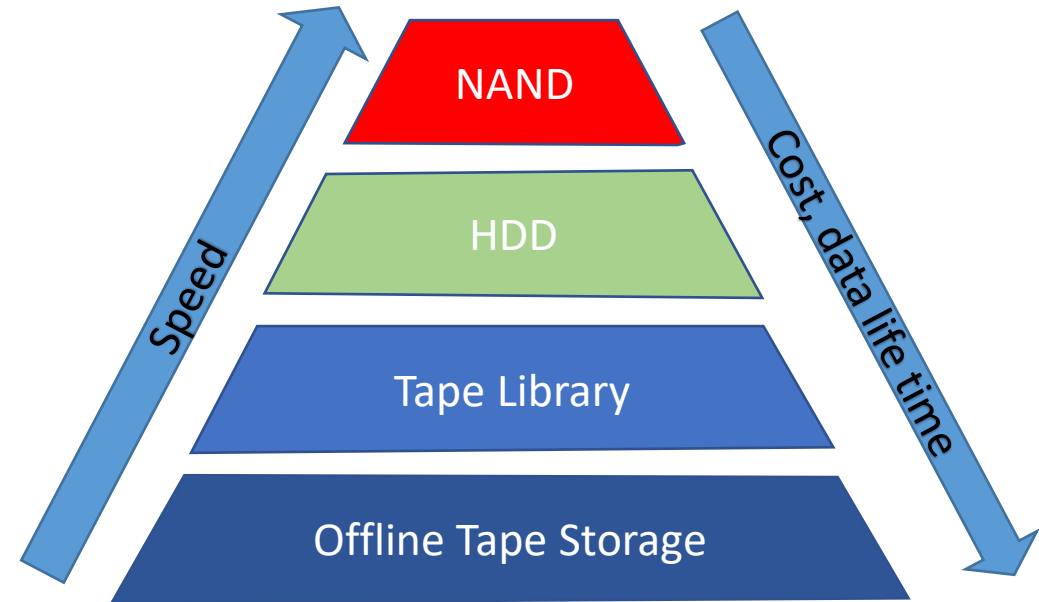


A Changing Storage Landscape – Tape, HDD, NAND



LOC Designing Storage Architecture for Digital Collections
March 23th, 2023,



Georg Lauhoff (Sr Engineer) and Gary M Decad (Sr Manager)
IBM Storage, Tape Technology, San Jose, CA

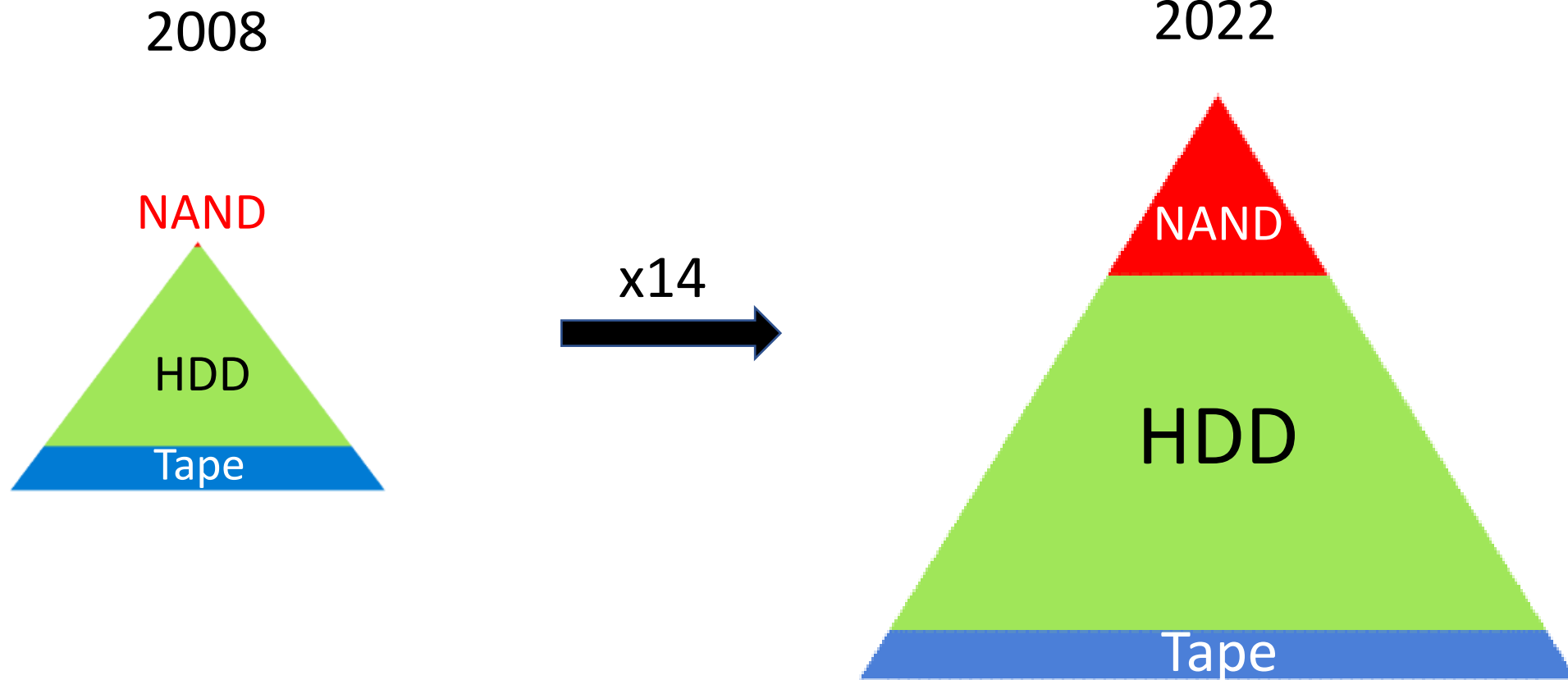
- Data added to the previous study: *R. Fontana, G. Decad AIP Advances 8 (5) 056506 (2018) and Library of Congress presentations*
- Data obtained from publicly available sources
- Parameters considered
 - Tape: LTO media only
 - HDD: All hard disk drives with no differentiation for capacity, disk diameter, platter number
 - NAND: All chip shipments (not just SSD) 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
- Tape data – 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

