

COLLECT \$200 SALARY AS YOU PASS

GO

NETWORK ATTACHED STORAGE (NAS)

\$220

STORAGE AREA NETWORK (SAN)

\$240

EDGE STORAGE

\$200

FLASH STORAGE (ALL-FLASH)

\$260

JUST VISITING

SSD DRIVE (PCIe NVMe)



HDD DRIVE (SATA)



TAPE LIBRARY (LTO-9)



OBJECT STORAGE (S3 COMPATIBLE)



CLOUD STORAGE (AWS S3)



BLOB STORAGE (AZURE)



COLD STORAGE (GLACIER)



ARCHIVE STORAGE (DEEP ARCHIVE)



DISTRIBUTED STORAGE (CEPH)



FREE PARKING



CHANCE ?

PARALLEL FILE SYSTEM (LUSTRE)

\$220

DATA COMPRESSION

\$200

GO TO JAIL

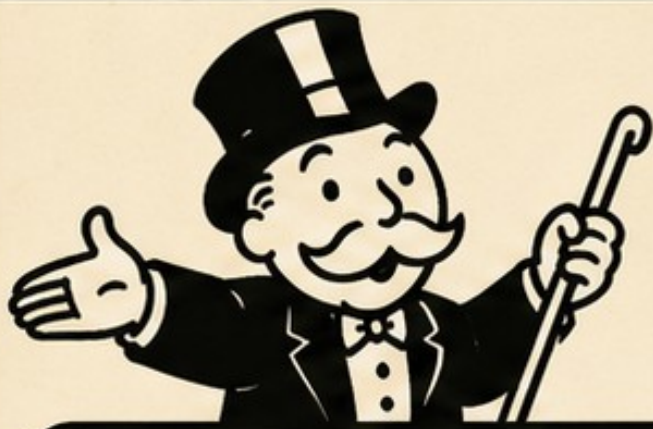


How to Store an Exabyte

Matt Starr
Spectra Logic







WHO IS SPECTRA?



46 YEARS OLD IN OCTOBER



STARTED FROM \$500, WITH NO
OUTSIDE INVESTMENT SINCE.
CASH STRONG, NO DEBT.
WE OWN OUR BUILDINGS.



