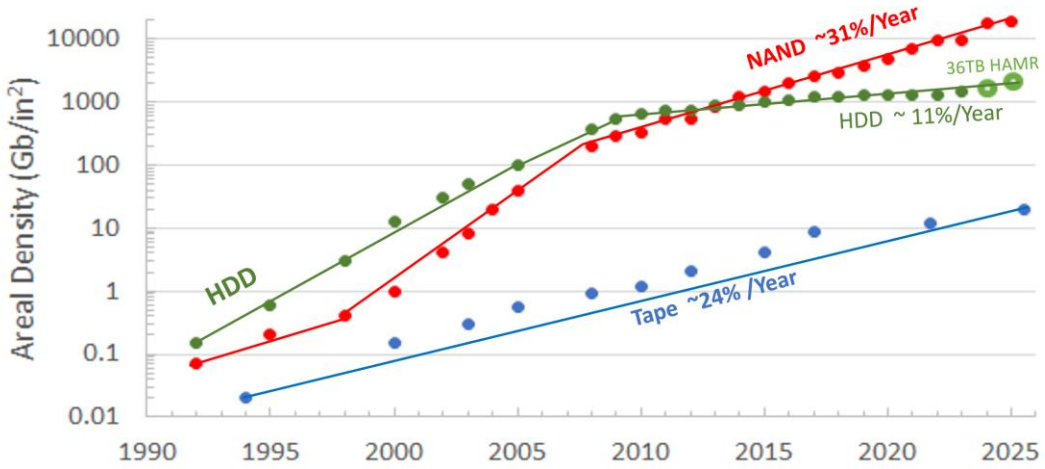
# Data Storage Trends: NAND, HDD and Tape Storage

**Georg Lauhoff, Sassan Shahidi** IBM Tape Storage, San Jose




This talk builds on studies by
*G. Lauhoff et al, "Storage Infrastructure in the AI Era," IEEE Trans Mag 61, 4 (2025)*
*R. Fontana, G. Decad AIP Advances 8 (5) 056506 (2018).*

Library of Congress, Washington DC
Designing Storage Architecture for Digital Collections, March 9, 2026

# Archival Storage Overview

## Trends in Tiered Data Storage

- NAND and Tape continues to become faster and denser.
- HDD density growth has slowed in recent years,  demand is increasing.
- Archival Storage: Tape reliable, cost-effective, and energy-efficient archival medium which  continues to evolve rapidly

## Challenges of Alternative Archival Technologies

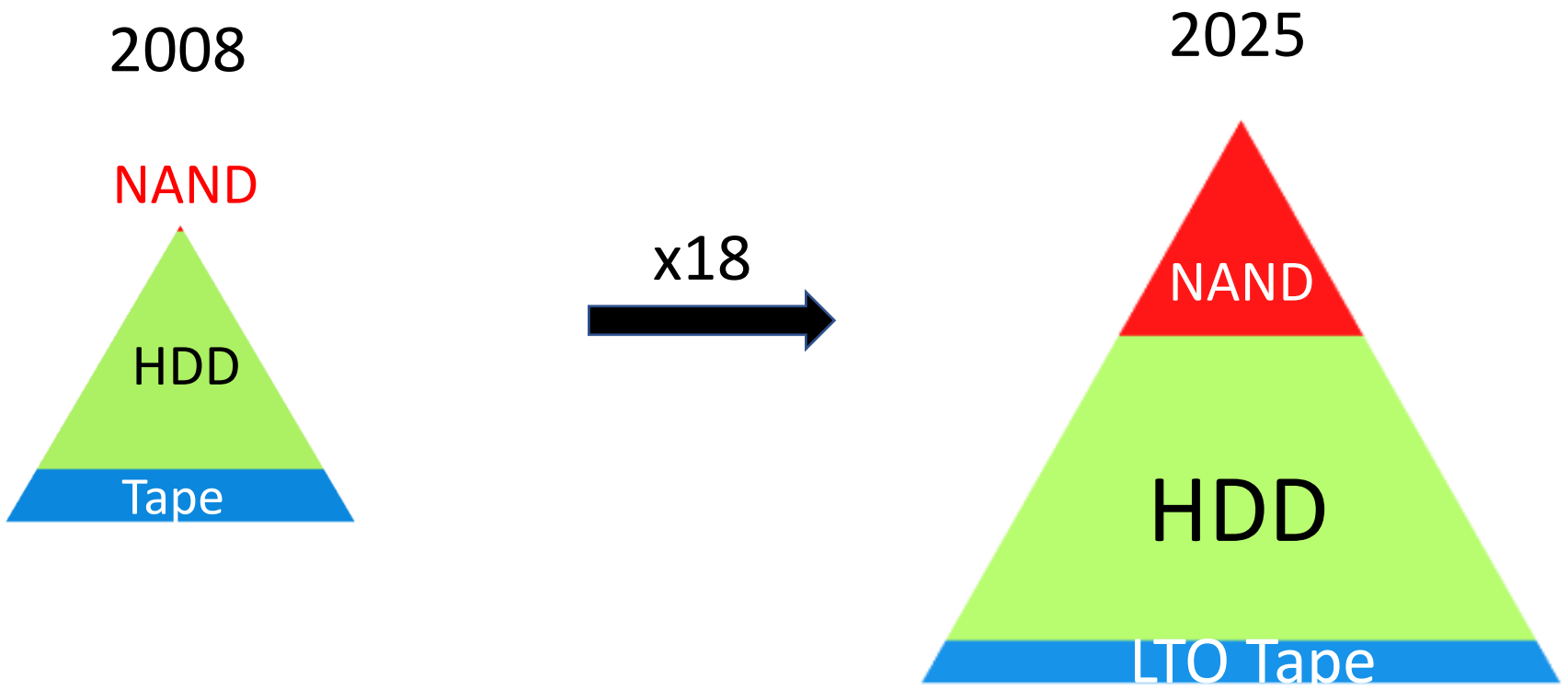
- Alternative archival technologies face technical and economic hurdles.

