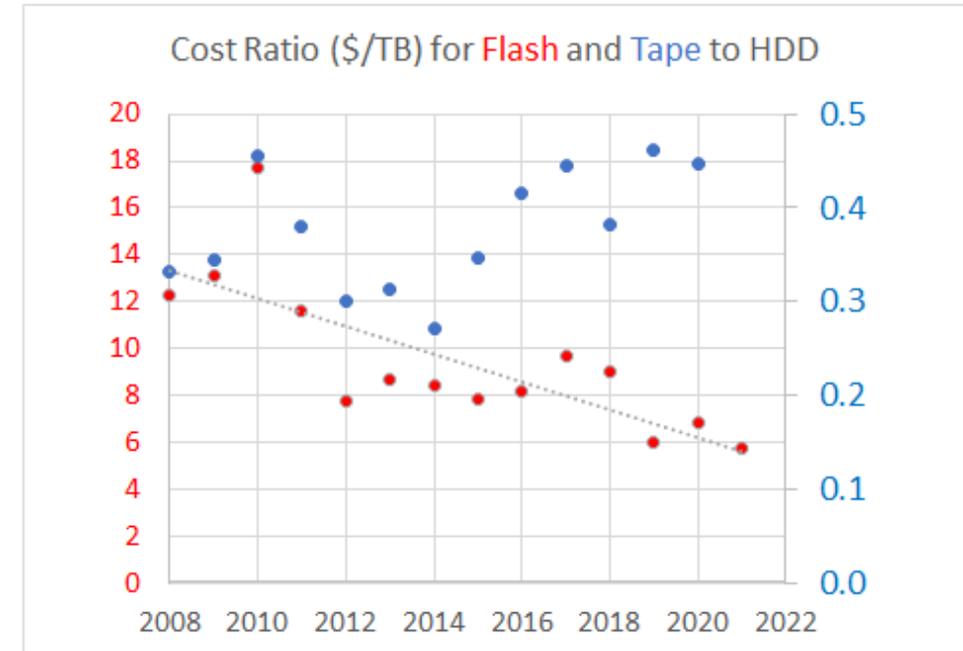
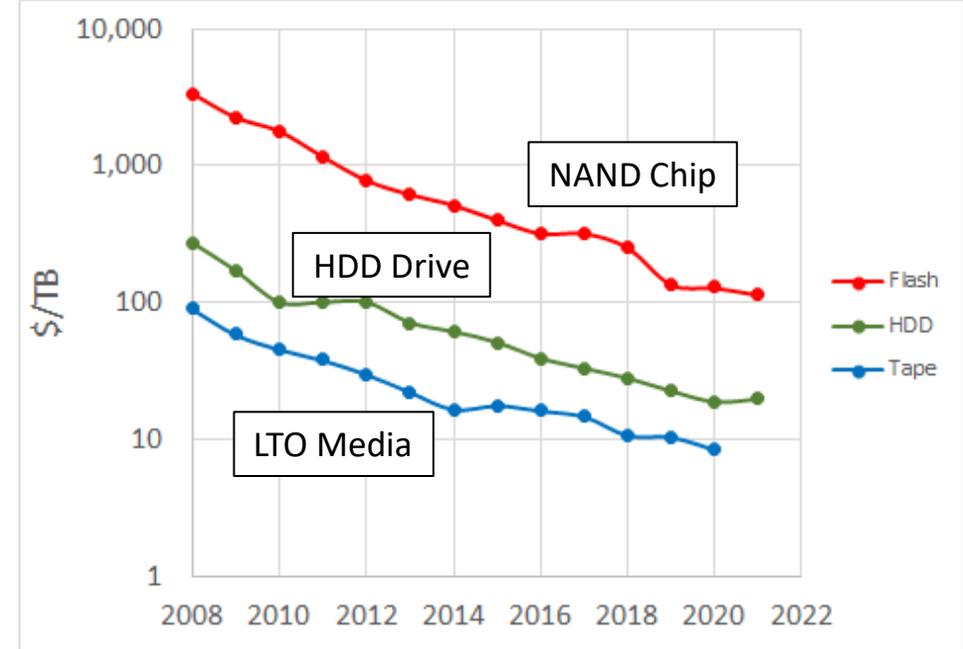
- Total Revenue and Revenue Trends are driven by NAND market changes.
- NAND -- increase in 2020 & 2021 after \$14B drop in revenue in 2019
- HDD – Slow downward trend in revenue
- LTO Tape Media – Revenue drop after recovery from Sony/Fuji Issues
- General Observation: Magnetic storage technologies are showing revenue decreases over time.