Storage Landscape History

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
<u>HDD</u>															
Units (HDD millions)	540	557	652	620	577	551	564	470	425	406	374	315	268	258	~175
Bits Shipped (EB)	125	200	330	335	380	470	549	565	693	780	938	1034	1190	1418	1233
Areal Density (Gb/in ²)	380	530	635	750	750	900	900	1000	1100	1200	1200	1300 (2.5"SMR)	1300 (2.5"SMR)	1300	1100 (22TB CMR) 1300 (26TB SMR)
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	19
\$/TB Shipped	272	170	100	100	100	71	61	51	39	33	28	22.5	18.8	19.7	15.5
<u>NAND</u>															
Wafers (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	20.5	21.7
Bits Shipped (EB)	3	5.43	10.46	18.60	28	39	62.50	83	120	175	250	338	439	598	631
Areal Density (Gb/in ²)	200	280	330	550	550	850	1200	1500	2000	2500	3000	3800	4700	6970	9414
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	60.1
\$/TB Shipped	3333	2230	1770	1160	780	615	515	401	320	320	252	136	129	115	95
<u>LTO TAPE MEDIA</u>															
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	11.9	8.6	9.3	
Bits Shipped (EB)	11	12	15.3	18.4	20.7	24.3	30.1	33.0	40.3	44.8	40	46	42.5	59.2	
Areal Density (Gb/in ²)	0.9 (LTO4)		1.2 (LTO5)		2.1 (LTO6)			4.1 (LTO7)		8.5 (LTO8)				12 (LTO9)	
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	0.51	
\$/TB Shipped (comp)	36.2	23.4	18.2	15.2	12.0	8.9	6.6	7.1	6.5	5.9	4.3	4.2	3.4	3.4	2.9

A Changing Storage Landscape

Annual capacity Shipments (Bits)



Data Storage trends for NAND (Flash), HDD and Tape Storage review in this talk

This study build on previous studies by *R. Fontana, G. Decad AIP Advances 8 (5) 056506 (2018)*

Data obtained from publicly available sources

Introduction



World-wide electricity consumption from data center/transmission ~ 1% . *

- doubled since 2015.
- further demand increase (AI, Internet of Things ..)

* IEA (2022), Data Centres and Data Transmission Networks, IEA, Paris <https://www.iea.org/reports/data-centres-and-data-transmission-networks>

Governments support semiconductor memory recently for geo-political reasons

- Few policies address the energy and emissions footprint.

To create Energy Efficient Data Storage Technology progress needed & here reviewed
Tape storage is essential to realize energy efficiency in storage landscape

Implement Energy Efficient Data Storage



Tape storage.

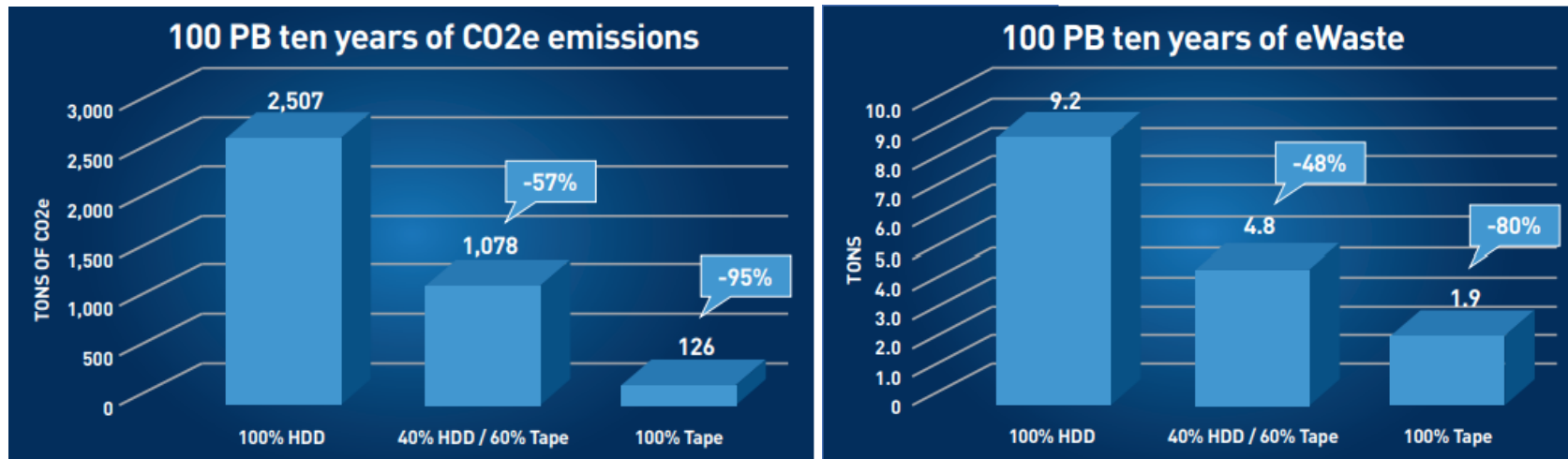
Most energy efficient per bit stored

Solid-state drives (SSDs) vs HDD

SSD use less energy compared to HDD (operation cost) even though there is still debate when considering manufacturing

From https://www.energystar.gov/products/implement_efficient_data_storage_measures

Tape storage reduces energy consumption and electronic Waste while preserving data

