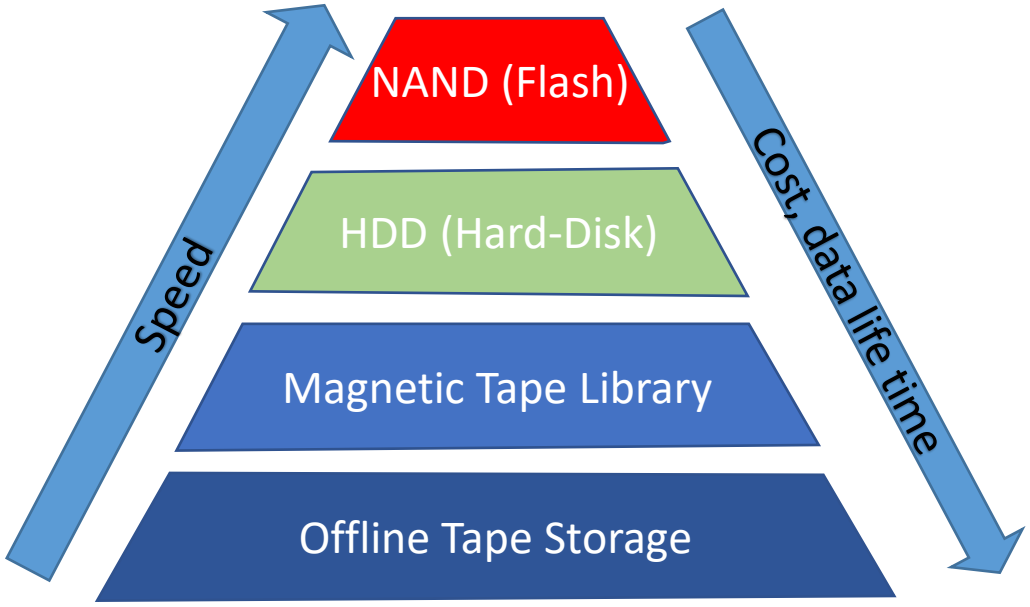
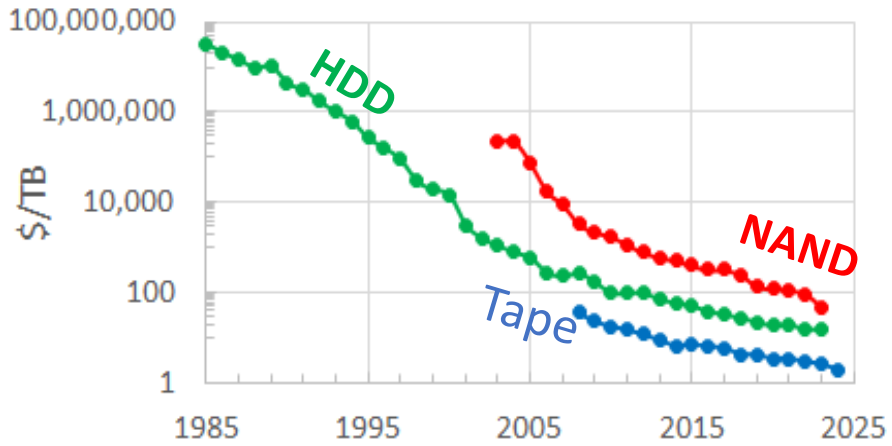
NAND, HDD and Tape Storage Technology Trends

Georg Lauhoff and Gary M Decad, IBM Storage





Library of Congress, Washington DC
Designing Storage Architecture for Digital Collections , April 15, 2024

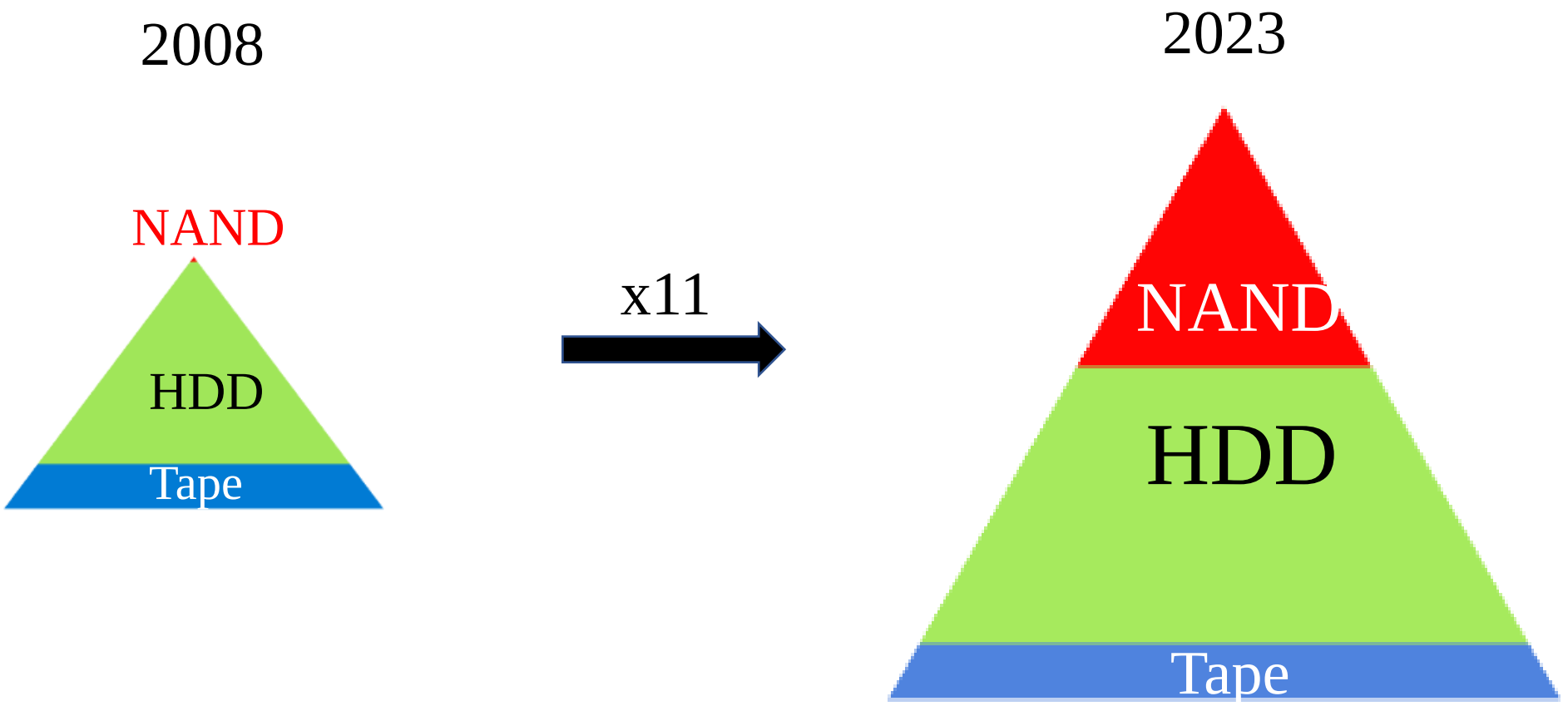
This study builds on previous studies by *R. Fontana, G. Decad AIP Advances 8 (5) 056506 (2018) and our previous Library of Congress presentations*

