SEAGATE

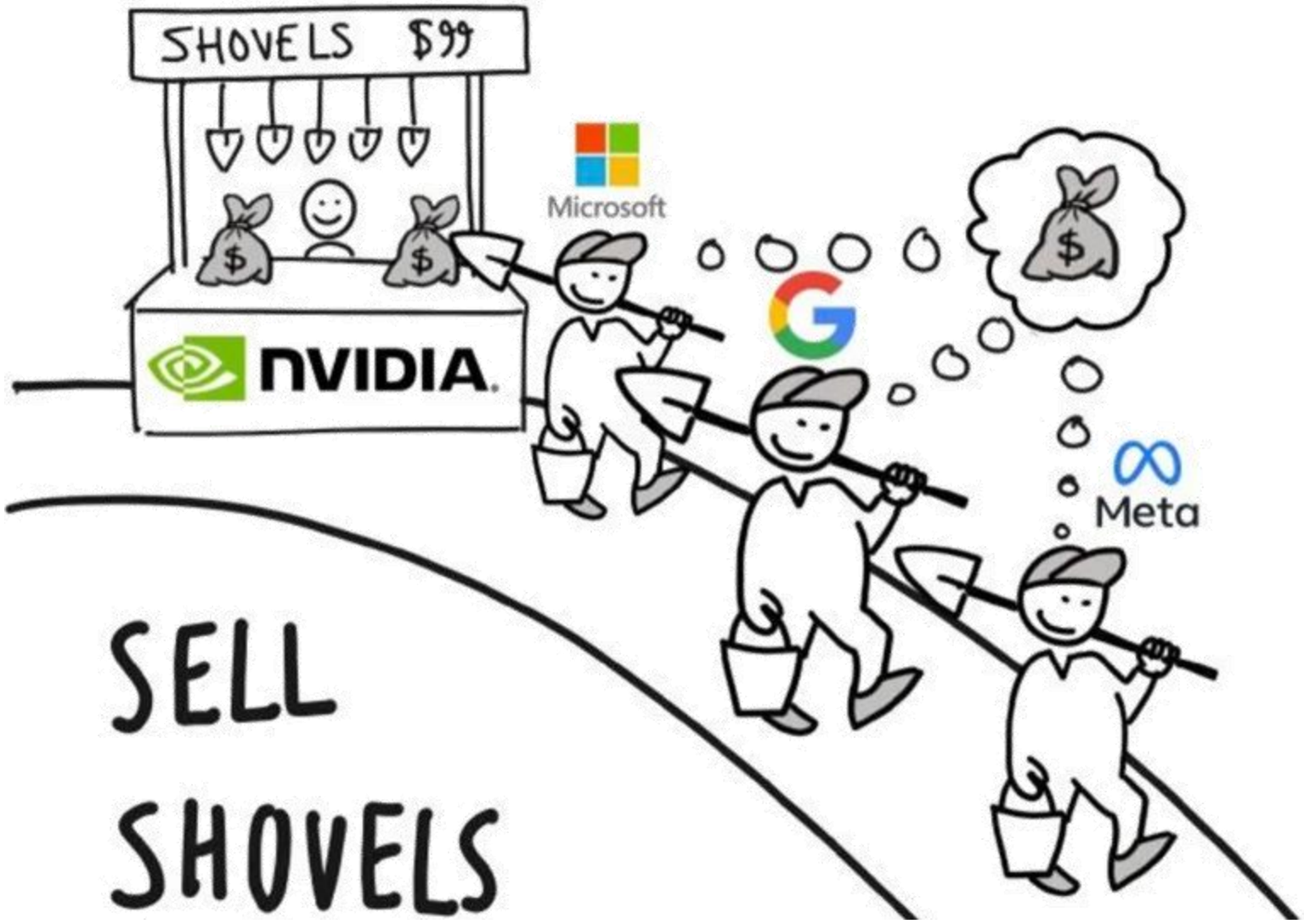
HAMR: The Path to 10TB/Disk and Beyond

HAMR: Heat Assisted Magnetic Recording

September 2025