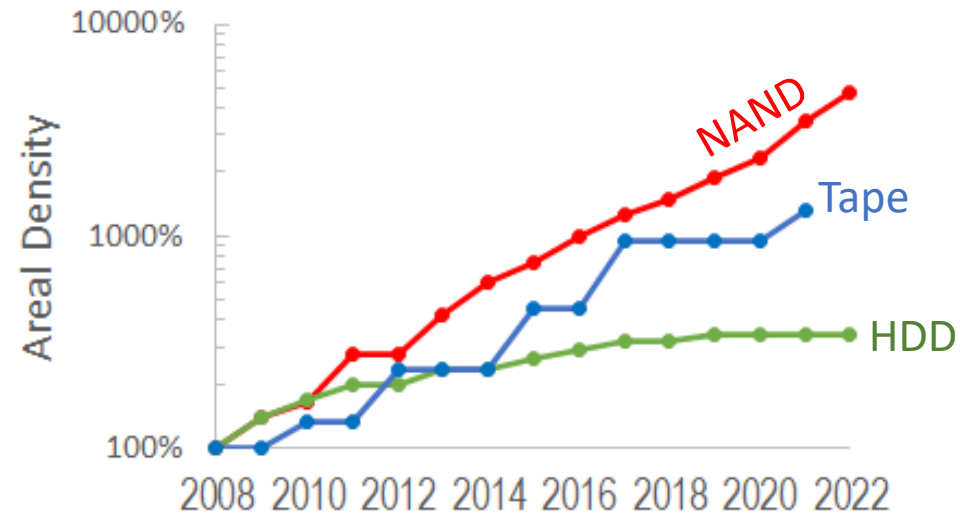
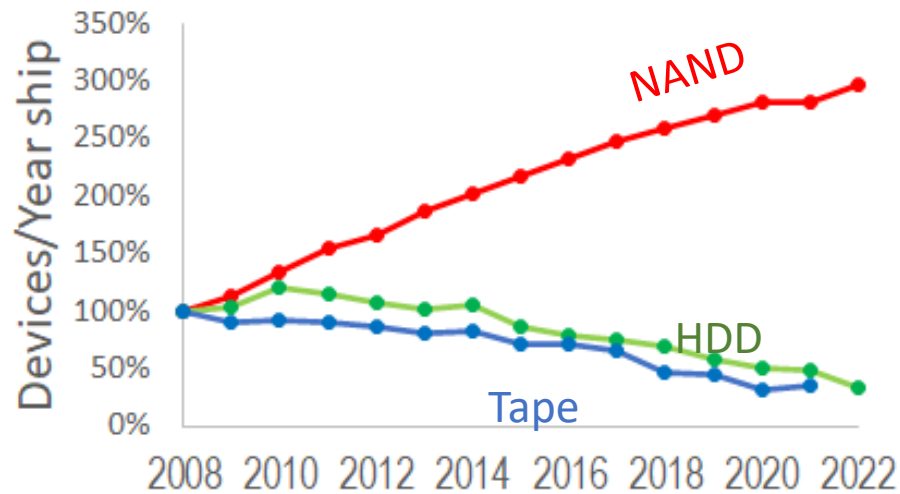
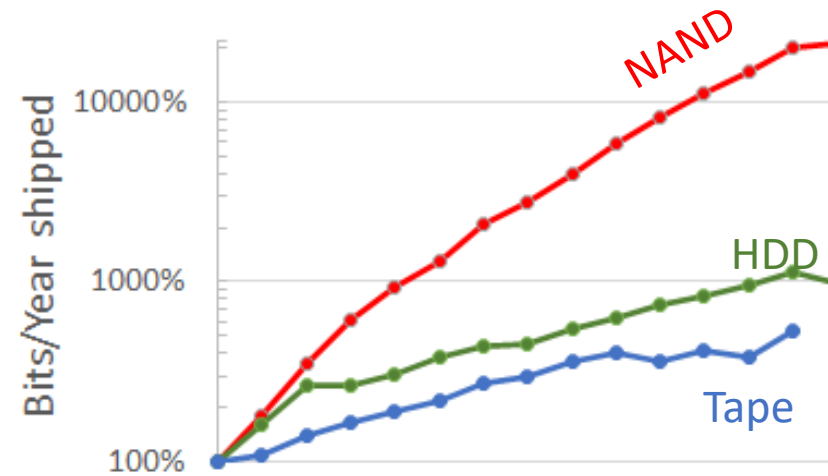
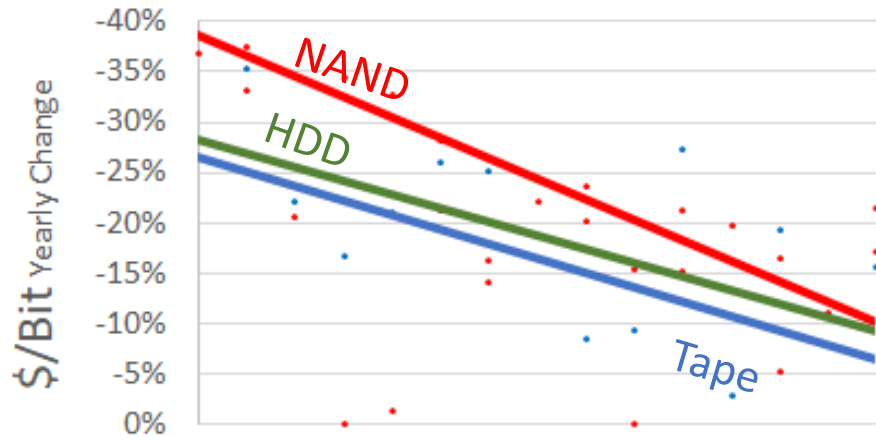


https://asset.fujifilm.com/www/sg/files/2021-09/d9c014a35ae86bdc41d78abf6e693bb1/Improving_IT_Sustainability_with_Tape_BJC.pdf