Introduction

- **Foundational Infrastructure**: Data storage is fundamental to the digital economy.
- **Environmental Concerns**: The carbon footprint of data storage is substantial and growing.
- **Archival Storage**: Tape data storage is reliable and cost-effective and energy conserving with no viable alternatives available.
- **Trends in Tiered Data Storage**: NAND and Tape improve @ historical rates in cost and storage densities while HDD progress slowed down
- **Challenges of Alternative Archival Technologies**: Despite the promise of alternative archive storage technologies, challenges persist. Enduring relevance of tape storage, which itself is rapidly evolving.

A Changing Data Storage Landscape

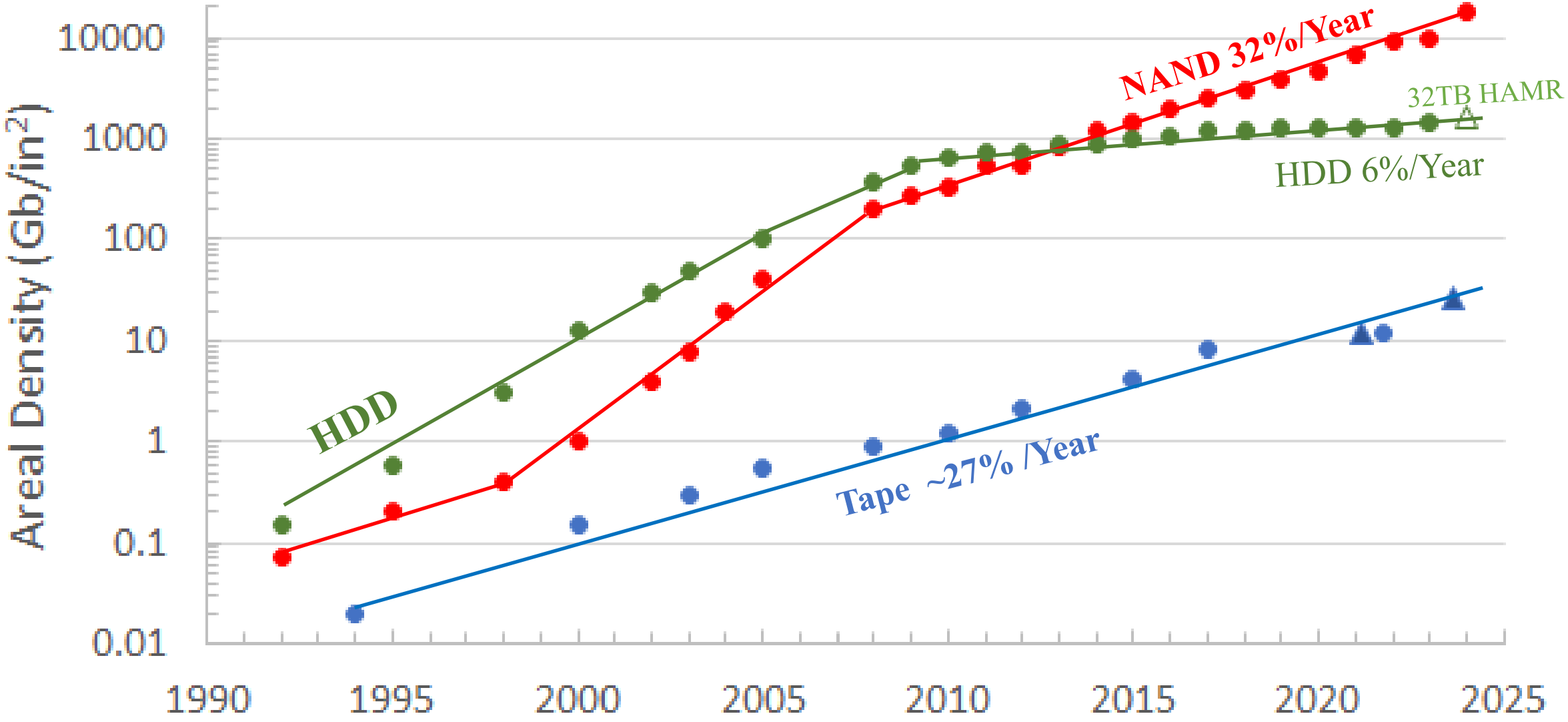
Annual capacity Shipments (Bits)