Riyan Mendonsa
Office of the CTO

WHEN EVERYONE DIGS FOR GOLD



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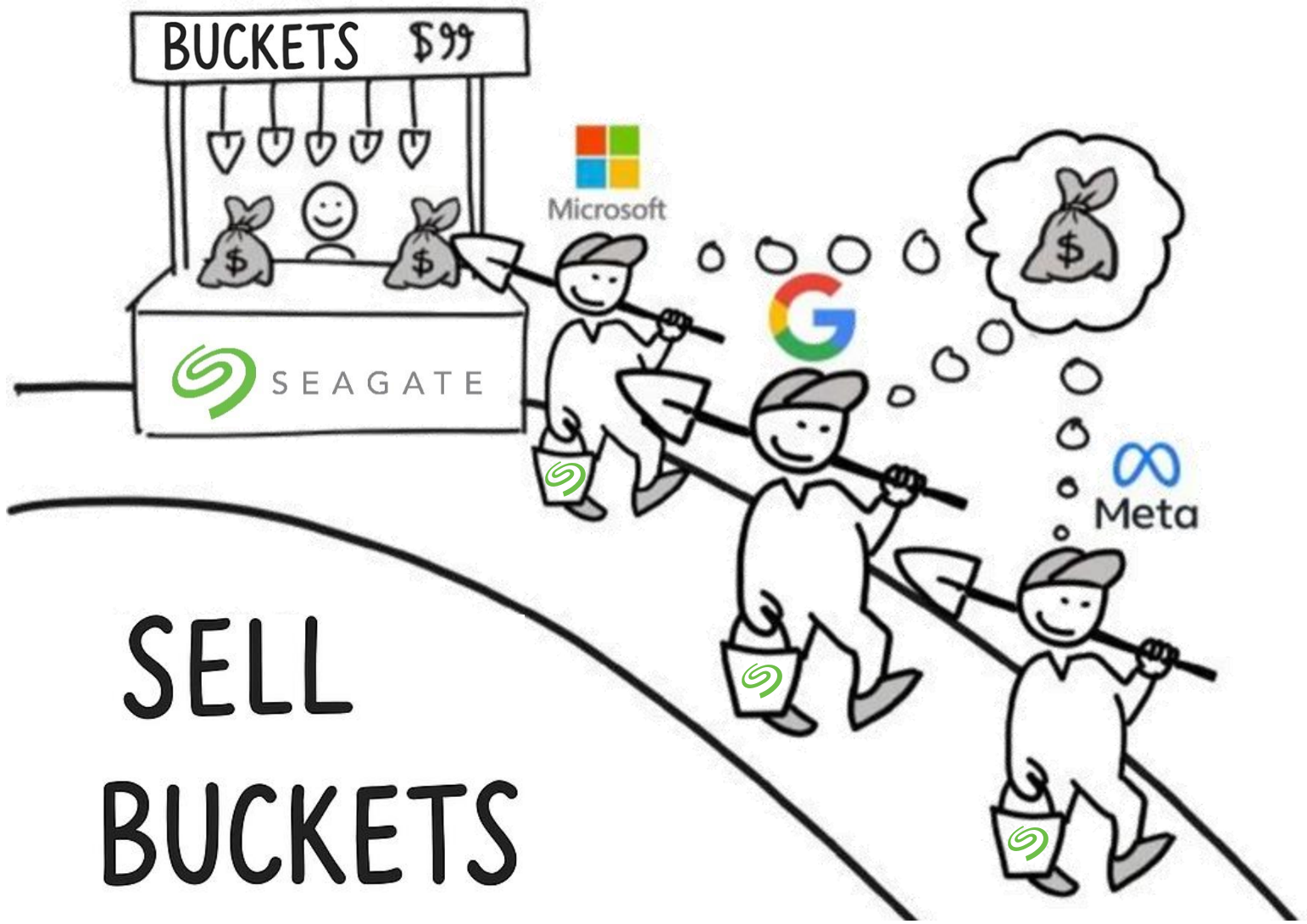