40 COUNTRIES



PRIMARY FOCUS IS ARCHIVE
AND BACKUP STORAGE SYSTEMS

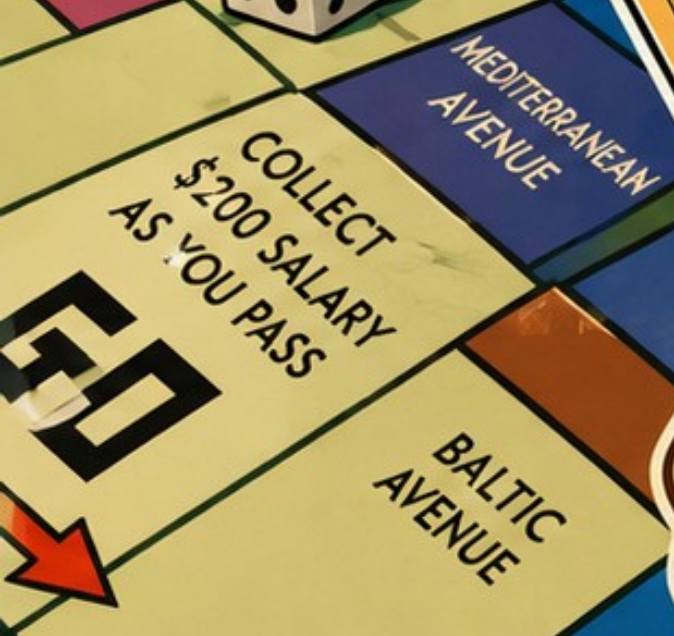


COLLECT \$200 SALARY
AS YOU PASS GO





MONOPOLY

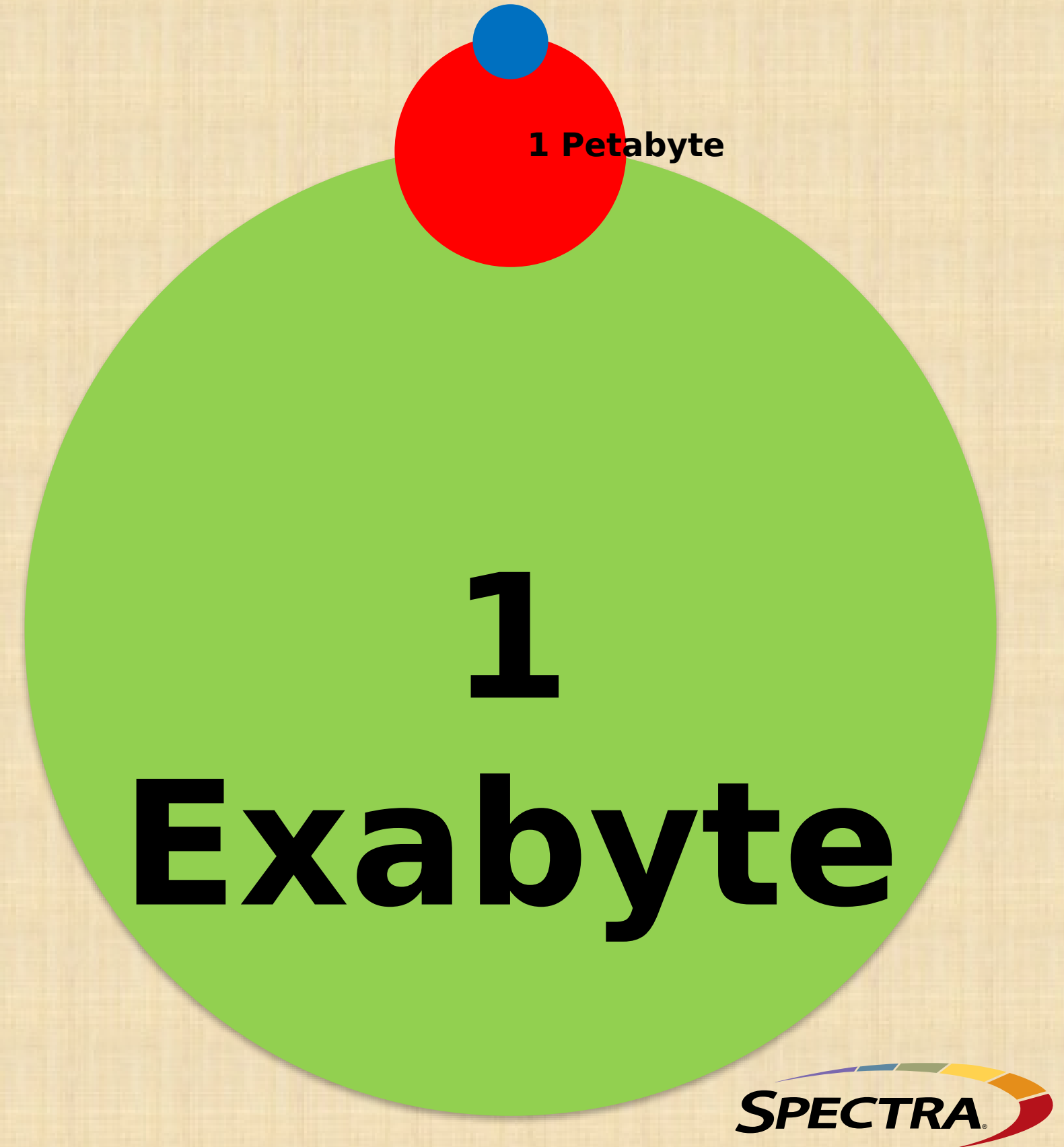


What is an Exabyte

A circle that represents **1 Terabyte**
has a radius of 0.056 inches or 1.43mm

A circle that represents **1 Petabyte**
has a radius of 1.78 inches or 45.3mm

A circle that represents **1 Exabyte**
has a radius of 56.4 inches or 1433mm





~~\$\$\$800-1500/TTB~~



~~\$\$\$1250-1500/TTB~~

MEDIA DEVICE COMPARISONS

(No compression or deduplication)