\$/TB TRENDS

	2020 (\$/TB)	%/YR ('15- '20)
• LTO Media (Tape)	8.4	-14%
• HDD	18.8	-18%
• NAND Chip (Flash)	129	-20%

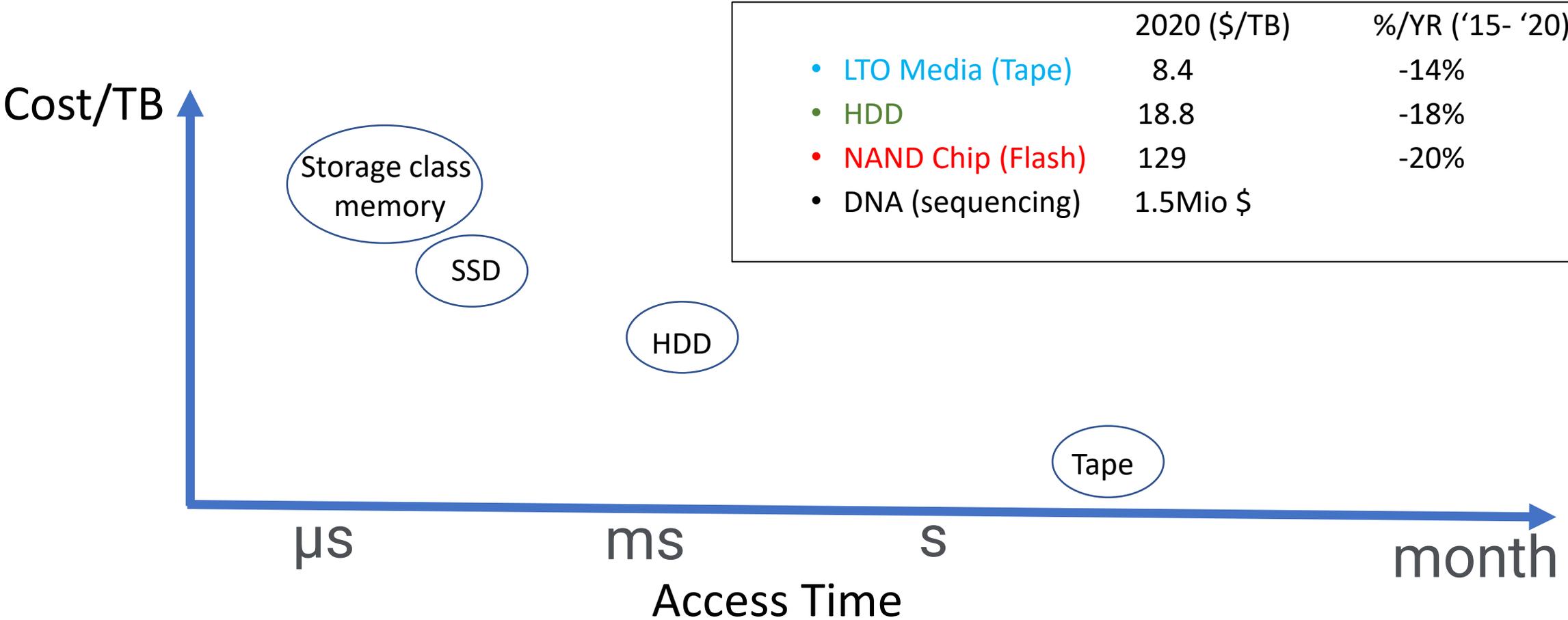
- Annual \$/TB decreases for all technologies
- Strong decrease for Flash drives the trend to use more Flash in Data Centers
- Both Tape and Flash use less power compared to HDD reducing Total Cost relative to HDD
- Other performance factors here not considered