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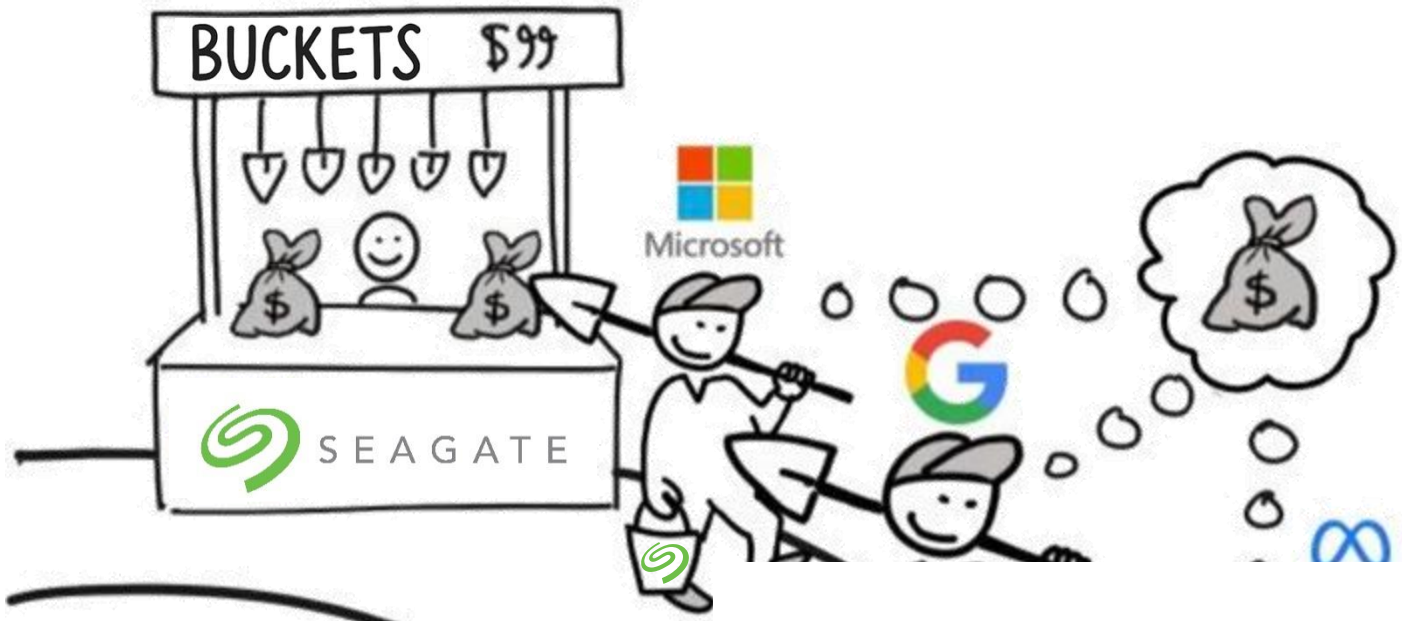

SELL BUCKETS

THE WALL STREET JOURNAL.