Storage Type	 Cost (per TB per device level)	 Performance	 Power Consumption	 Environmental Impact
Flash Storage 	High \$80-125 per TB	Fast access, fast xfer	High 20 watts for 25TB active 7 watts in-idle (U.2 NVMe)	High
Disk Storage 	Moderate \$14-25 per TB	Medium access, lower xfer	Medium Active: 9-10 wts Idle: 3-5 watts	High
Tape Storage 	Very low \$3-5 per TB	Slow access, high xfer	Low Active: 35 watts Idle: 0 watts	Ultra-Low

SSD / Flash

10.8 sq. Inches

2.5-Inch Form Factor

2.75" x 3.94"



Flash will grow, likely double
but cost and power will grow
proportionally with capacity.

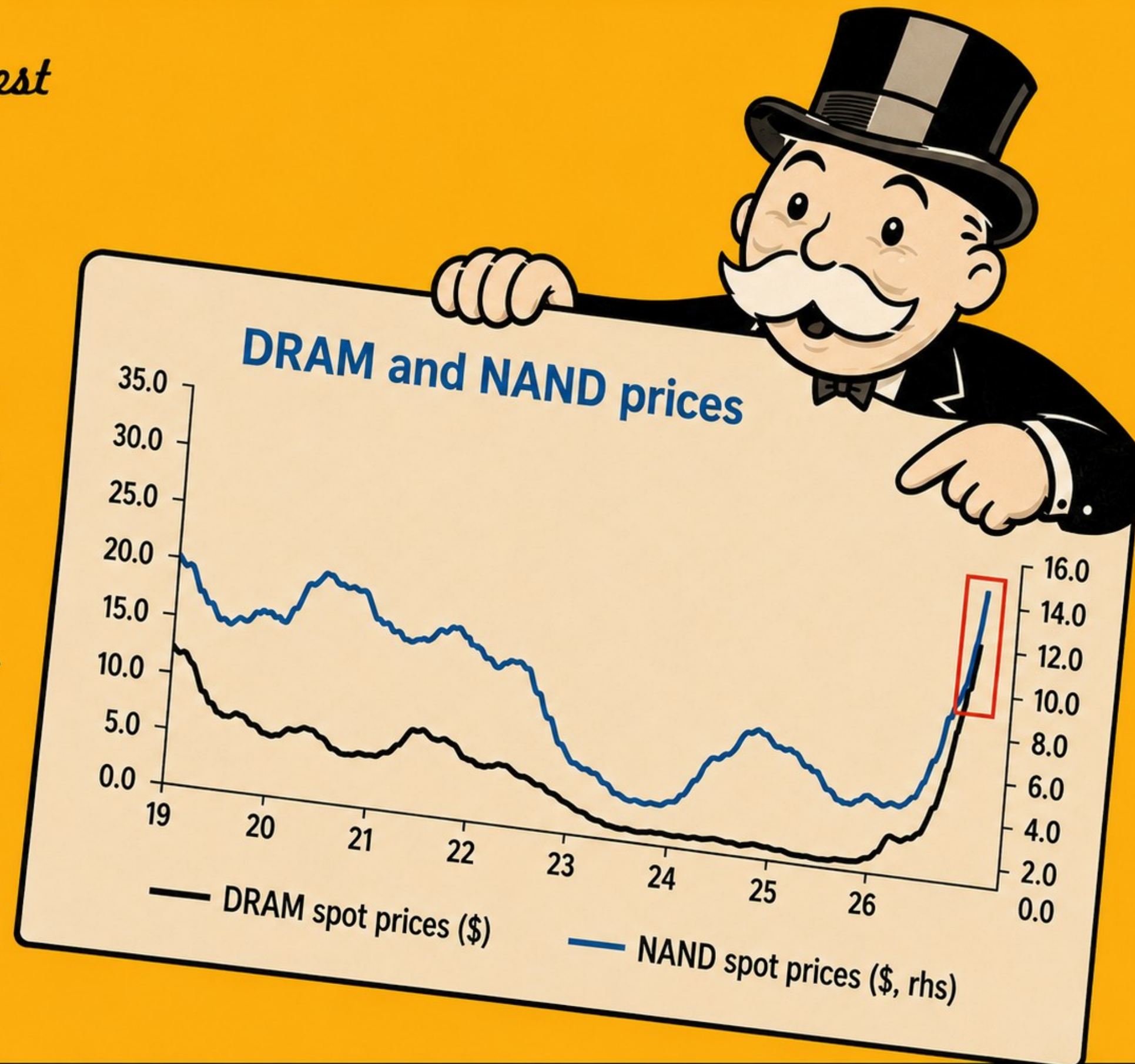
In single chip (die) 3-8 Tb/sqin

SPECTRA 

Community Chest

DRAM & NAND PRICES SURGE!

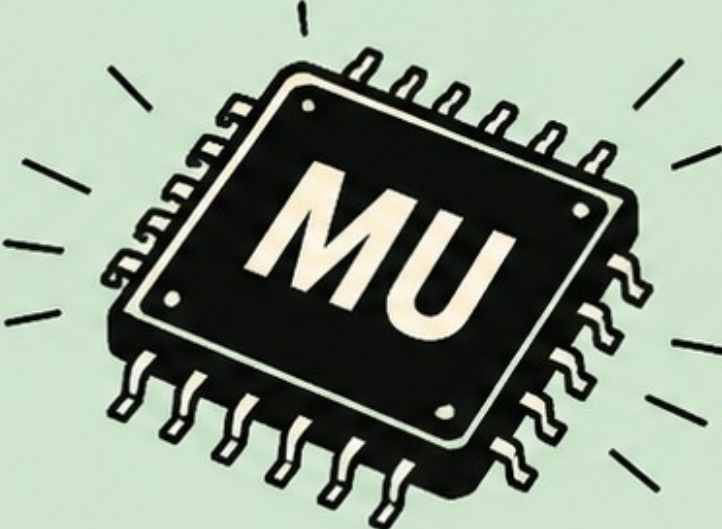
Memory chip prices
have skyrocketed.
Pay your supplier more.



MICRON TECHNOLOGY,
INC. (MU)



SEMICONDUCTOR INNOVATION
DRIVING THE FUTURE.

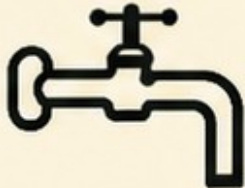


PRICE \$150

MICRON TECHNOLOGY, INC. (MU)