# Content

- Tape, HDD and NAND storage trends
  - Annual Capacity Shipments
  - Product Areal Densities and Forecast
  - Cost Trends
- Hierarchy of Storage and Memory Technologies
- Optical Storage, Tape, HDD and SSD
  - Read Speed Improvements
  - Storage density trends
  - Storage and Memory Technologies: Cost and Read Speed trends
  - DNA Data Storage vs Traditional Media Cost

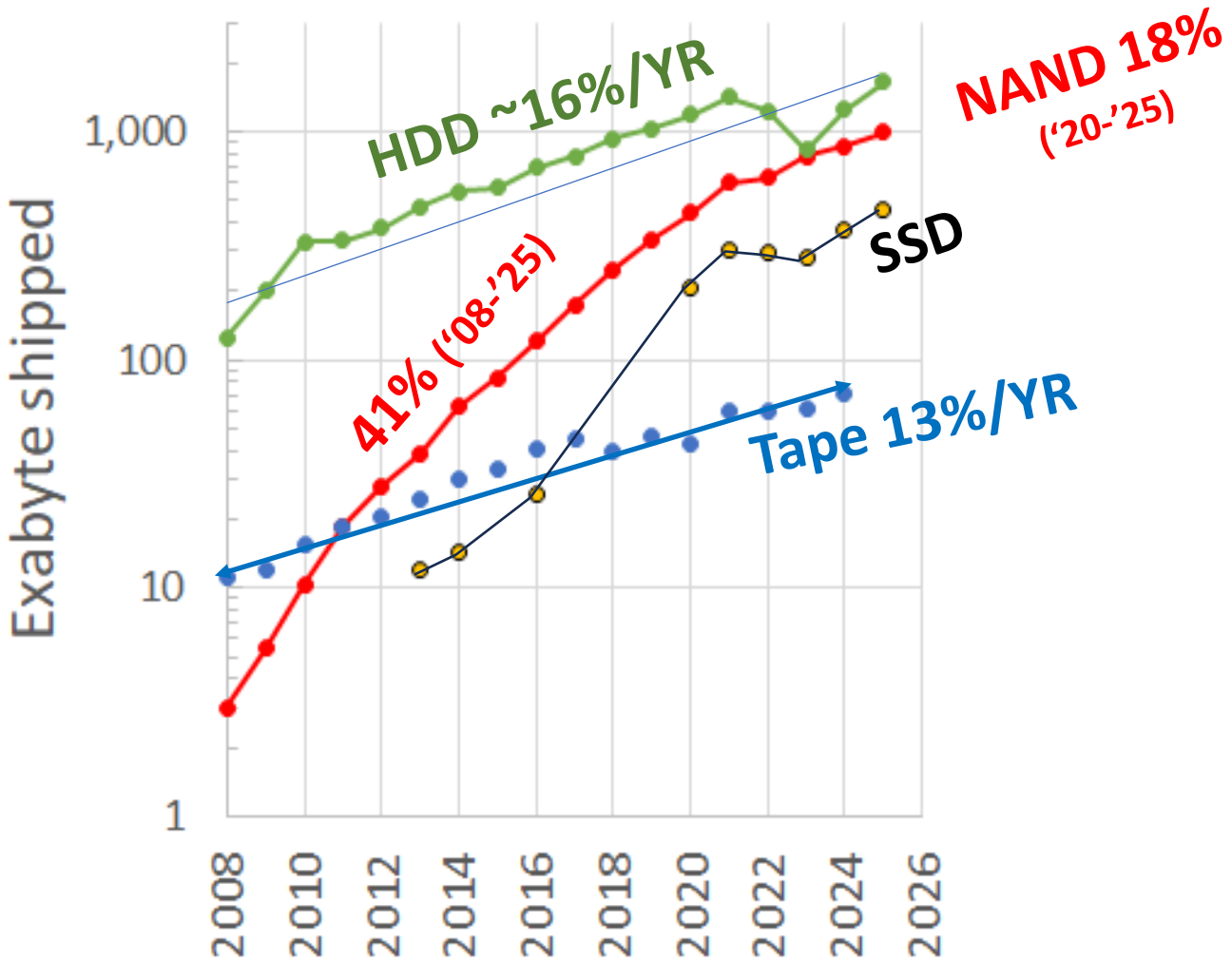
# A Changing Data Storage Landscape

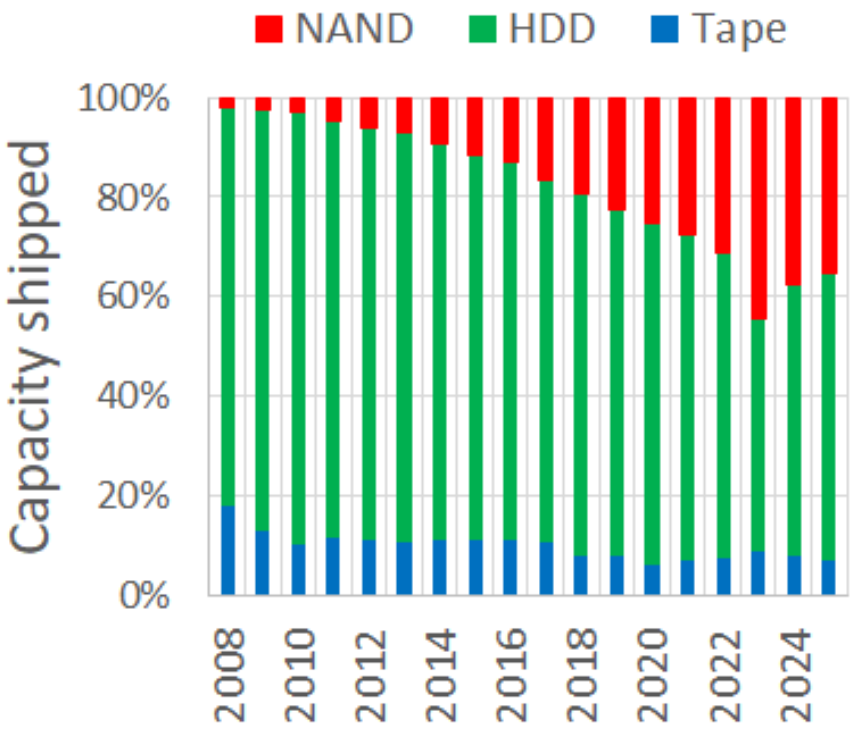
## Annual capacity Shipments (Bits)