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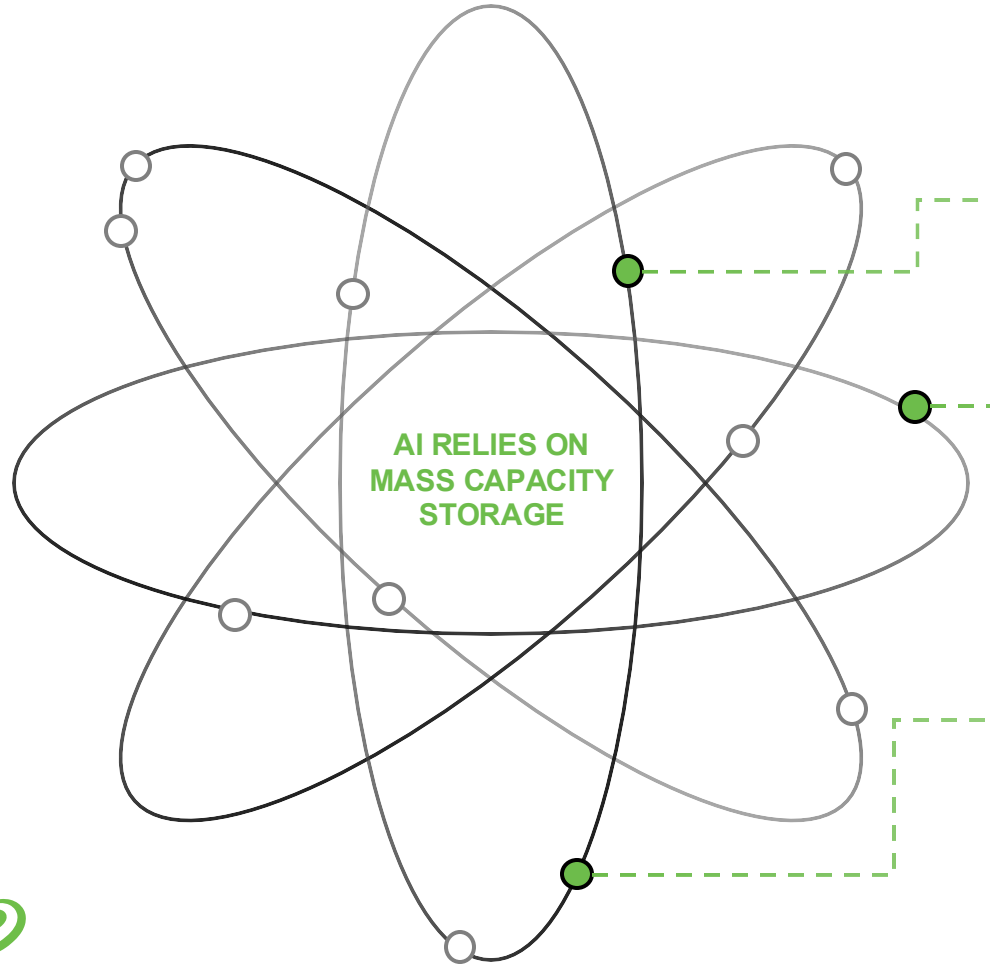
Hard Drives Are Making an AI Comeback. Yes, Hard Drives.