1D	5D	1M	6M	YTD	1Y	5Y	ALL
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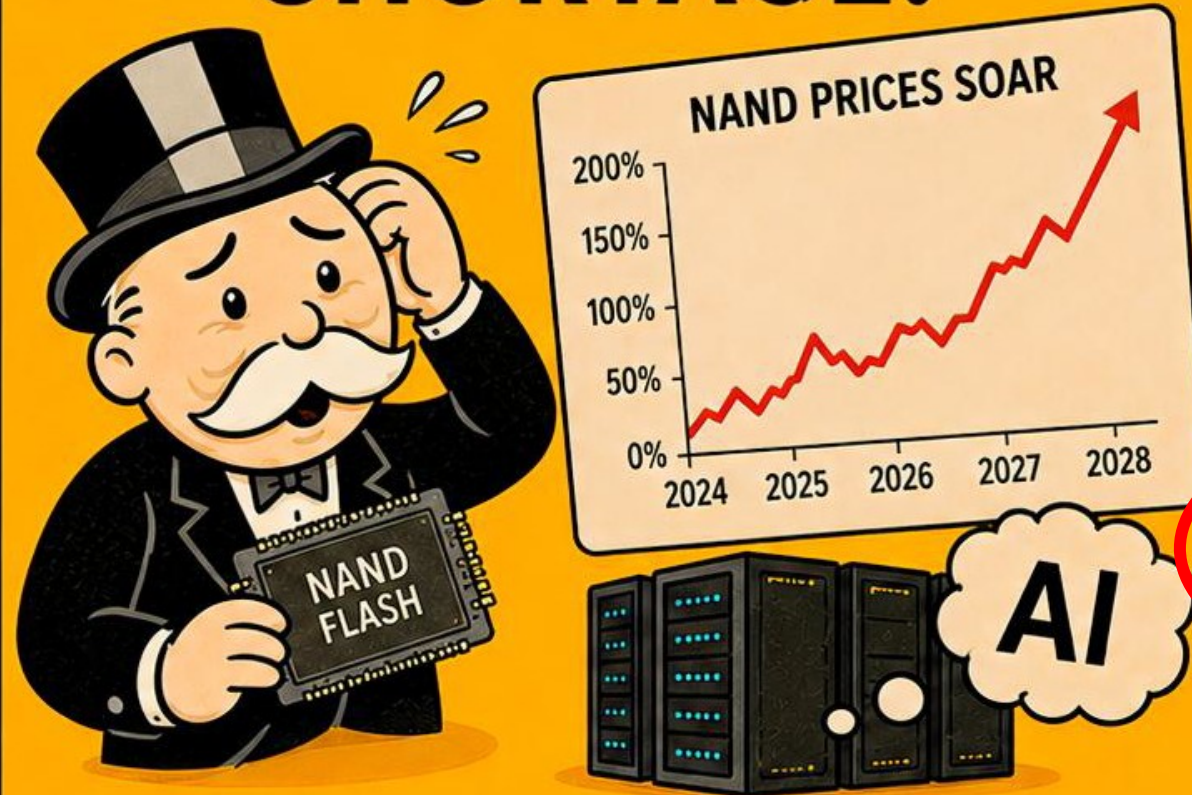


WATER WORKS
PRICE \$150



ELECTRIC COMPANY
PRICE \$150

CHANCE NAND FLASH SHORTAGE!



Pay your supplier
500%.



Stay informed with industry reports from TrendForce, Tom's Hardware, and more.

KEY DRIVERS



Capacity Reallocation:

Manufacturers prioritize high-margin HBM and enterprise SSDs for AI data centers, squeezing consumer NAND production.



Long Lead Times:

Raw NAND is hard to secure. Foundries demand long lead times and cash prepayments.



Price Surges:

Contract prices for memory chips have risen steeply across the board.

INDUSTRY IMPACT



Consumers Hit Hardest:

Consumer electronics, set-top boxes, and camera memory cards face the worst shortages as foundries limit retail shipments to fulfill data-center contracts.

OUTLOOK



Market Relief Timeline:

New fabs take 24–36 months to build and qualify. Meaningful supply relief isn't expected until late 2027 or 2028.

DRAM has gone up
by between 100%
and 500%

NAND has gone up
by between 200%
and 600%

HDD

130.8 SQ. INCHES

3.5-INCH PLATTERS

3.94"



✂ **Disk** – we are almost at the end of conventional storage density.
HAMR/MAMR/
Energy Assist tech may add some capacity.



SPECTRA

Currently 1.5 – 5 Tb/sqin



INSTRUCTIONS

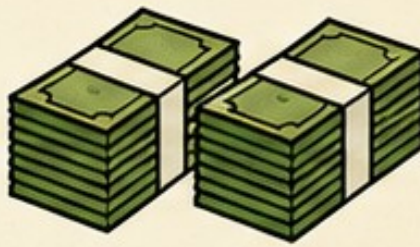
FOR PLAYING THE HAMR MILESTONE GAME

A JOURNEY THROUGH INNOVATION

COLLECT
\$200 SALARY
AS YOU PASS

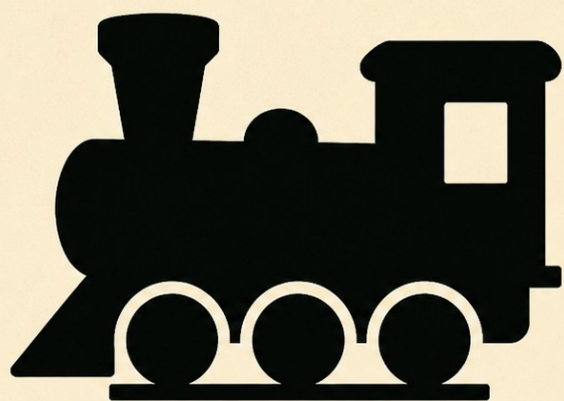
GO

Follow the milestones below to see how Heat-Assisted Magnetic Recording (HAMR) became a reality.
Move forward through each stage of innovation!