Annual Cost/bit, Bit shipments, Device Shipments and Areal Density Change

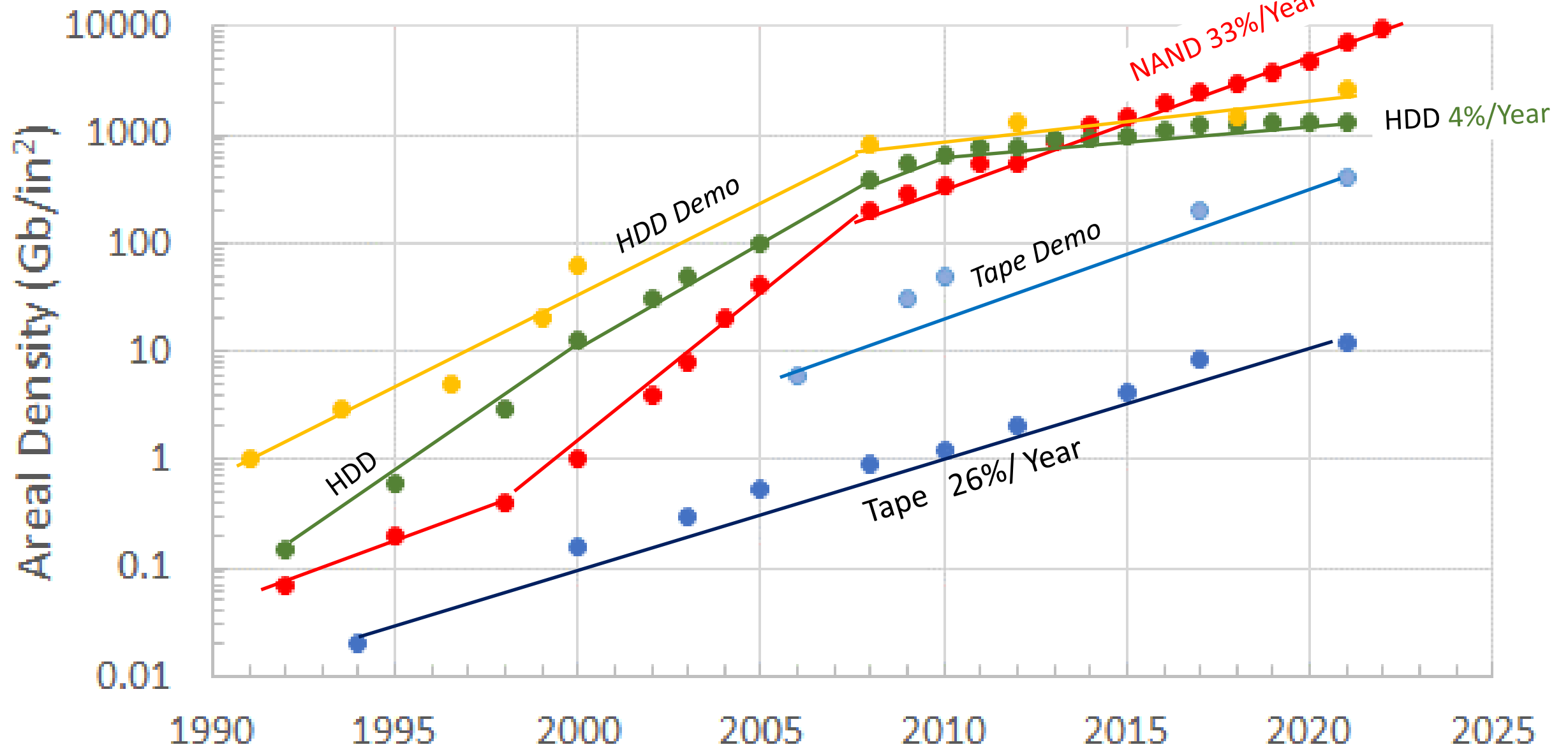


- NAND
- HDD
- Tape

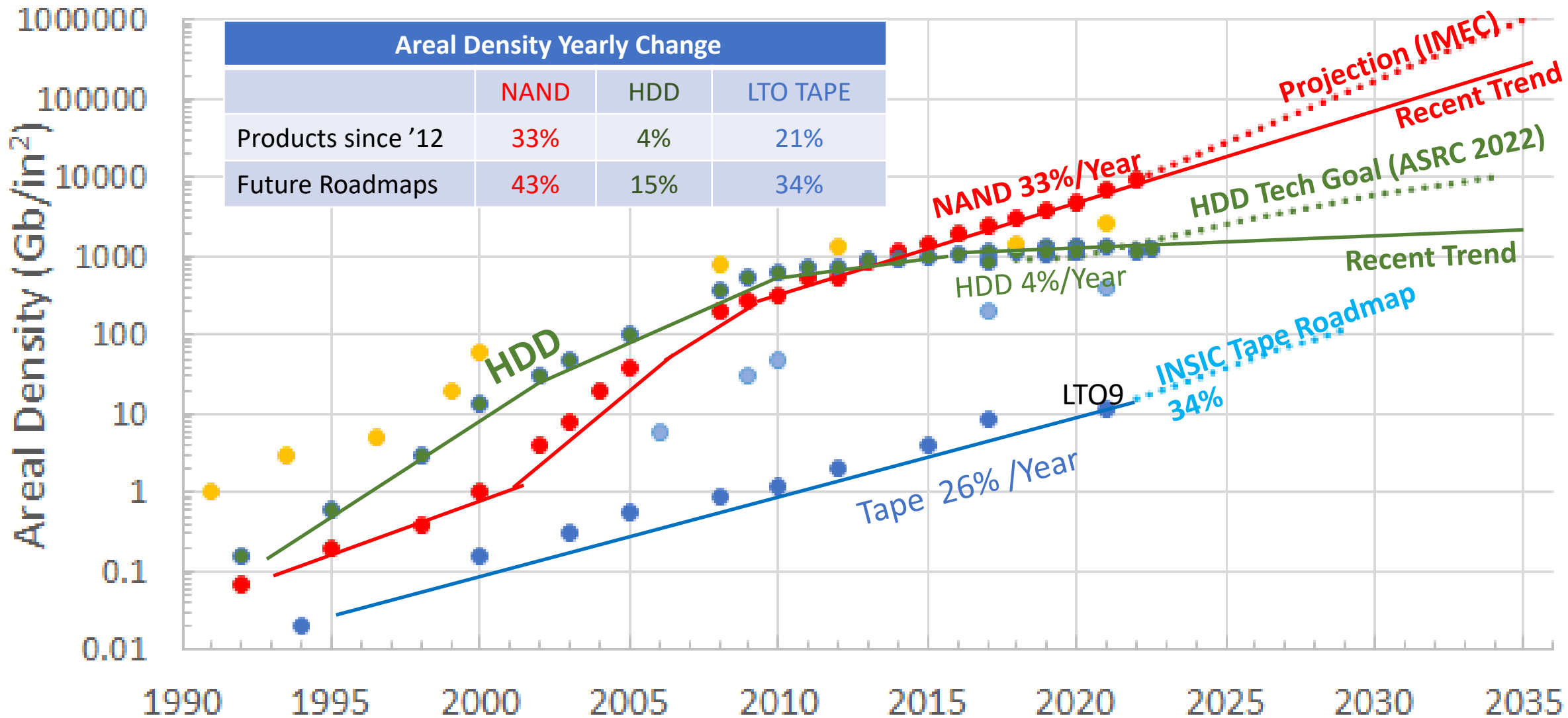


Tape in growth phase, as demand for archival storage, which mitigates climate change issues, grows in the cloud hyperscale storage facilities, while having clear Roadmap for Areal Density Growth

Technology Trends (Areal Density) of NAND, HDD, Tape



Products and Projections of Areal Densities



Areal Density improvements leads to Cost reduction and Energy Savings:

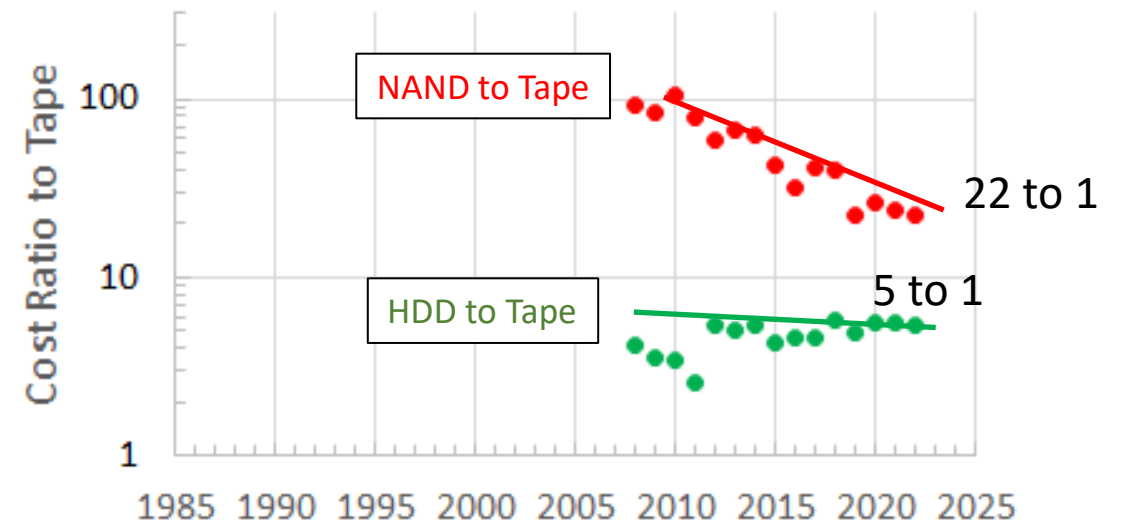
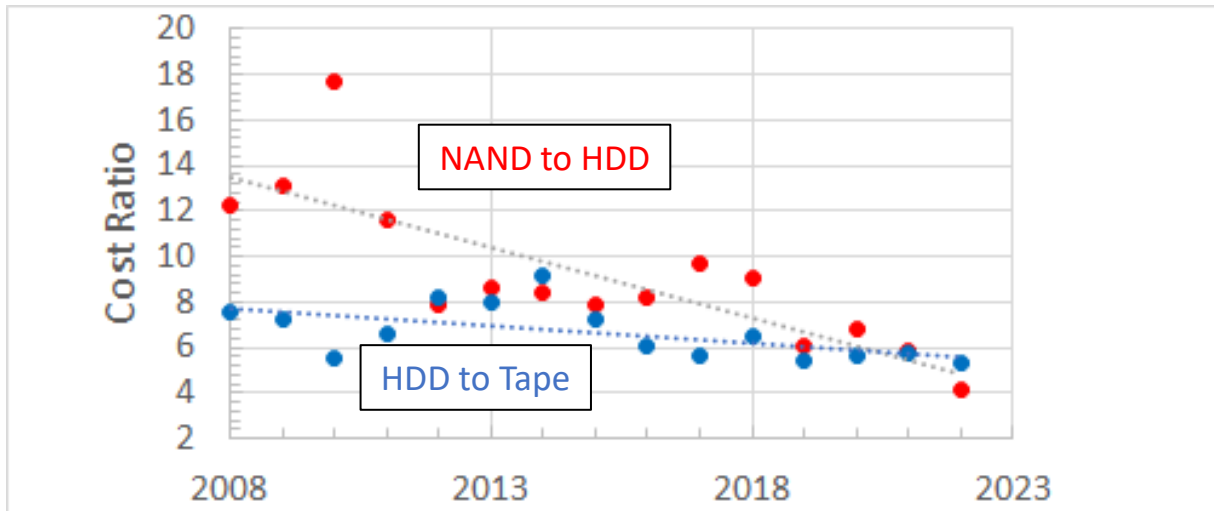
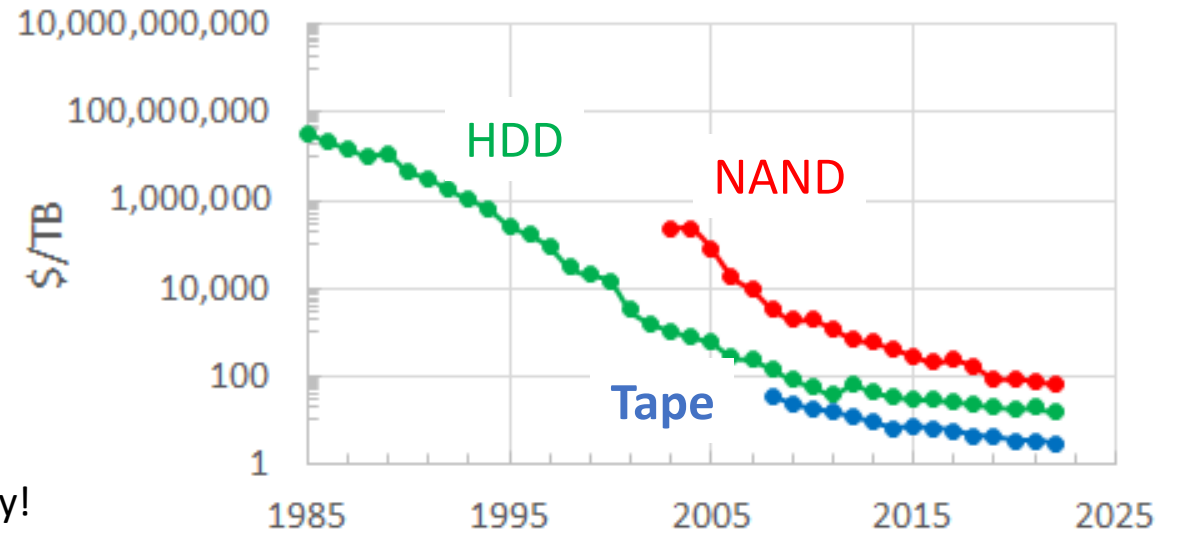
Tape and **NAND** predicted to improve more than **HDD**

Cost Trends



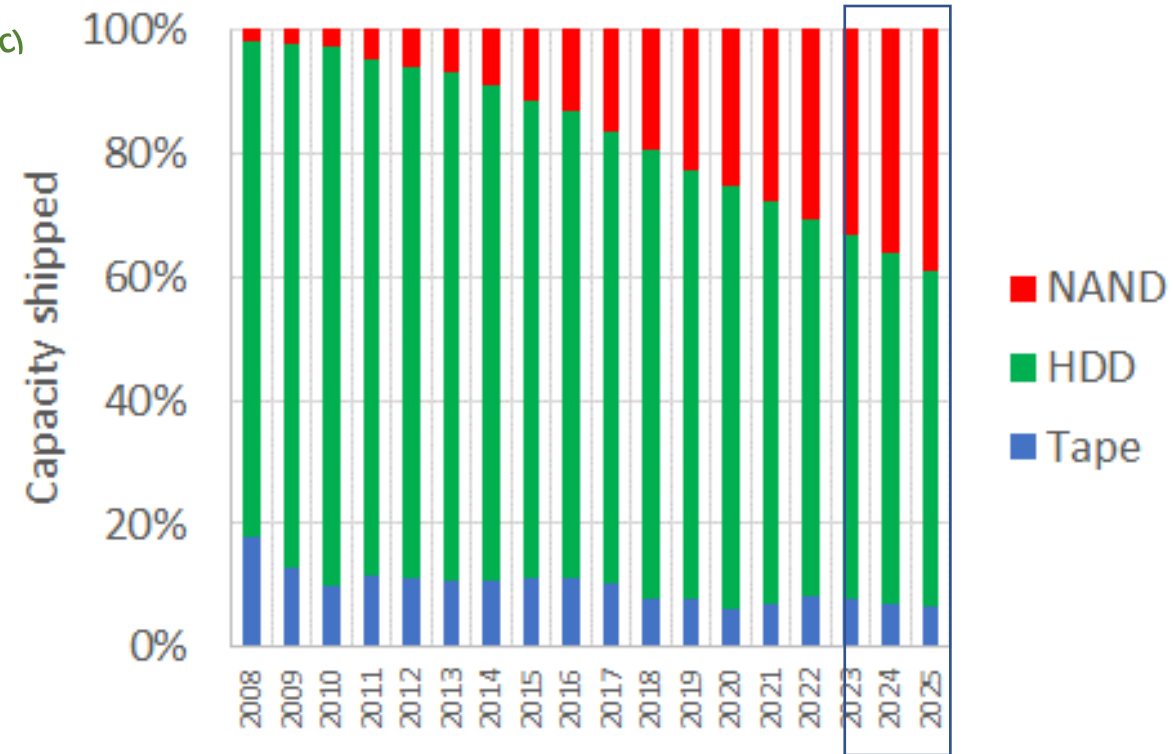
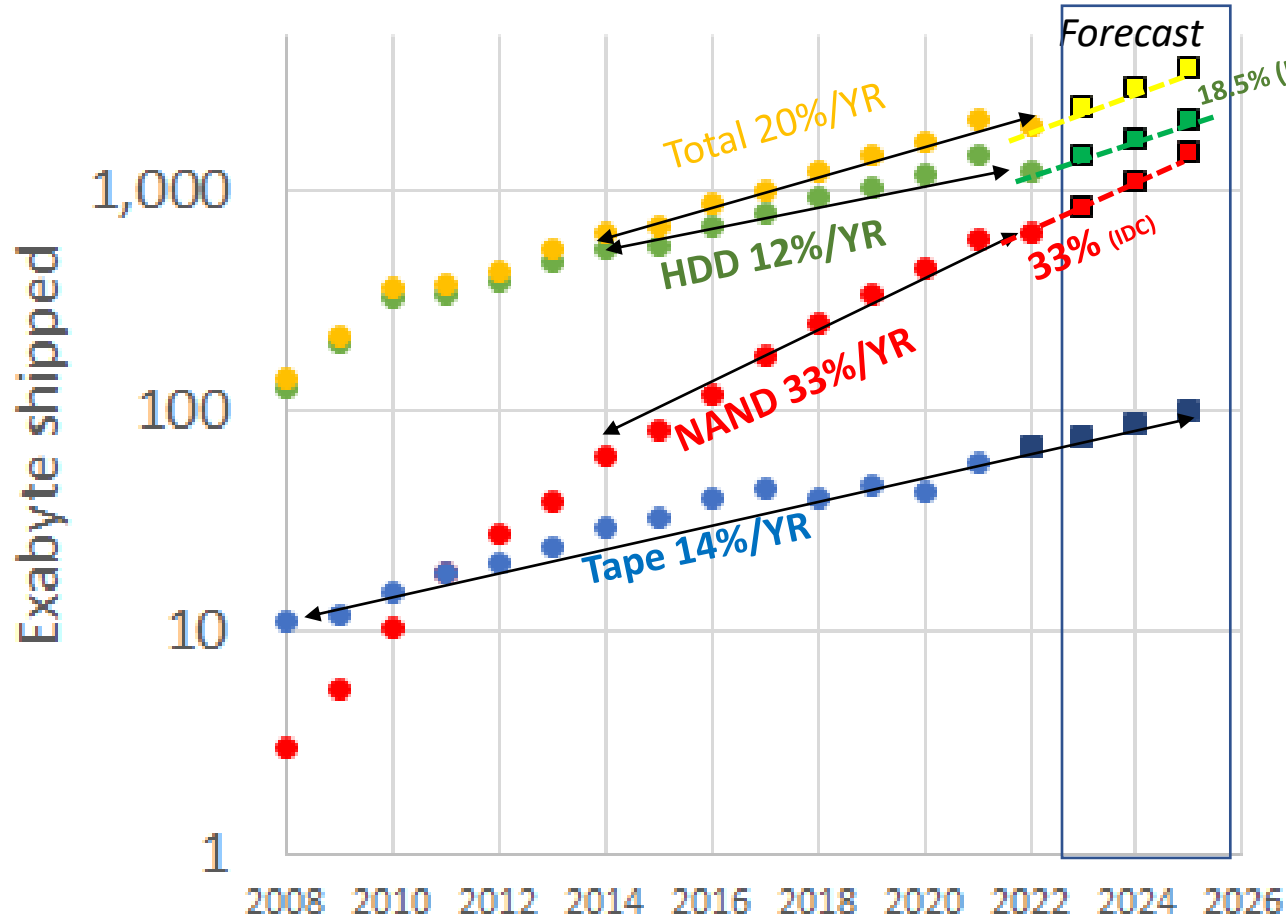
	NAND	HDD	LTO TAPE
2022 (\$/TB)	64	15	3
Cost/TB Ratio to Tape	22	5.4	
Energy Consumption per capacity	Medium	Largest	Smallest