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

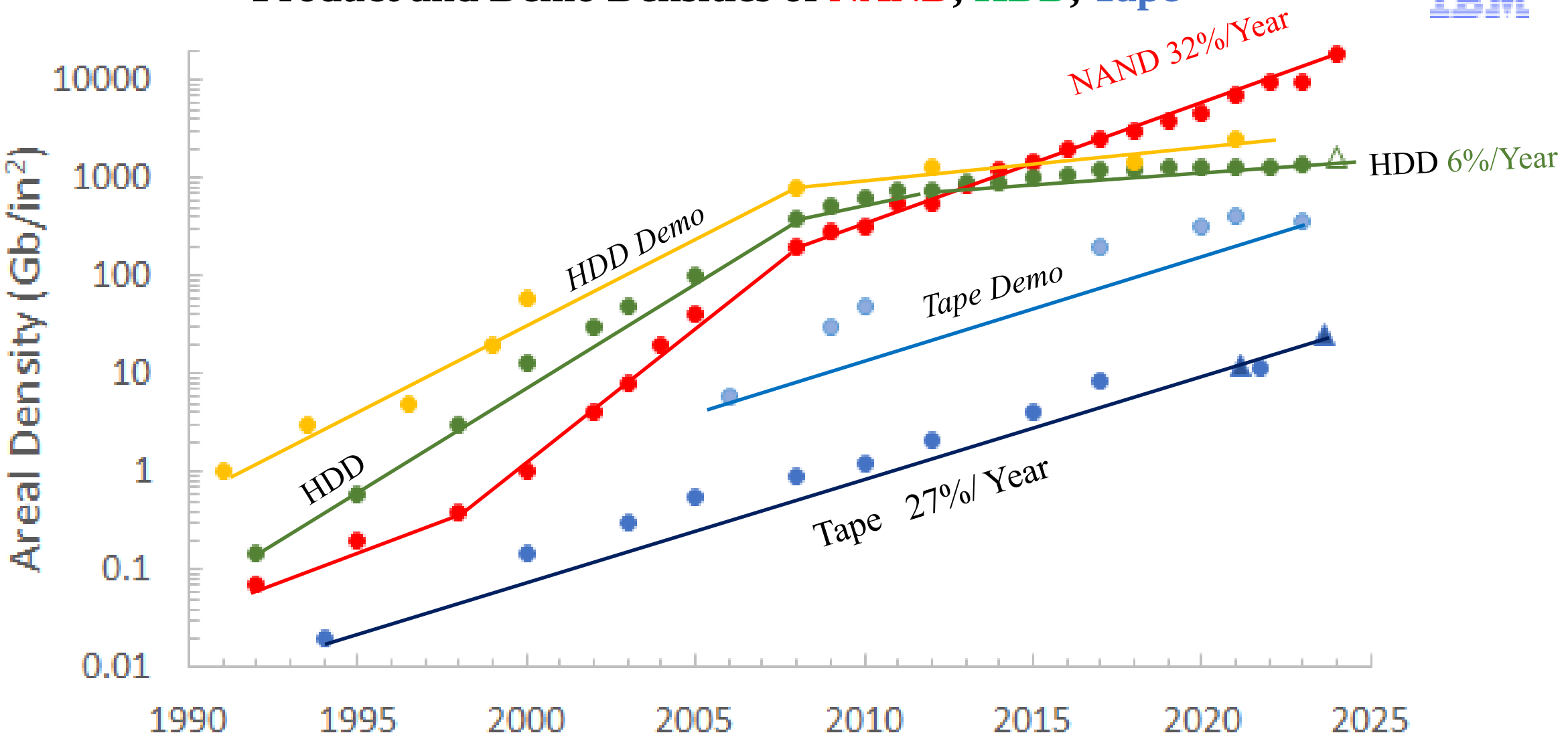
This study build on previous studies by ***R. Fontana, G. Decad AIP Advances 8 (5) 056506 (2018)***
Data obtained from publicly available sources

Products **Areal Densities of NAND, HDD, Tape**



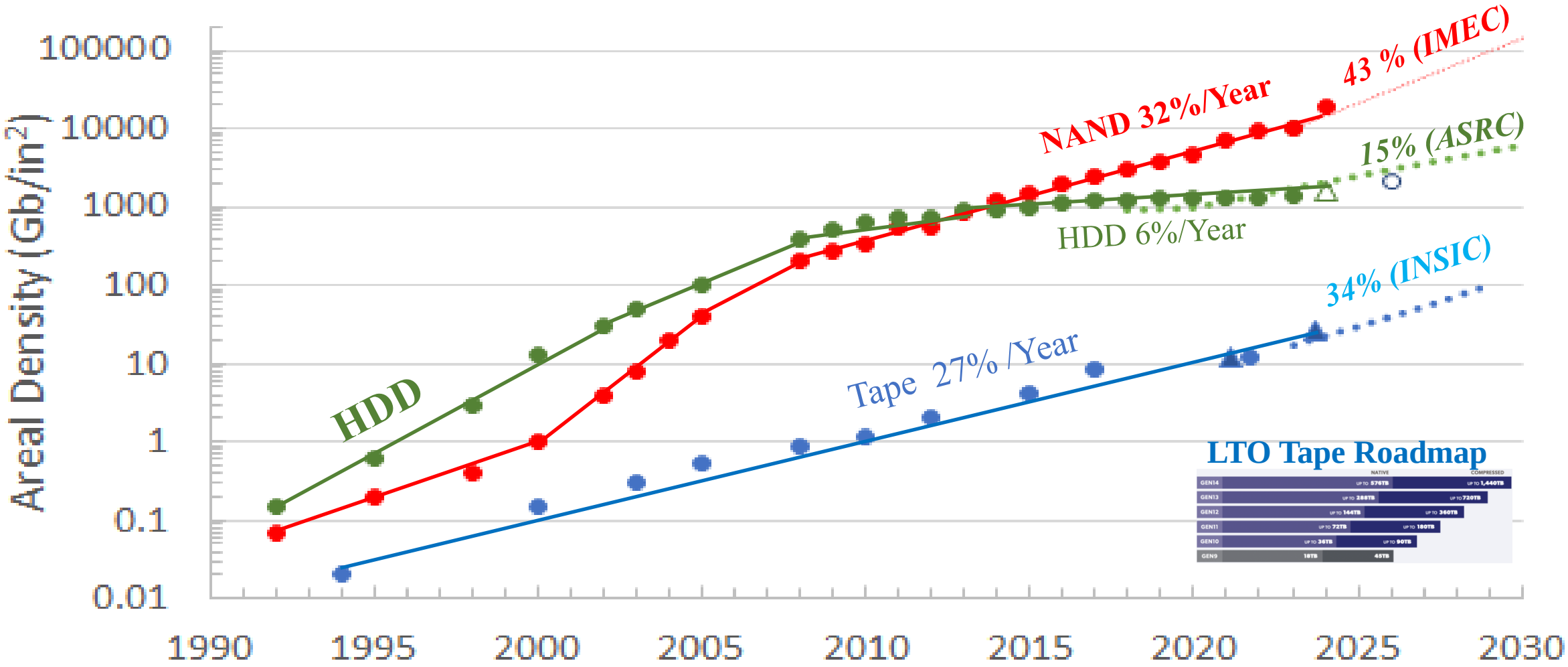
Tape and NAND improves more than HDD in areal densities