Future Data Storage Technologies



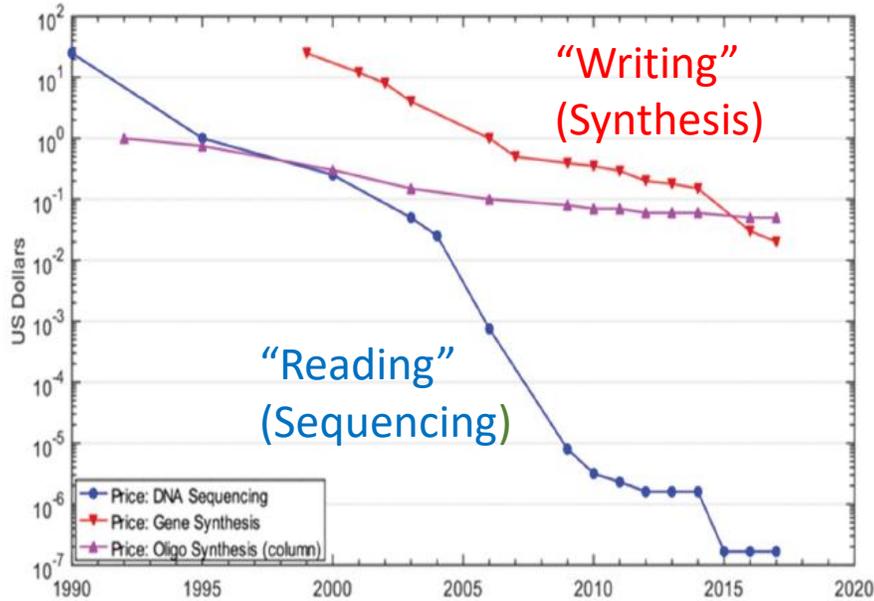
DNA Data Storage?
(Expensive + Slow)



	2020 (\$/TB)	%/YR ('15- '20)
• LTO Media (Tape)	8.4	-14%
• HDD	18.8	-18%
• NAND Chip (Flash)	129	-20%
• DNA (sequencing)	1.5Mio \$	

Outlook: DNA Data Storage ?

Long Term Storage,
No energy consumption, High density
BUT Slow & expensive



DNA Costs by Carlson, Bioeconomy Capital

Reading: Cost per human genome

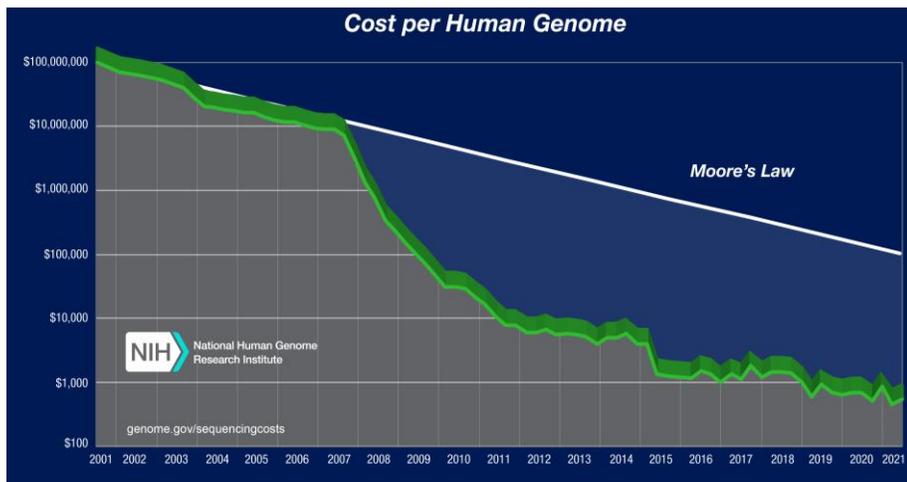
~ \$1000 per 700 megabyte -> **1.5Mio USD per TB**

Sequencing cost 8 Orders reduced in 30 years

Another 20 years to bring down to 8 USD/TB with same slope

But WRITING still 5 orders more expensive than reading

DNA Data storage will be very different and this is just a naïve calculation



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• NAND Chip (Flash)	129	-20%
• DNA (sequencing)	1.5Mio \$	- 46% (since 1990)

Summary

- \$/TB reduction bigger for NAND than HDD.
- \$/TB advantage of LTO (cartridge) over HDD (drive) remains
- Total bit growth remains at ~19% per year → while data growth ~ 23%/YR : less is retained
- Both HDD and Tape revenue shrink
- NAND AND Tape technology has significant device capacity/areal density for years to come
- HDD technology is facing significant hurdles for increased device capacity. Current HDD products still do not use HAMR in 2022

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