1	1954		1954: BASIC PRINCIPLE PATENTED The basic principle of using heat to record data was first patented.	COLLECT FUTURE INNOVATION RIGHTS.	
2	LATE 1990s		LATE 1990s: SEAGATE BEGINS RESEARCH Seagate began researching modern HAMR development.	ADVANCE TO SEAGATE LABS! SPEND SEVERAL TURNS IN R&D.	
3	MARCH 2012		MARCH 2012: BREAK THE DENSITY BARRIER Seagate announced it built the first 1 Terabit-per-square-inch HAMR hard drive.	COLLECT A TECHNOLOGY BONUS!	
4	2019		2019: PILOT PRODUCTION BEGINS Following extensive customer trials, Seagate began shipping early-generation commercial HAMR drives in pilot volumes.	ROLL THE DICE CAREFULLY – HYPERSCALERS ARE WATCHING.	
5	PRESENT DAY		PRESENT DAY: MAINSTREAM ADOPTION HAMR has achieved mainstream market adoption in enterprise data centers, with capacities now spanning into the 32TB+ range.	ADVANCE TO THE NEXT STORAGE GENERATION. COLLECT EXABYTES AS YOU PASS GO	

Seagate sparks
memory sell-off as
CEO says it would
'take too long' to
build new factories

WESTERN DIGITAL



UNITS
SHIPPED

54.5
MILLION

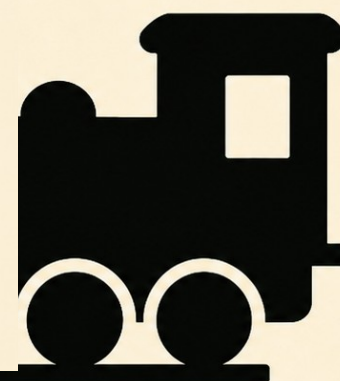


RAILROAD

If one "Railroad" is owned,
rent is 2 times amount shown.
If both "Railroads" are owned,
rent is 4 times amount shown.



SEAGATE



UNITS
SHIPPED

50.7
MILLION



RAILROAD

If one "Railroad" is owned,
rent is 2 times amount shown.
If both "Railroads" are owned,
rent is 4 times amount shown.



TOSHIBA



UNITS
SHIPPED

21.1
MILLION



RAILROAD

If one "Railroad" is owned,
rent is 2 times amount shown.
If both "Railroads" are owned,
rent is 4 times amount shown.