Product and Demo Densities of NAND, HDD, Tape



Tape has clear path to higher densities as demonstrated by demos;
With more investments more can be achieved in even shorter time

Product Areal Densities and Forecast

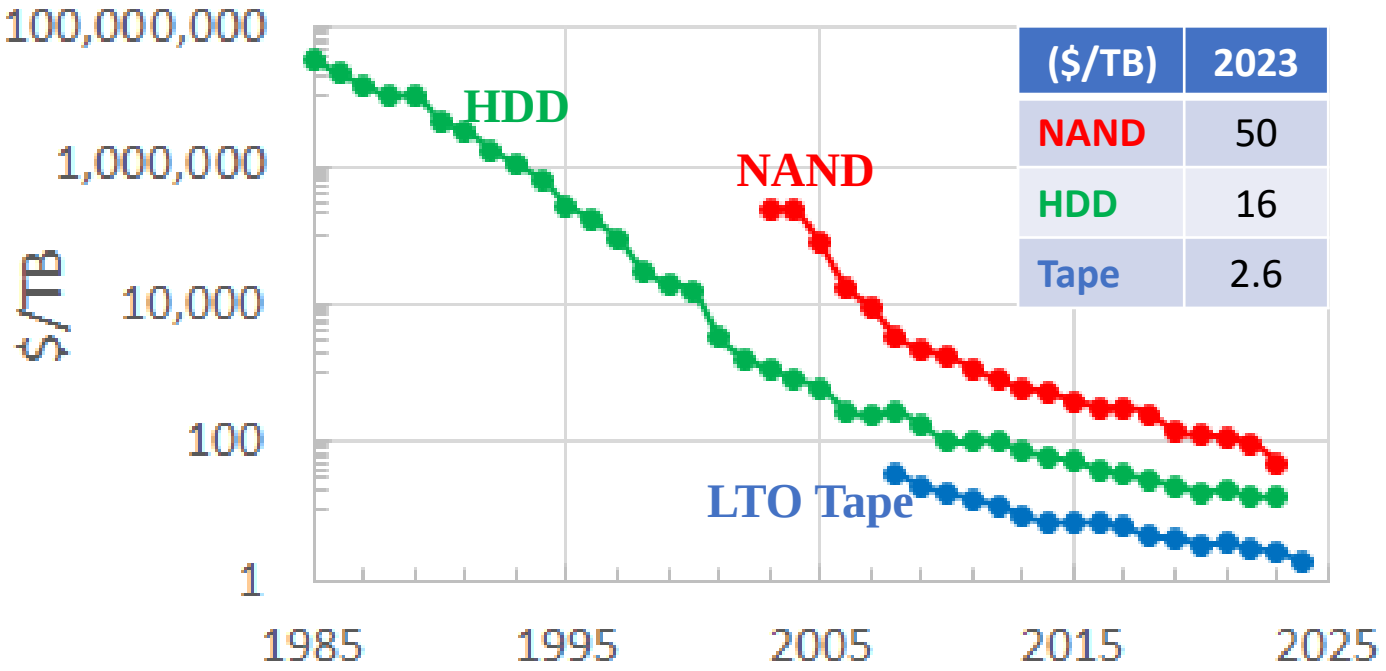


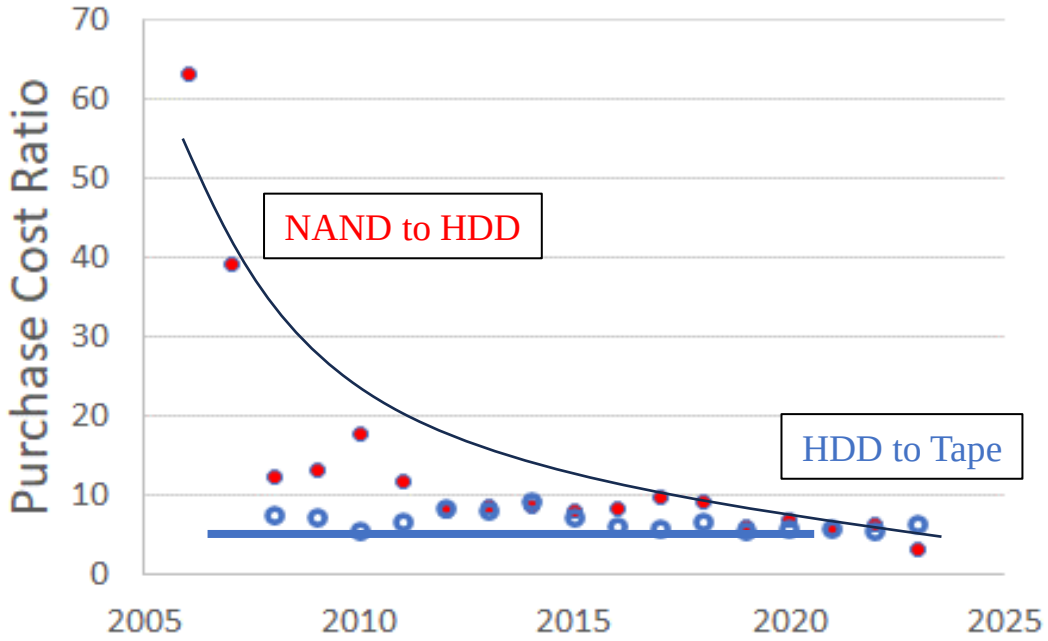
***NAND** and **HDD** forecast more optimistic compared to recent trend*