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

# Annual Bit Shipments



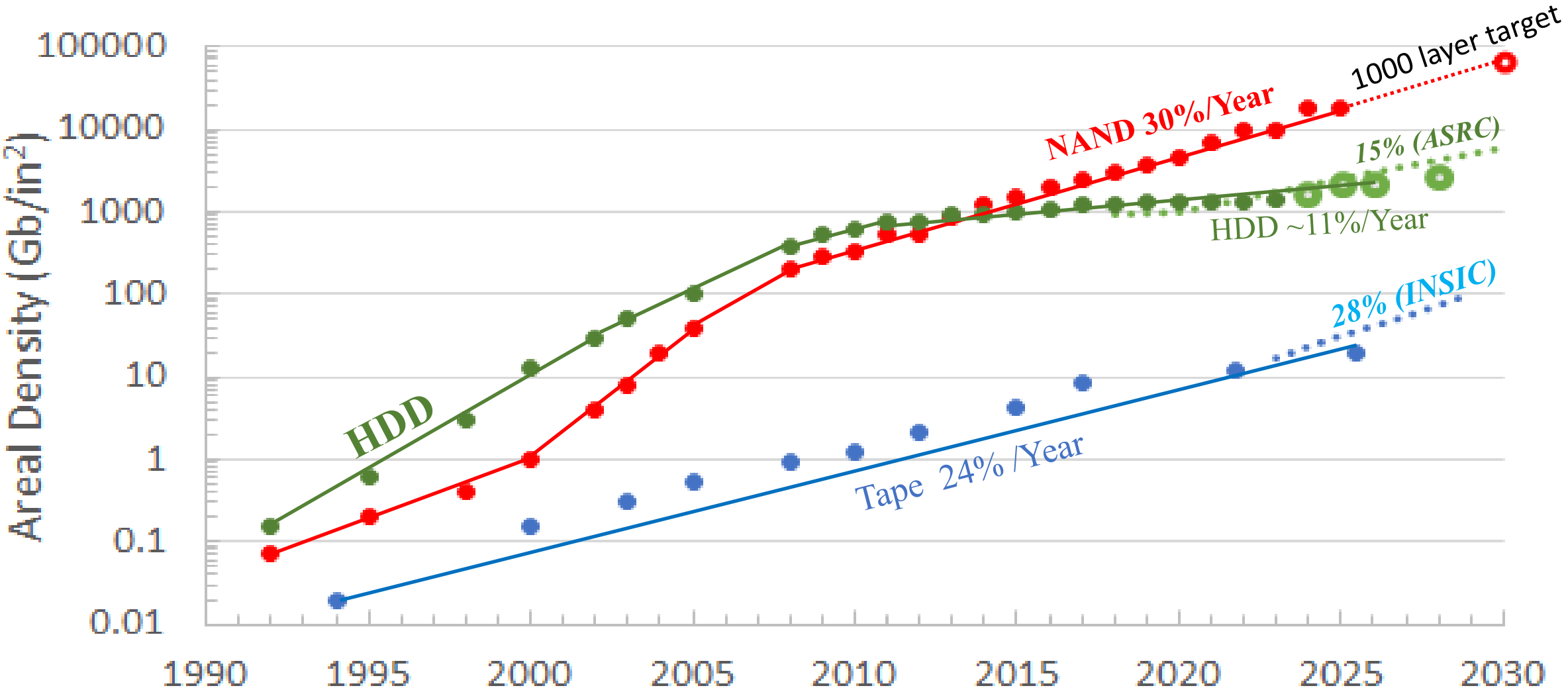




| | 2025 Exabyte % |
|---|---|
| NAND | 35% |
| SSD | 16% |
| other | 19% |
| HDD | 58% |
| LTO Tape ('24) | 6% |