124.3 million
unit



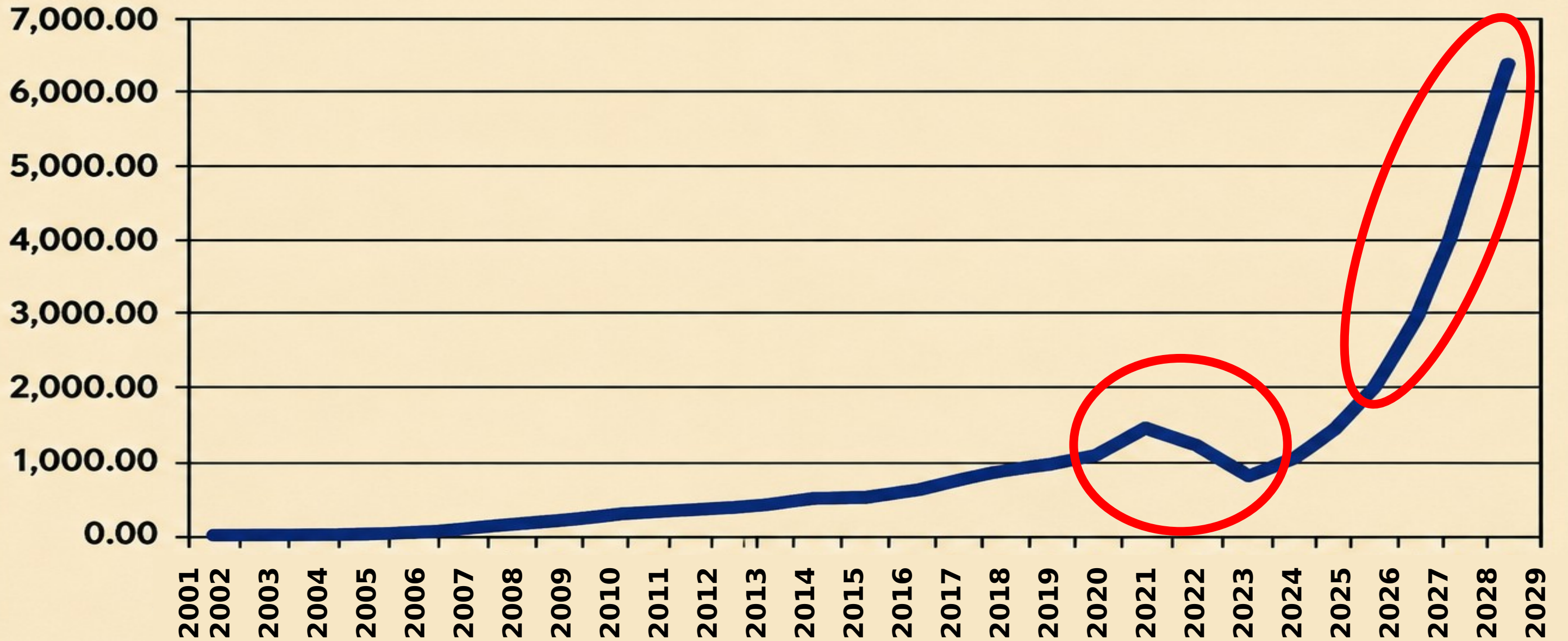


FIGURE 9

PROJECTION OF DISK DRIVE ANNUAL CAPACITY SHIPMENT



EXABYTES
SHIPPED



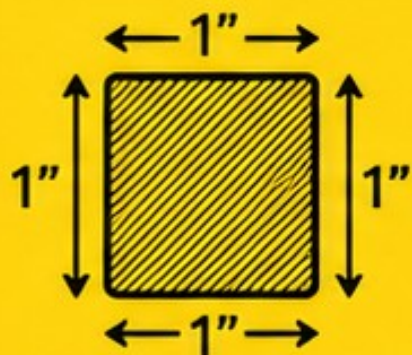
LTO



20,373 Inch²



Tape — there is a lot of room, literally, to double storage density on tape media many more times.



1 square inch of LTO tape (1" x 1") can store:

12 Gb (30TB Tape)

9 Gb (40TB Tape)



LTO-10 (30TB Native)
Uncompressed capacity

20,293
square inches
of tape surface.

12 Gb per square inch



LTO-10 (40TB Native)
Uncompressed capacity

26,215
square inches
of tape surface.

9 Gb per square inch



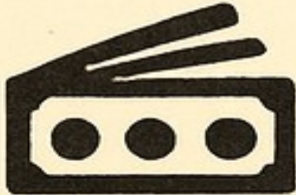
FACTORY CAPACITY
(NATIVE CAPACITY)