Forecast and product improvements similar for Tape

Cost Trends of NAND, HDD and LTO tape

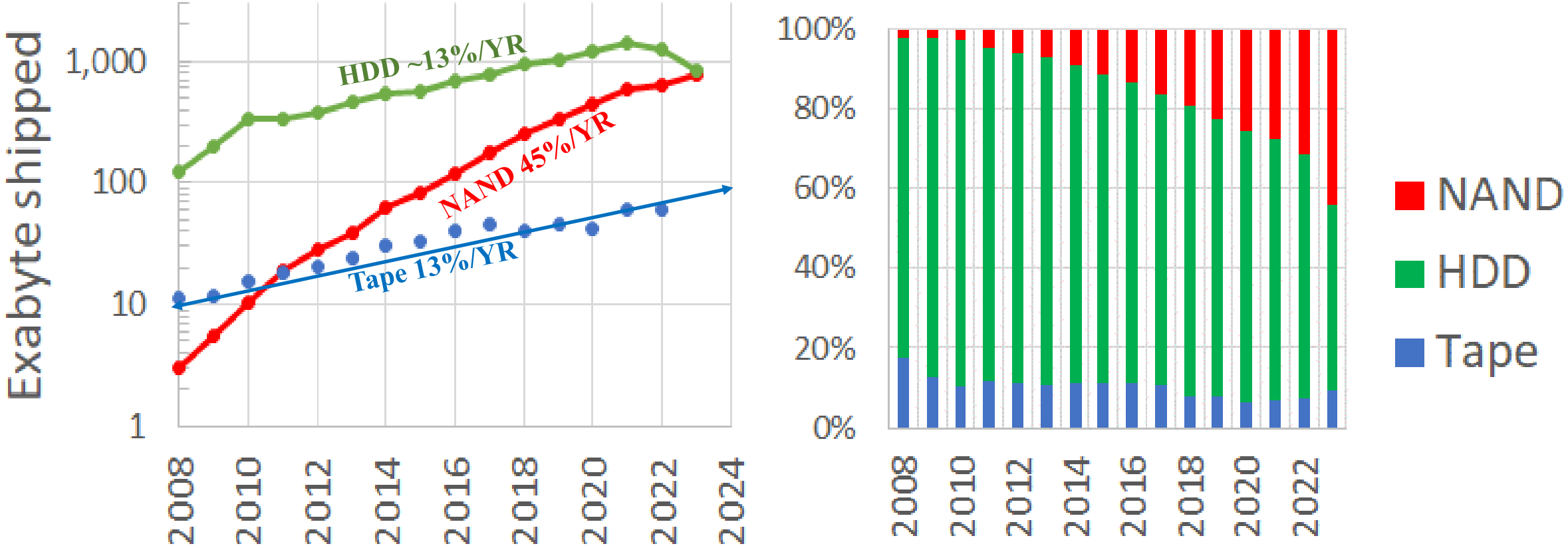
- Purchase cost decreases for all technologies
  - Tape to HDD cost ratio stable
  - NAND becomes relative to HDD more affordable





For Tape the Price per TB is for compressed storage

Bit Shipments



NAND (includes SSD, Flash Drives, memory cards..) and HDD bit shipments in 2023 about equal!