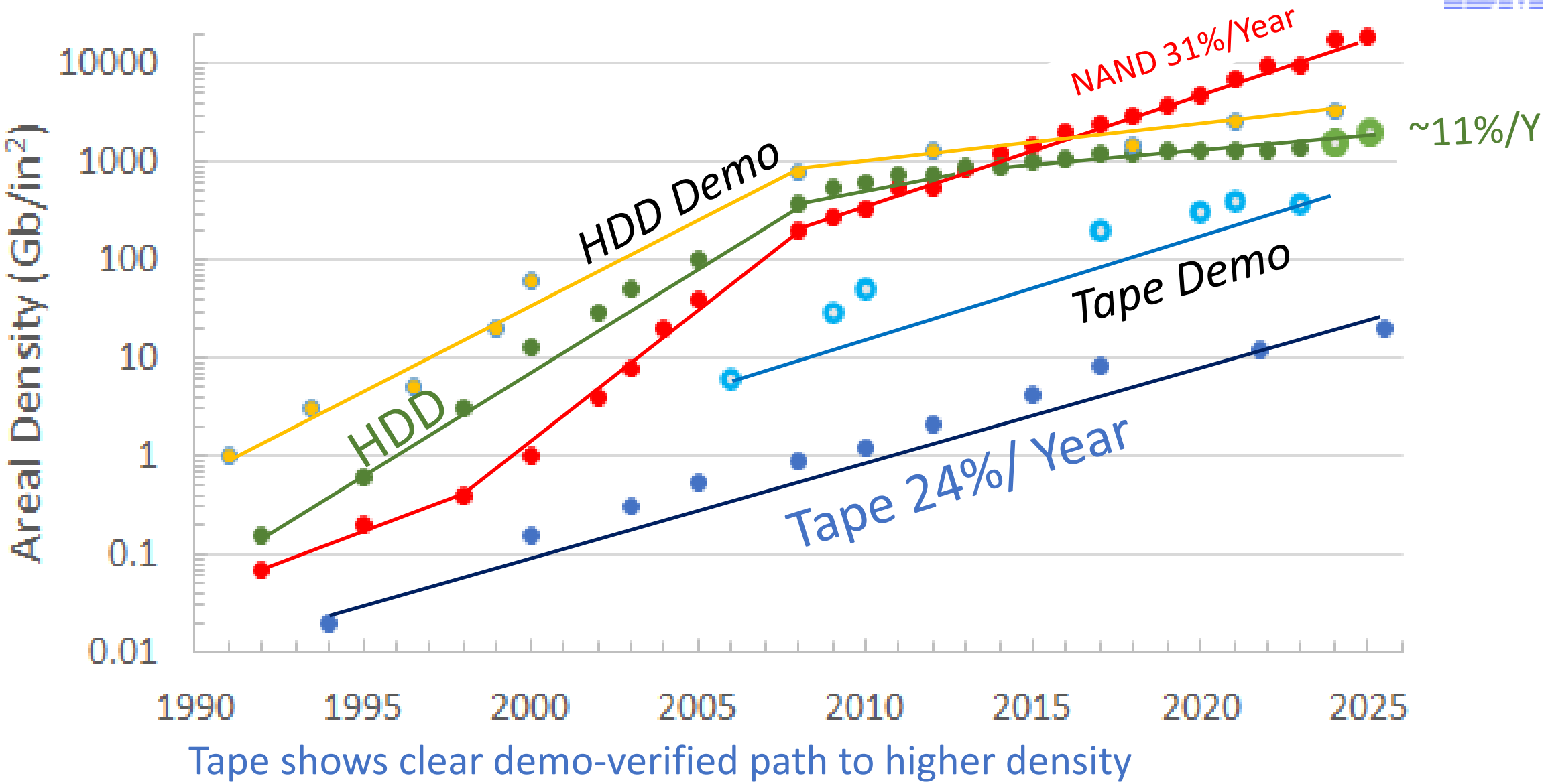
HDD >> SSD bit shipments

More **Tape** demand: Cheap, energy efficient and easier to use

# Product Areal Densities

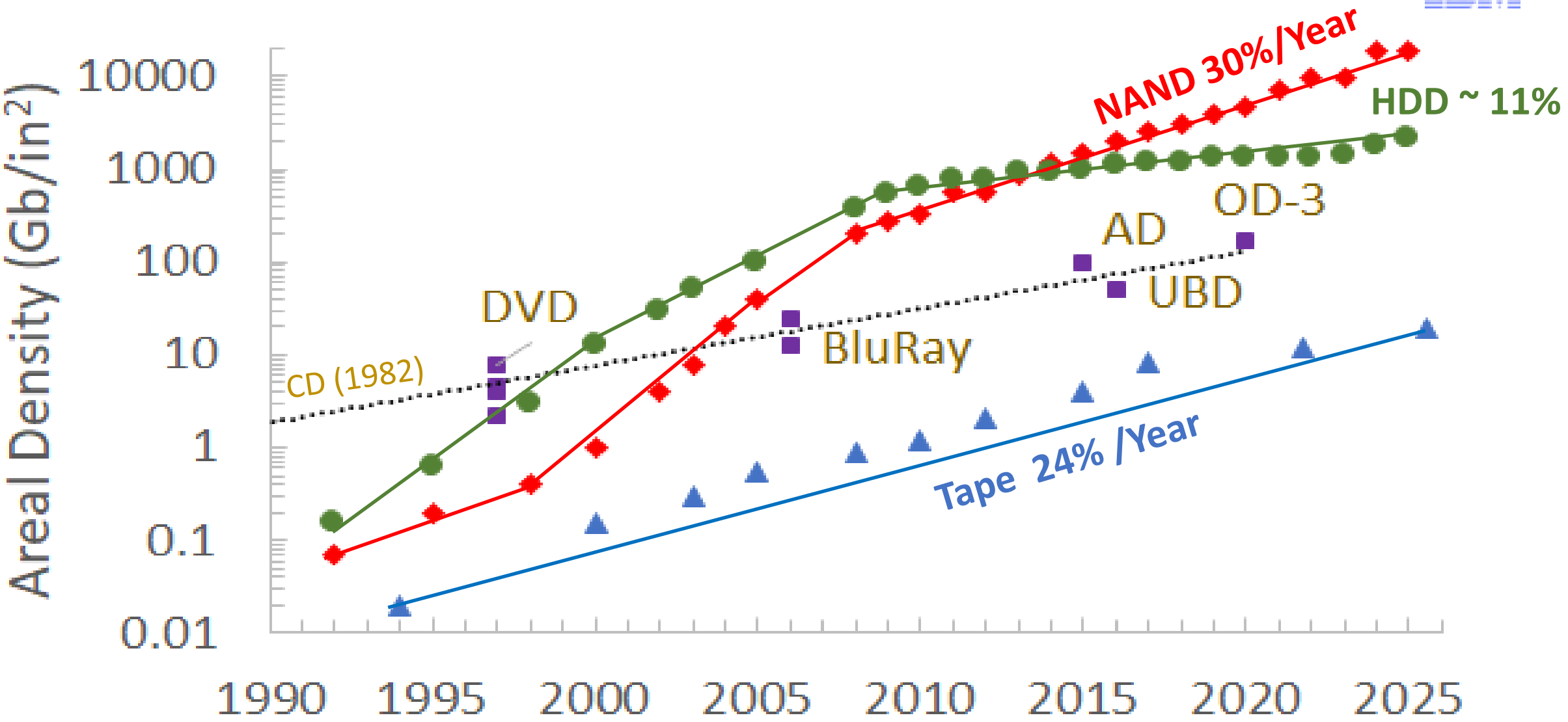


# Product and Demo Densities of NAND, HDD, Tape




Tape shows clear demo-verified path to higher density

# Areal Densities of NAND, HDD, Tape, Optical



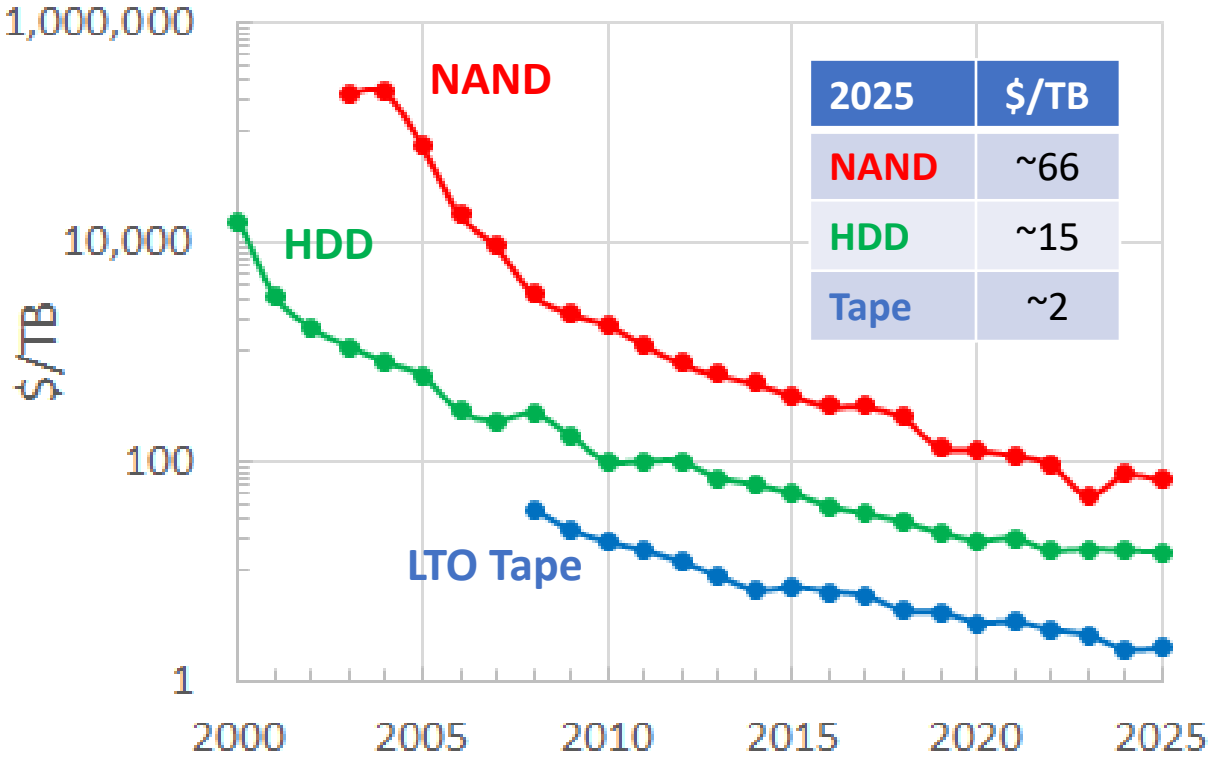