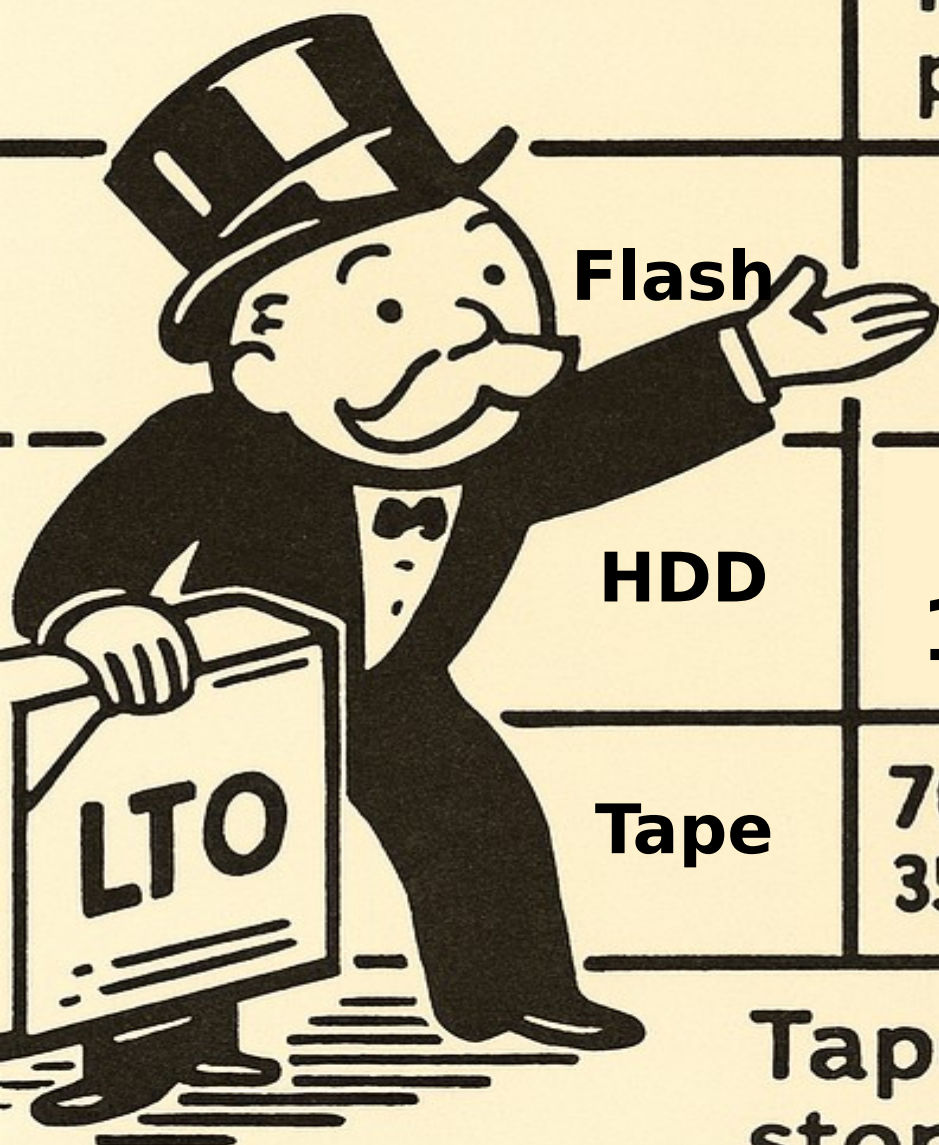


CAPACITY USED
(DATA STORED)

MEDIA DEVICE COMPARISONS

(NO COMPRESSION OR DEDUPLICATION)

STORAGE TYPE	 Power used per Raw TB	 Full System W/TB	 TB Cost	 Power Cost \$0.165/KW hr
Flash	5W idle 15W active	.667 W/TB	Very High	\$1 million per year
HDD	5W idle 10W active	1.46 W/TB	High	\$2 million per year
Tape	700 W robotic 35 W per tape drive	0.007 W/TB	Ultra-Low	\$5,200 per year



Tape —there is a lot of room, literally, to double storage density on tape media many more times.

TCO 5 years

Last Year

1 EB of Flash \$110 Million plus
1 EB of Hard disk \$30-40 million
1 EB of Tape \$8-12 million

This Year

1 EB of Flash \$400-500 Million plus
1 EB of Hard disk \$45-80 million
1 EB of Tape \$9-13 million

1PB
FLOPS at nearly any cost.

1TB



1 EB