- Annual \$/TB decreases for all technologies
- Tape most sustainable as it uses least power and is cheapest to buy!



For Tape the Price per TB is for compressed storage

Bit Shipments

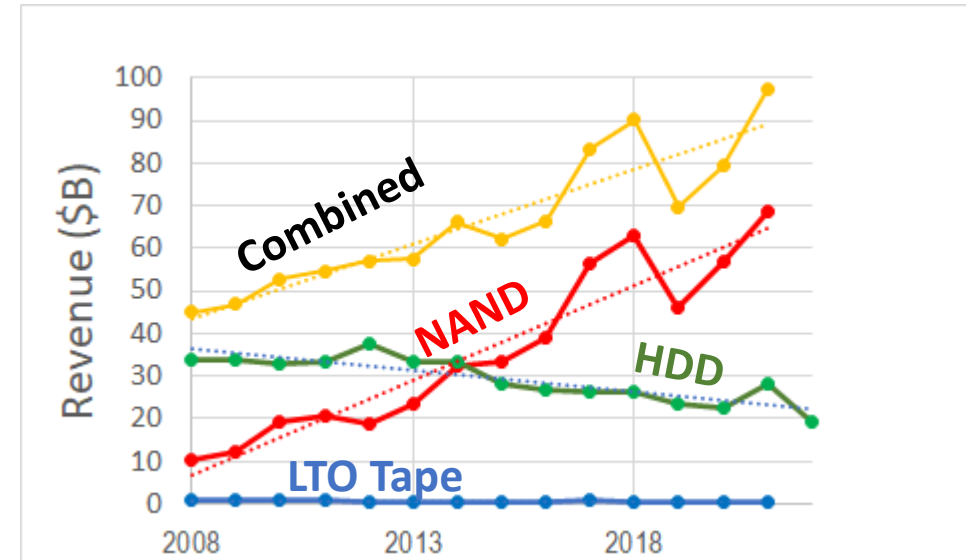
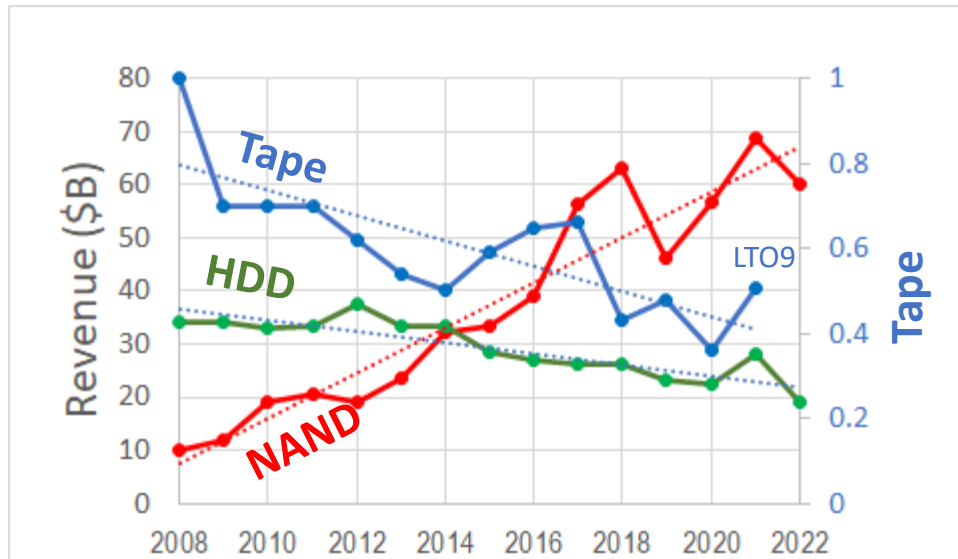
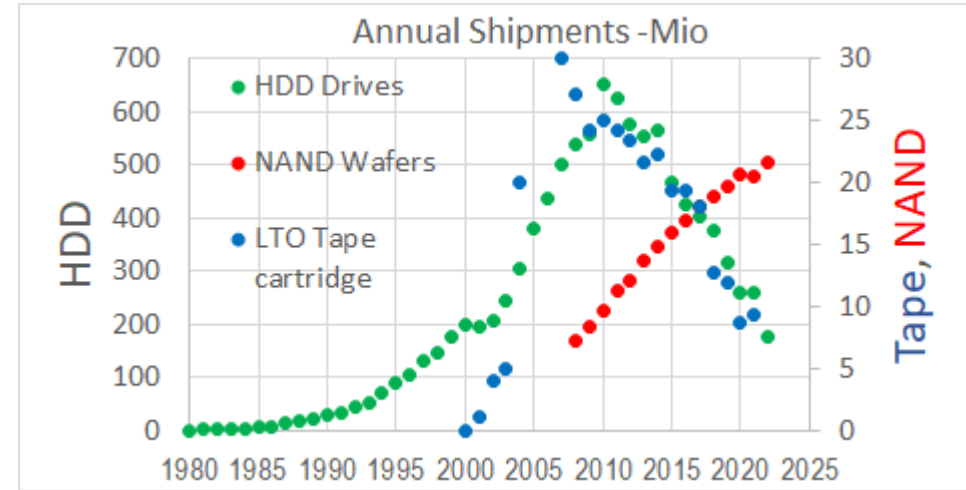