**Optical Storage**: limited adoption for archival storage. Optical Archival (OD-3) was discontinued in 2023.

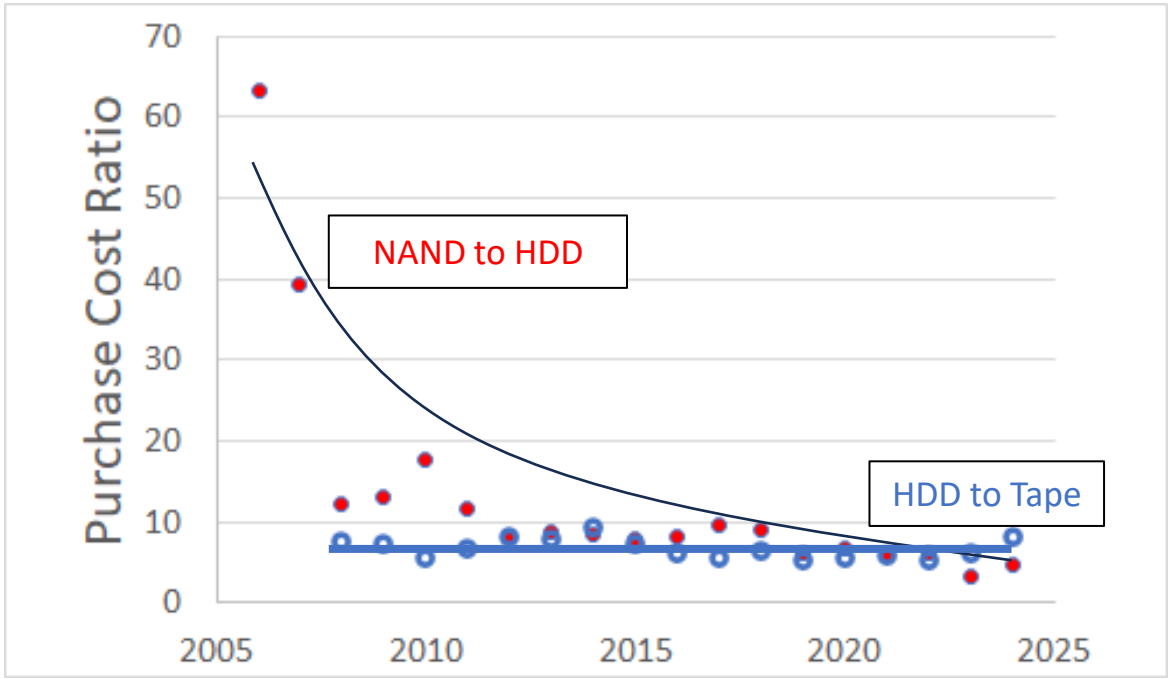
# Cost Trends of NAND, HDD and LTO tape

- Purchase cost decreased for all technologies long term

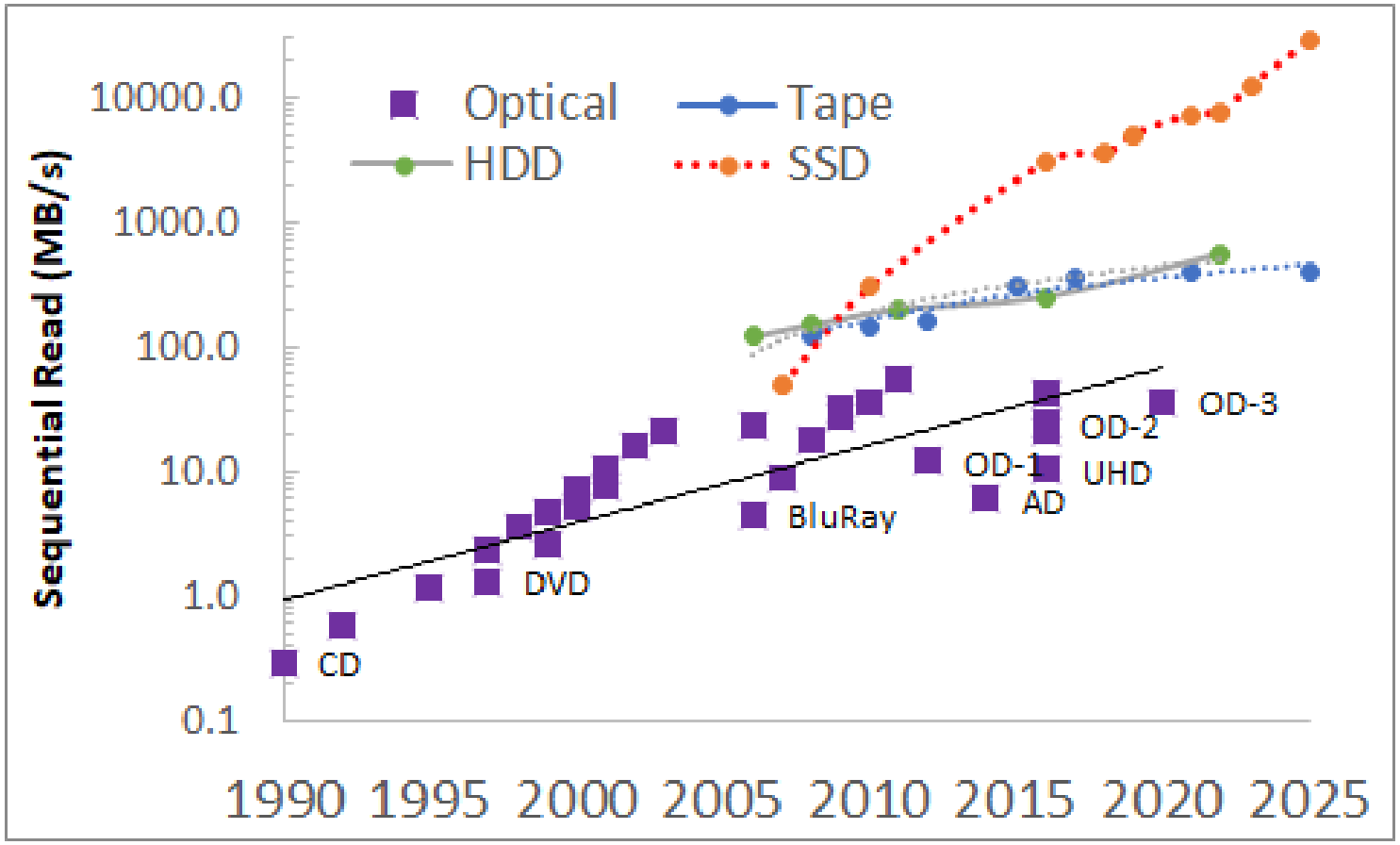
For NAND and HDD, the price per TB is derived by dividing revenue by bit shipments