Data-storage needs are growing, lifting Seagate and Western Digital

By *Asa Fitch* Follow

Sept. 19, 2025 5:30 am ET

AI Poised to Drive Next Wave of Mass Capacity Storage Demand

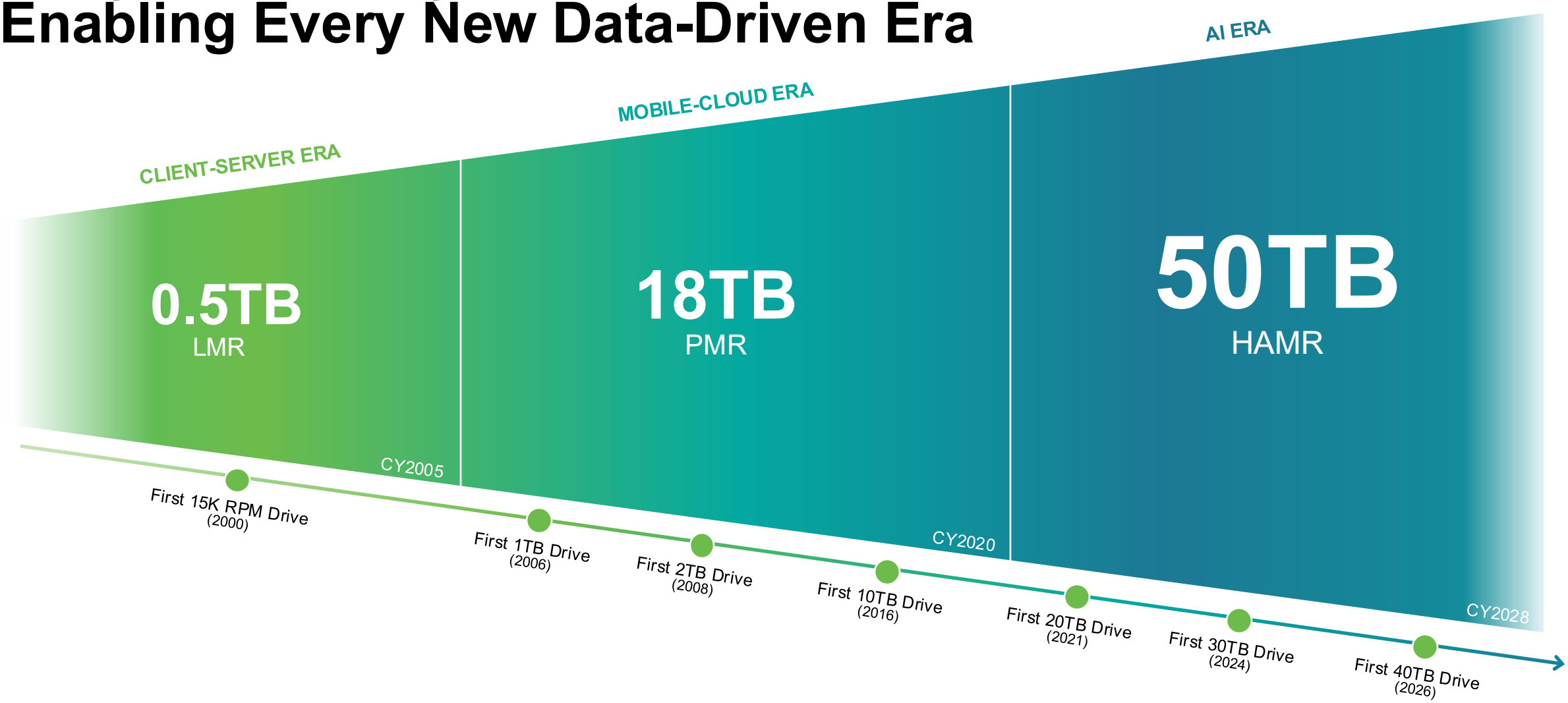


More data improves the quality of AI model output
Hard drives feed data to AI models

With AI, people and machines will generate data at a pace unlike any before
Hard drives preserve valuable content created from AI models

AI gets more intelligent in an infinite loop
Hard drives maintain AI model checkpoints and query data

Seagate's Storage Innovation Enabling Every New Data-Driven Era



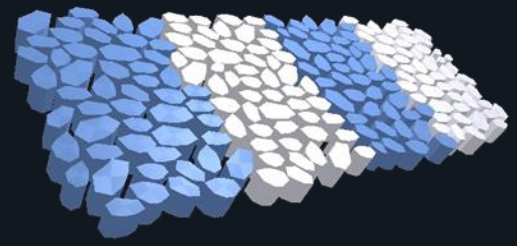
Represents Seagate's highest capacity drive shipped in CY2005, CY2020, and CY2028 (projected).

Hard Drive Capacity Scaling is Reaching Limits With PMR Technology

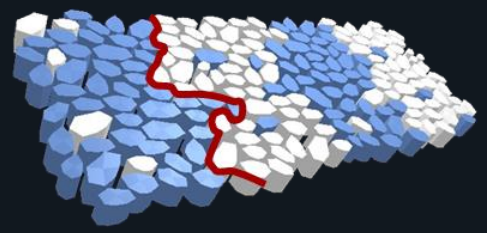
	CY2010		CY2015			CY2020						CY2025
 **# Disks / Drive**	5		6	7	8	9	10					
 **Areal Density** (TB / Disk)	PMR											HAMR
	0.6	0.8	1.0	1.33	1.43	1.5	1.75	1.78	2.0	2.0	2.2	2.4	3.0
 **Drive Capacity** (TB / Drive)	3	4	6	8	10	12	14	16	18	20	22	24	30