We expect more **Tape** demand for Cloud Storage (less \$ and Energy)

Revenue and Unit shipment Trends



- NAND largest Revenue
- NAND and HDD drop in 2022
- HDD – Slow downward trend in revenue
- LTO Tape Media – Revenue increase with LTO9 Intro
- General Observation: Magnetic storage technologies are showing revenue decreases over time.



Summary



- NAND largest growth
- HDD Drive capacity increase by adding disks to a drive
- Tape most energy efficient & long-term large storage capacity growth outlook

	Yearly Change 2012-2022			2022		
	NAND	HDD	LTO MEDIA (to '21)	NAND	HDD	LTO MEDIA (to 2021)
Bit Shipments (EB)	36%	13%	12%	598	1230	59
Cost/Bit (\$/TB)	-19%	-17%	-13%	95	15.5	2.9 (compressed)
Revenue (\$B)	12%	-3%	-2%	60	19	0.51
Areal Density (Gb/in ²)	33%	4%	21%	9400	1100	12

US Chip Act strengthen manufacturing base for semi-conductor
Future storage technologies require R&D government and industry focus
to create resilient and energy-efficient storage systems

Appendix

Recent Products vs Technology Future Dreams

NAND (by IMEC)

HDD (by IDEMA 2022)

Tape (by INSIC 2019)

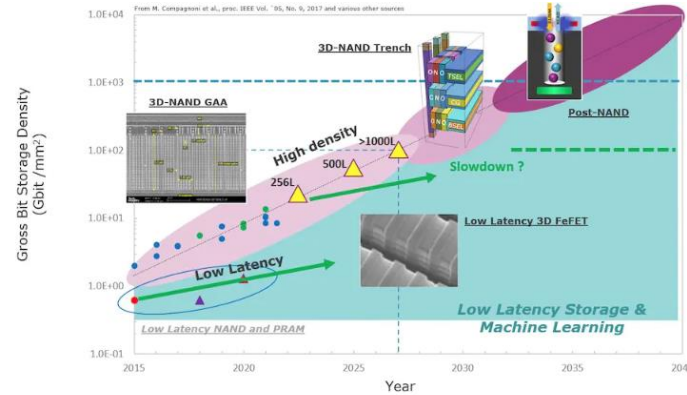
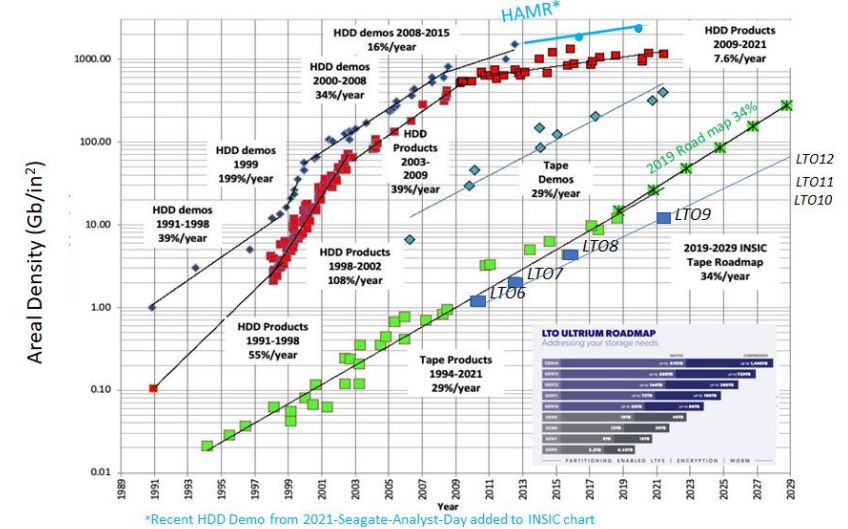
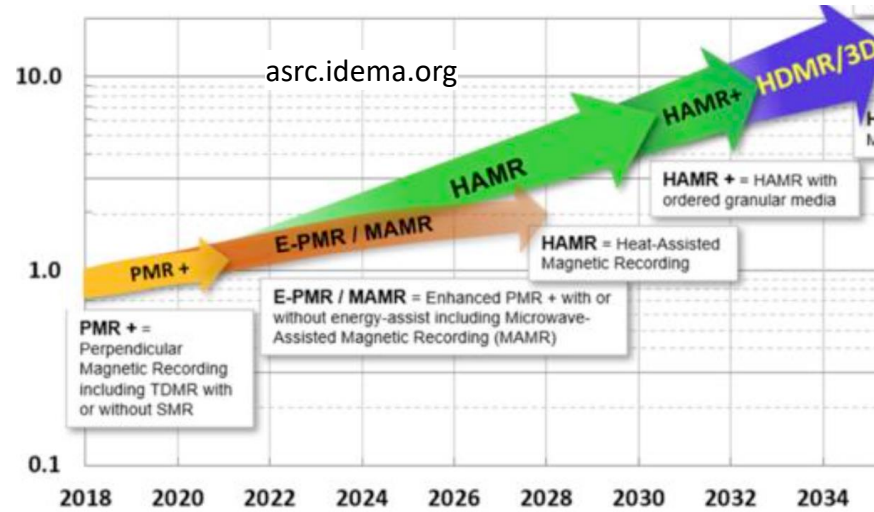


Figure 6: An imec view on the data storage roadmap.