For tape, the price per compressed TB is based on lowest available cartridge cost.



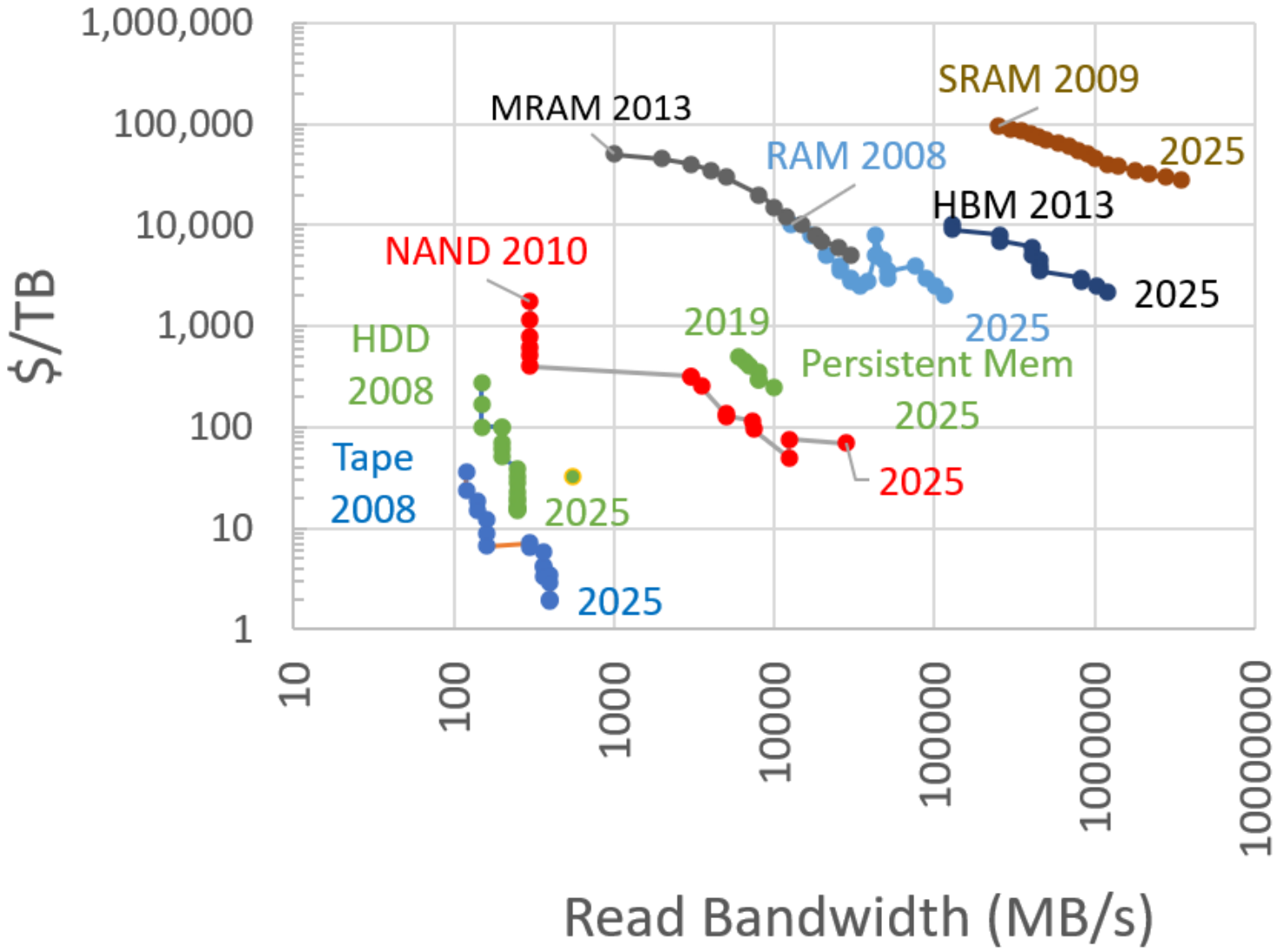
# Speed of SSD, HDD, Tape, Optical




**Tape** faster sequential Read speed compared to single actuator **HDD**, **Optical** disk

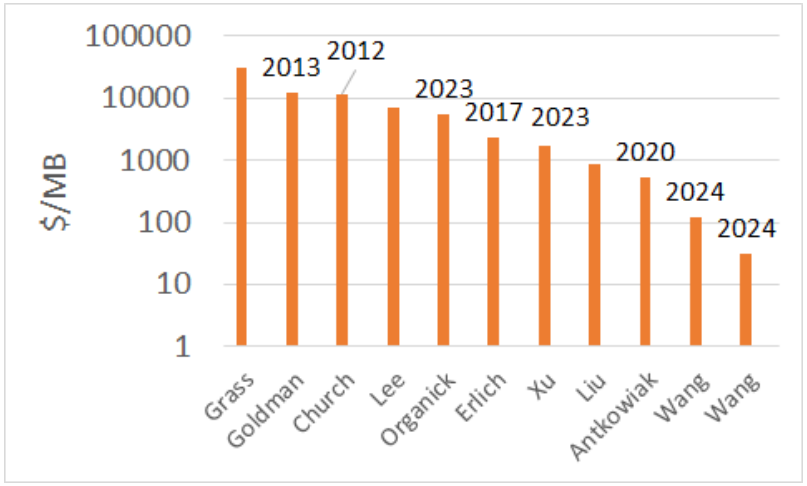
Tape drives read and write with 32 heads in parallel to achieve this.