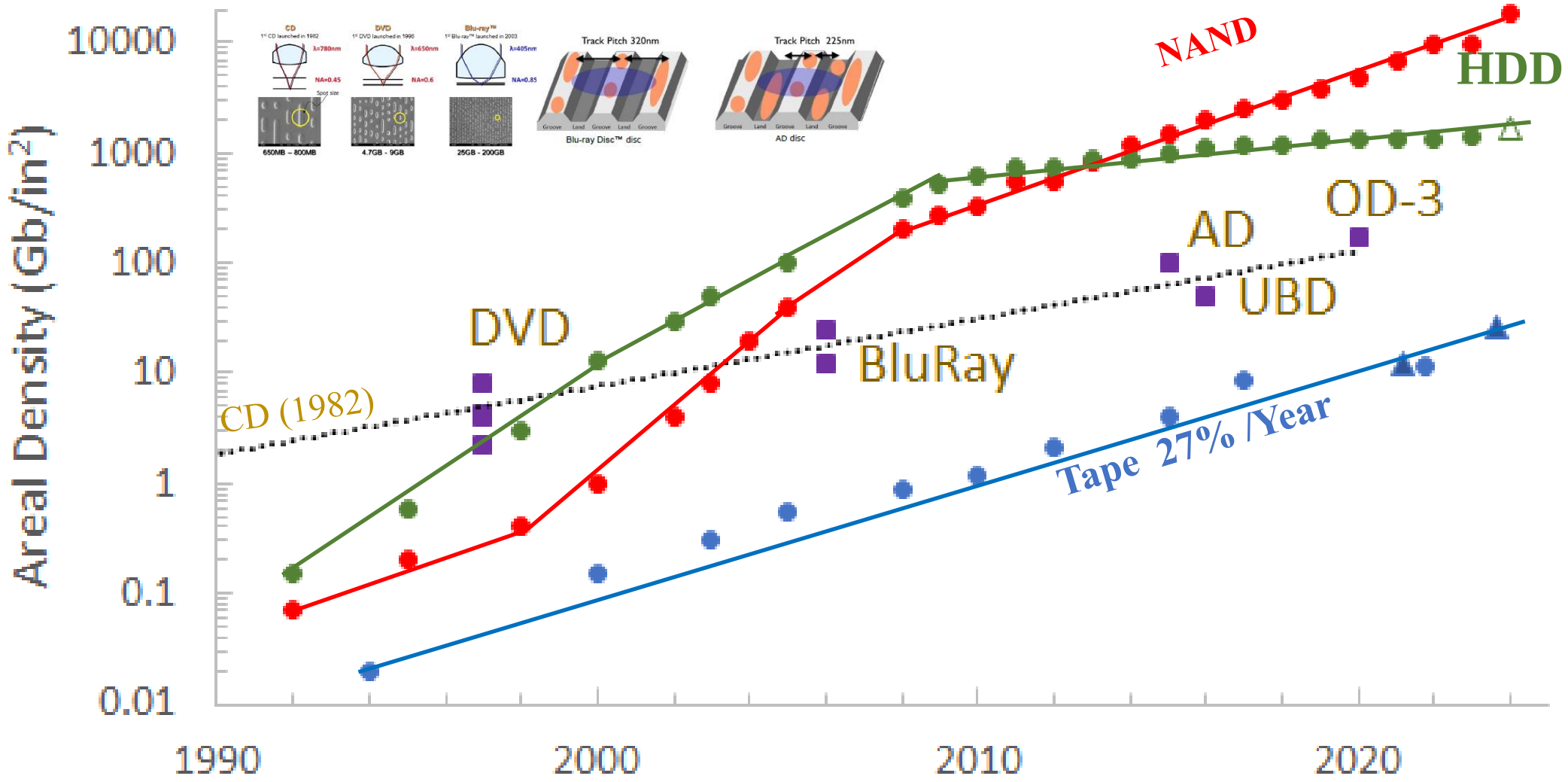
Expect more Tape demand: less $ and Energy and becomes easier to use (S3)

Challenges of Alternative Archive Storage Media

- **Optical Storage**: While once considered for archival storage, optical storage methods have seen limited adoption. Optical Archival (OD-3) was discontinued in 2023, indicating its declining relevance in the storage landscape.

- **DNA Storage:**
  - Cost and Access Time are just a few obvious coming into mind.
  - Large Market size needed to develop technology; a sub-tier below tape storage is small

Areal Densities of NAND, HDD, Tape, Optical

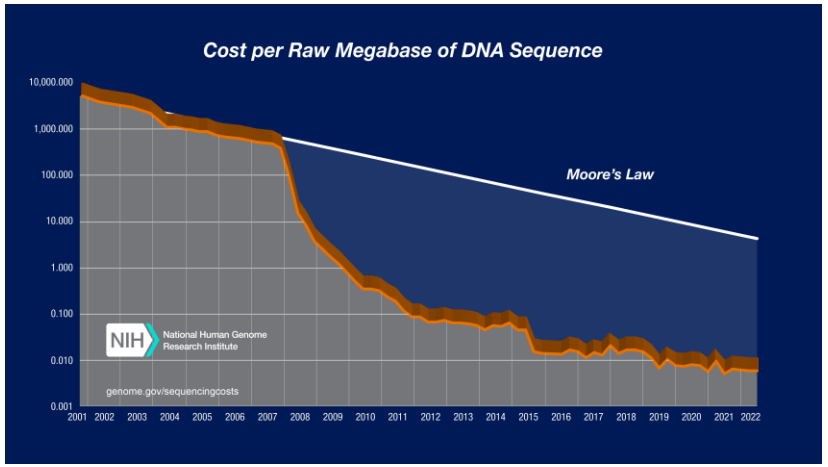


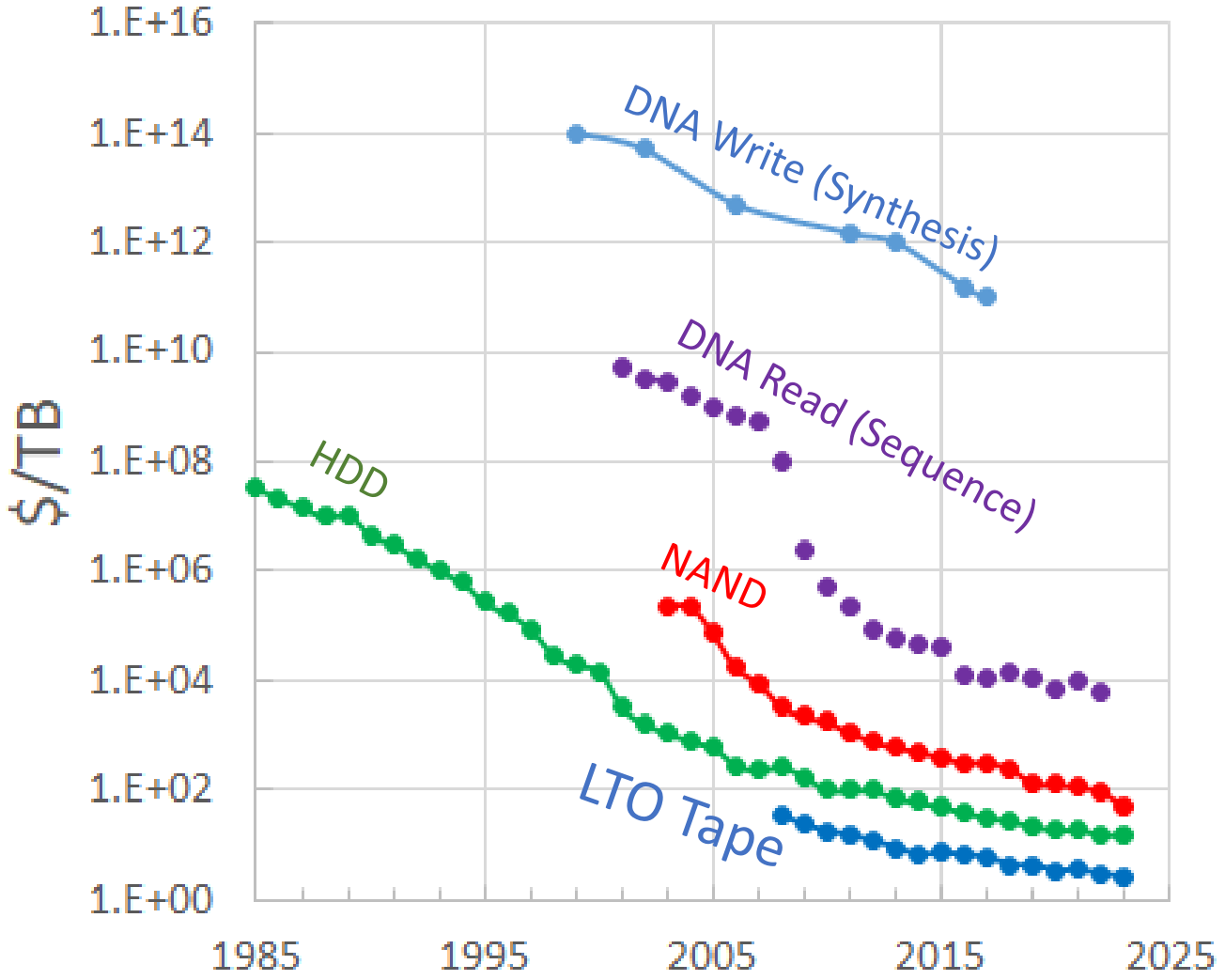
Optical Storage: While once considered for archival storage, optical storage methods have seen limited adoption. Optical Archival (OD-3) was discontinued in 2023, indicating its declining relevance in the storage landscape.