Areal Density Yearly Change			
	NAND	HDD	LTO TAPE
Products since 2012	33%	4%	21%
Roadmaps shown above	43%	15%	34%

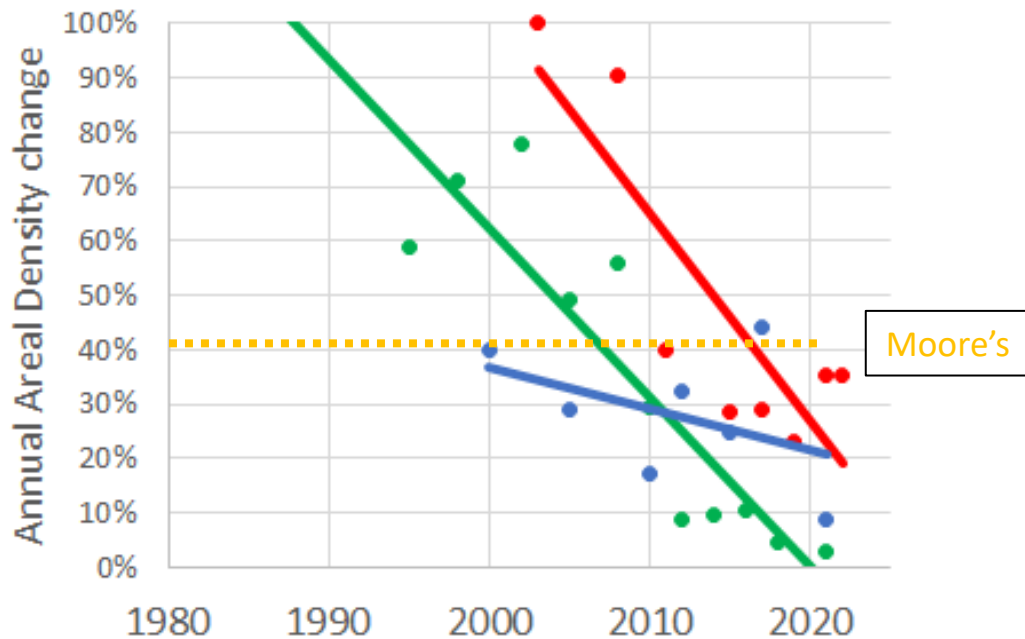
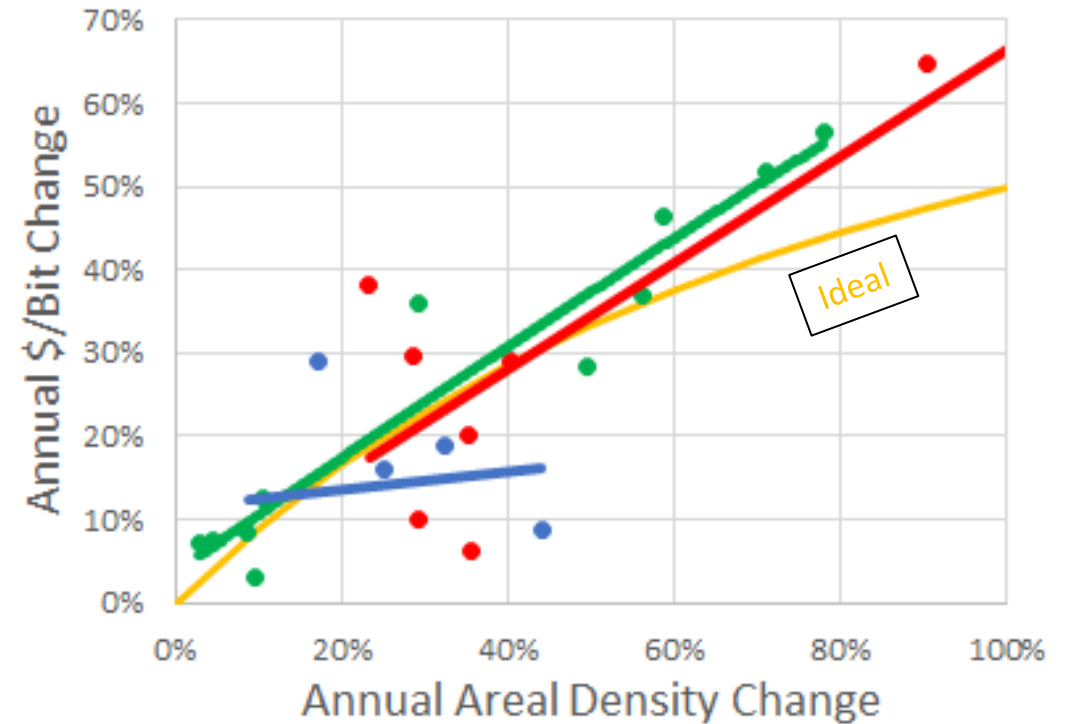
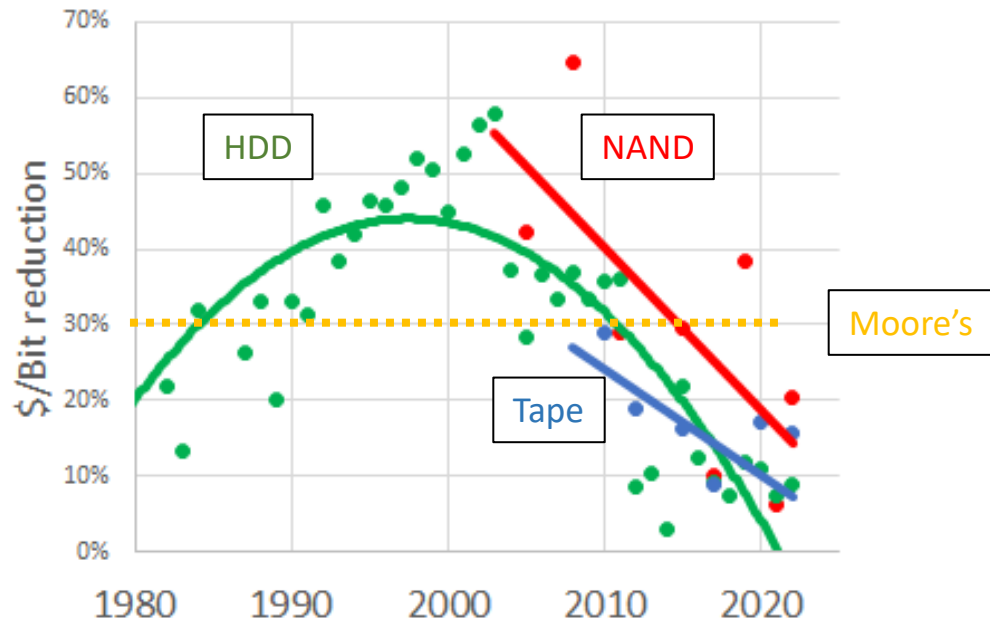
Future Roadmaps predict stronger growth compared to recent product improvements!

NAND Projection from : <https://www.imec-int.com/en/articles/role-3d-nand-flash-and-fefet-data-storage-roadmap>

HDD Projection from : <https://www.asrc.idema.org>

Tape Projections adapted from INSIC

Cost And Areal Density Trends & Moore's Law



The improvements are getting smaller with time for NAND, HDD and Tape

Yearly Change 2012-2022	NAND	HDD	LTO MEDIA
Cost/Bit	-19%	-17%	-13%
Areal Density	33%	4%	21%