# Hierarchy of Storage and Memory Technologies: Cost per TB vs Read Bandwidth



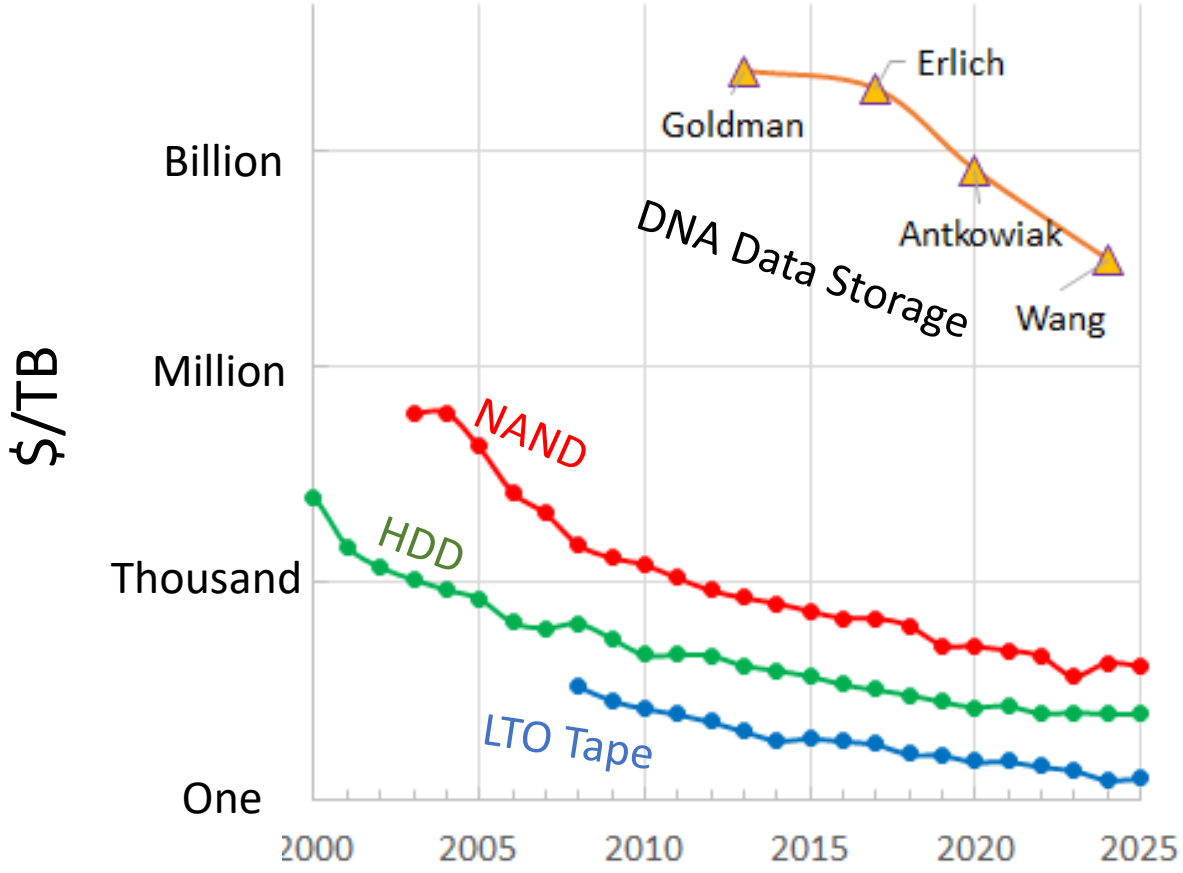
# DNA Data Storage vs Traditional Data Storage Media Cost