DNA Storage: Let's compare DNA Sequencing and Synthesis to Flash, HDD and Tape

- Very slow to write and read
- Very expensive
- Not so stable

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC10296570/

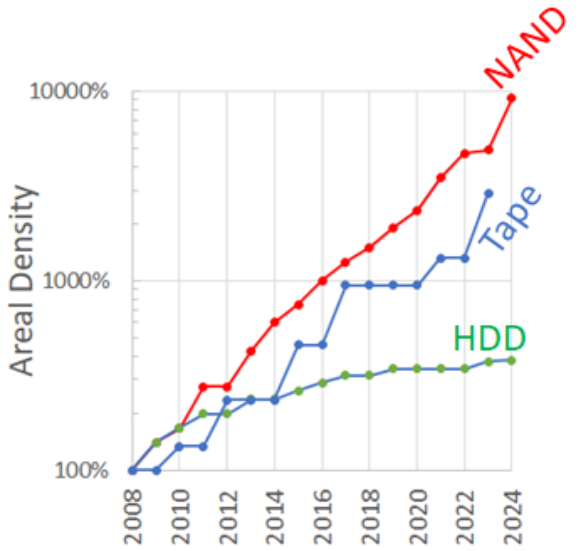




Summary

- **Tape Storage** continues to improve
- **HDD**: improvements slow down.
- **NAND**: well-suited for hot storage but not for archival purposes.
- **Lack of Alternatives**: Within the foreseeable future (within 10 years), there are no viable alternatives to Tape, HDD, and NAND storage.
- Therefore, continued investment in this data infrastructure is crucial to meet evolving storage demands while reducing energy consumption.

Yearly Change 2012-2023				2023		
	NAND	HDD	LTO MEDIA (to ‘22)	NAND	HDD	LTO MEDIA
Bit Shipments (EB)	35%	13%	13%	780	1230	59 (‘22)
Cost/Bit ($/TB)	-22%	-17%	-18%	50	16	2
Areal Density (Gb/in2)	30%	6%	26%	9800	1400	26 (JF)



Summary

- **Foundational Infrastructure**: In the digital economy, data storage serves as the bedrock infrastructure upon which all other activities rely.
- **National Strategic Imperative**: Many countries now view data as a critical component of their national strategy, recognizing the direct impact of data storage infrastructure on economic success.
- **Resilience and Efficiency**: Research and development efforts, along with government and industry focus, are directed towards creating storage systems that are resilient and energy-efficient, ensuring sustainability and competitiveness.
- **Investment Imperative**: Despite the rapid pace of technological advancement, there are currently no viable alternatives to Tape, HDD, and NAND storage solutions. Thus, continued investment in these technologies is essential for meeting evolving storage demands.
- **NAND's Growth and Maturity**: While NAND technology experiences significant growth, it is also approaching maturity, requiring a shift in focus towards enhancing efficiency and sustainability.
- **HDD Capacity Challenges**: Increasing HDD drive capacity by adding disks does not necessarily improve speed or cost-effectiveness, highlighting the need for alternative approaches to storage expansion.
- **Tape's Efficiency and Potential**: Tape storage stands out as the most energy-efficient option with a promising outlook for long-term areal density growth. Its fast sequential read speed presents significant opportunities, particularly in applications such as **artificial intelligence**.