DNA Data Storage cost by different authors



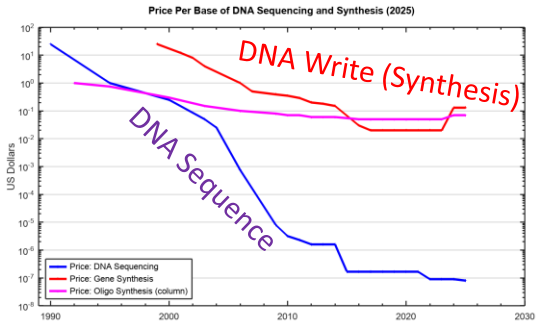

Adapted from Wang et al, 2024

doi.org/10.1002/advs.202411354




DNA Storage slow and expensive

# DNA Sequencing, Synthesis, DNA Data Storage vs Traditional Data Storage Cost




https://www.synthesis.cc/synthesis/category/Carlson+Curves

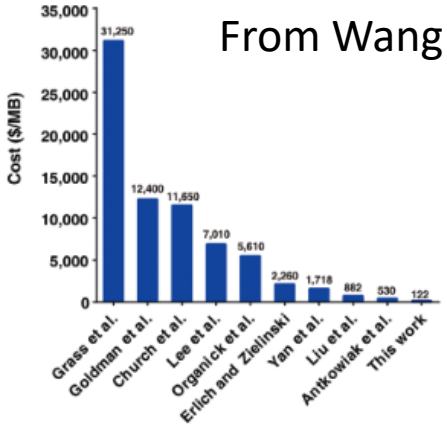
## 1 Genome encode 6 Gbit

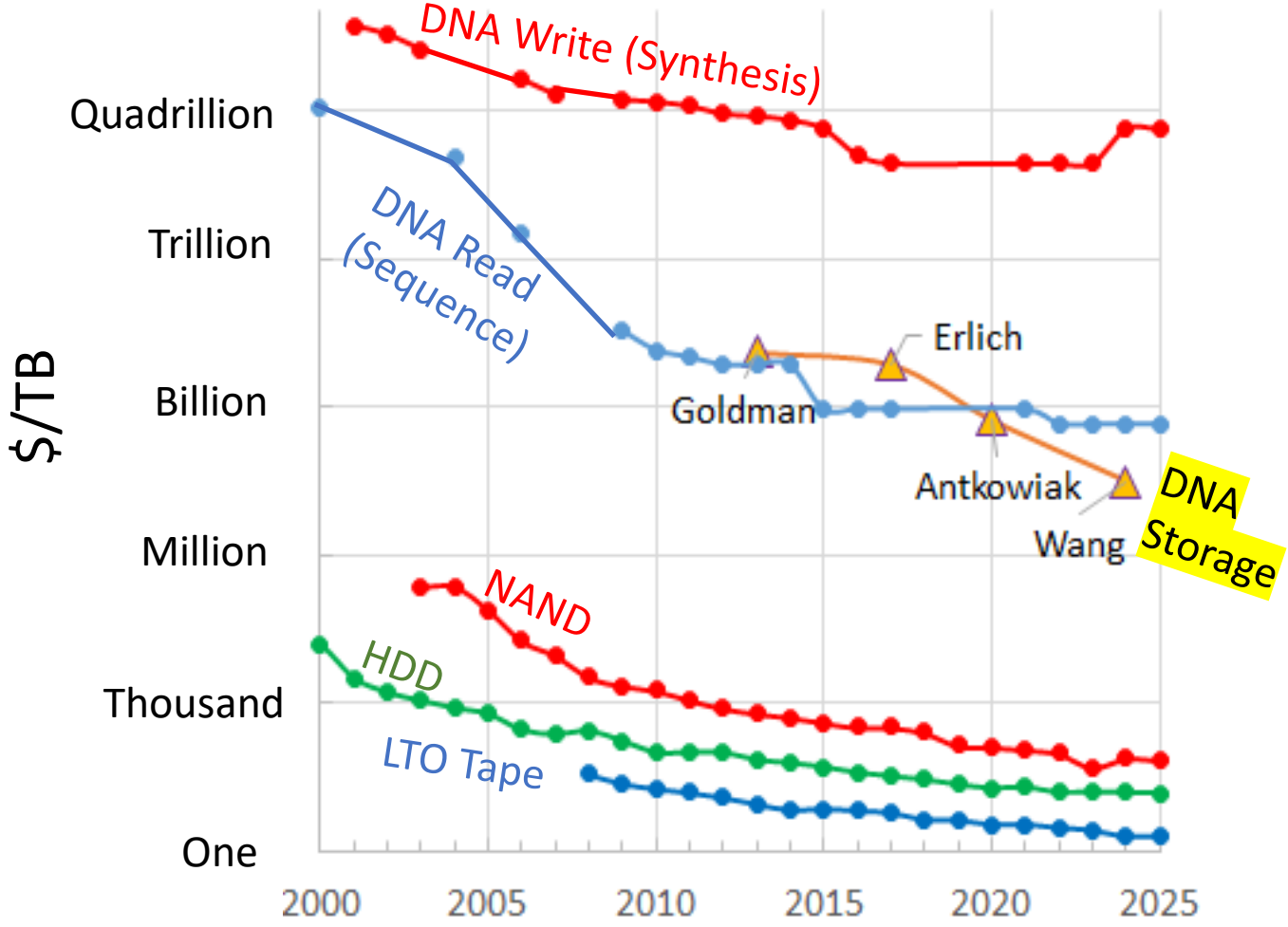
(from DNA Storage Alliance White Paper)

## DNA Data Storage cost

doi.org/10.1002/advs.202411354

From Wang et al, 2024



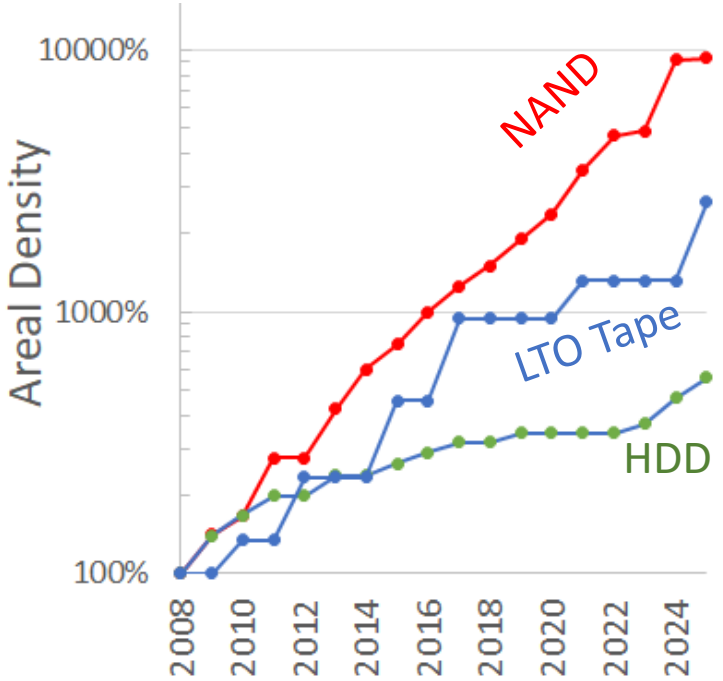

DNA sequencing/synthesis slow and expensive

DNA Storage long way to go

# Summary

- **Tape Storage:** continues to evolve.
- **HDD**:  improvements slow down but recently high demand.
- **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.
- **AI** leads to storage demands across the tiers

| Yearly Change 2012-2025 | | | | 2025 | | |
|---|---|---|---|---|---|---|
| | NAND | HDD | LTO MEDIA | NAND | HDD | LTO MEDIA (compressed) |
| Bit Shipments (EB) | 32% | 12% | 11% (12-24) | ~1000 | ~1645 | 177 (‘24) |
| Cost/Bit ($/TB) | -17% | -13% | -14% | ~ 70 | 15 | 2 (LTO9) |
| Areal Density (Gb/in2) | 31% | 8.5% | 19% | ~18600 | ~ 2130 | 20 (LTO10) |



# Appendix

# DATA METHODOLOGY

- This talk builds on studies by
  G. Lauhoff et al, "Storage Infrastructure in the AI Era," IEEE Trans Mag 61, 4 (2025)
  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