Appendix

DATA METHODOLOGY

- Data added to the previous study: ***R. Fontana, G. Decad AIP Advances 8 (5) 056506 (2018)*** *and our previous 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)
- 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
- Tape data – LTO Media Only
  - Media cost/bit is based on web-based pricing at www.tape4backup.com
  - Data is for media only and does not include contributions from drive sales, library sales

Storage Landscape History

	'08	'09	'10	'11	'12	'13	'14	'15	'16	'17	'18	'19	'20	'21	'22	'23
HDD																
Units (HDD millions)	540	557	652	620	577	551	564	470	425	406	374	315	268	258	175	122
Bits Shipped (EB)	125	200	330	335	380	470	549	565	693	780	938	1034	1190	1418	1233	830
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	1100/1300 (CMR/SMR)	1200/1400 (CMR/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	*~13*
$/TB Shipped	272	170	100	100	100	71	61	51	39	33	28	22.5	18.8	19.7	15.5	*15.8*
NAND																
Wafers (millions)	7.3	8.3	9.7	11.3	12.1	13.7	14.8	15.9	17.0	18.1	18.9	19.7	20.6	20.5	21.7	
Bits Shipped (EB)	3	5.4	10.5	19	28	39	63	83	120	175	250	338	439	598	631	779
Areal D. (Gb/in^2)	200	280	330	550	550	850	1200	1500	2000	2500	3000	3800	4700	6970	9414	9806
Revenue ($B)	10	12	19	22	22	24	32	33	39	57	63	46	57	69	60	39
$/TB Shipped	3333	2230	1770	1160	780	615	515	401	320	320	252	136	129	115	95	50
LTO TAPE MEDIA																
cartridge (millions)	27.1	24.3	25.0	24.3	23.4	21.6	22.2	19.4	19.4	18.0	12.7	11.9	8.6	9.3	7.3	
Bits Shipped (EB)	11	12	15.3	18.4	20.7	24.3	30.1	33.0	40.3	44.8	40	46	42.5	59.2	59.3	
Areal D. (Gb/in^2)	0.9 (LTO4)		1.2 (LTO5)		2.1 (LTO6)			4.1 (LTO7)			8.5 (LTO8)			12 (LTO9)		26 (JF)
Revenue ($B)[1]	*1*	*0.7*	*0.7*	*0.7*	*0.62*	*0.54*	*0.5*	*0.59*	*0.65*	*0.66*	*0.43*	*0.48*	*0.36*	*0.51*	*0.43*	
$/TB Shipped (compr)	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	1.9

Recent Products vs Technology Future Dreams

NAND (by IMEC)

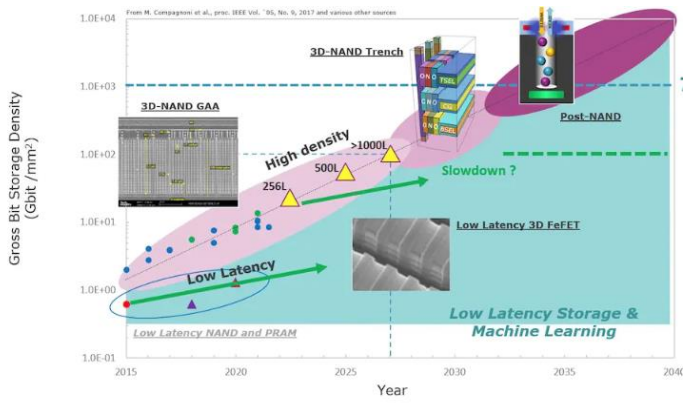
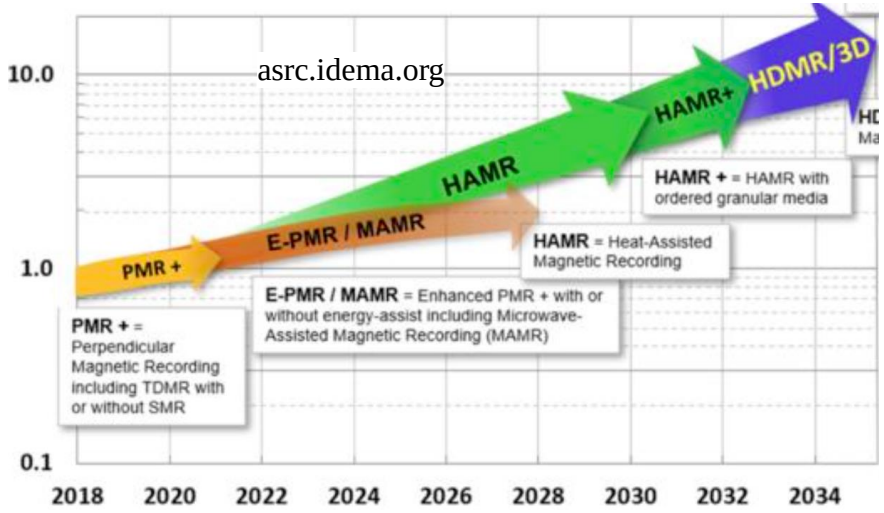
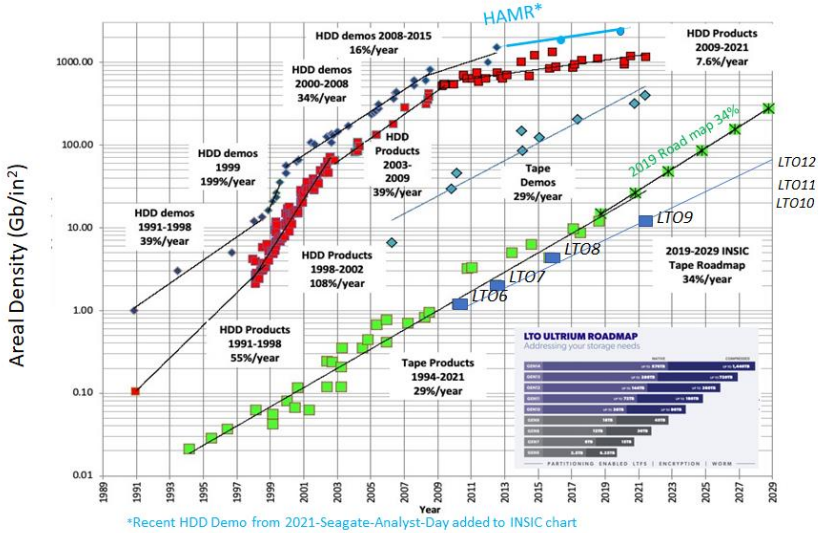


Figure 6: An imec view on the data storage roadmap.

HDD (by IDEMA 2022)



Tape (by INSIC 2019)



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

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