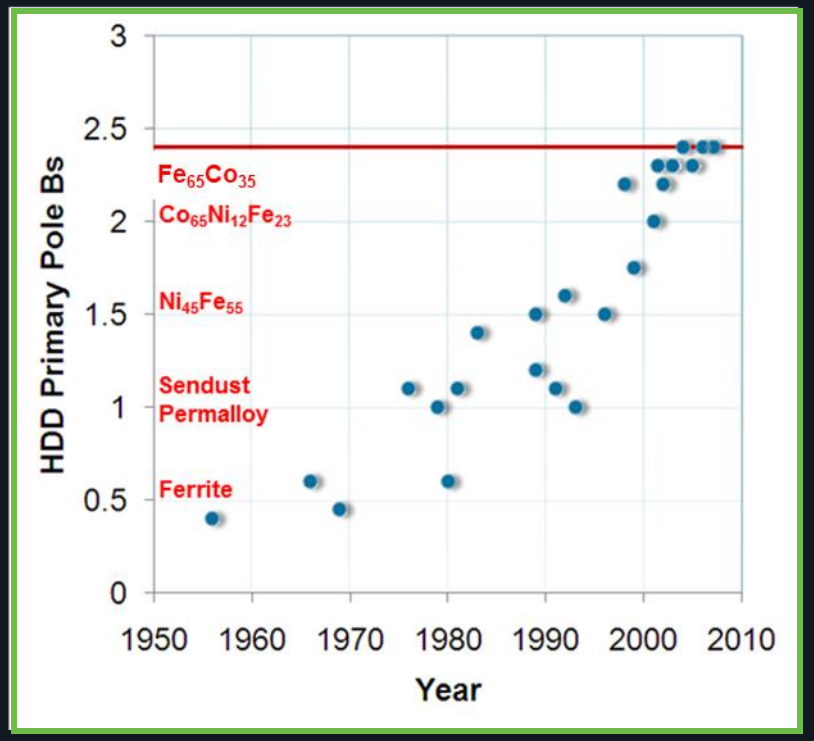
Areal Density Trilemma

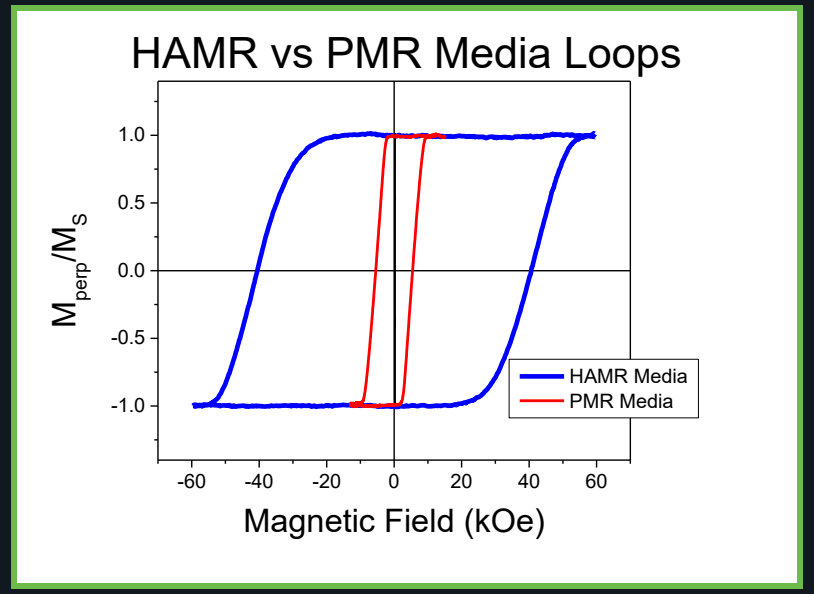
$SNR \sim \log_{10}(N)$



$$\tau = \frac{1}{f_o} e^{\frac{K_u V}{kT}}$$



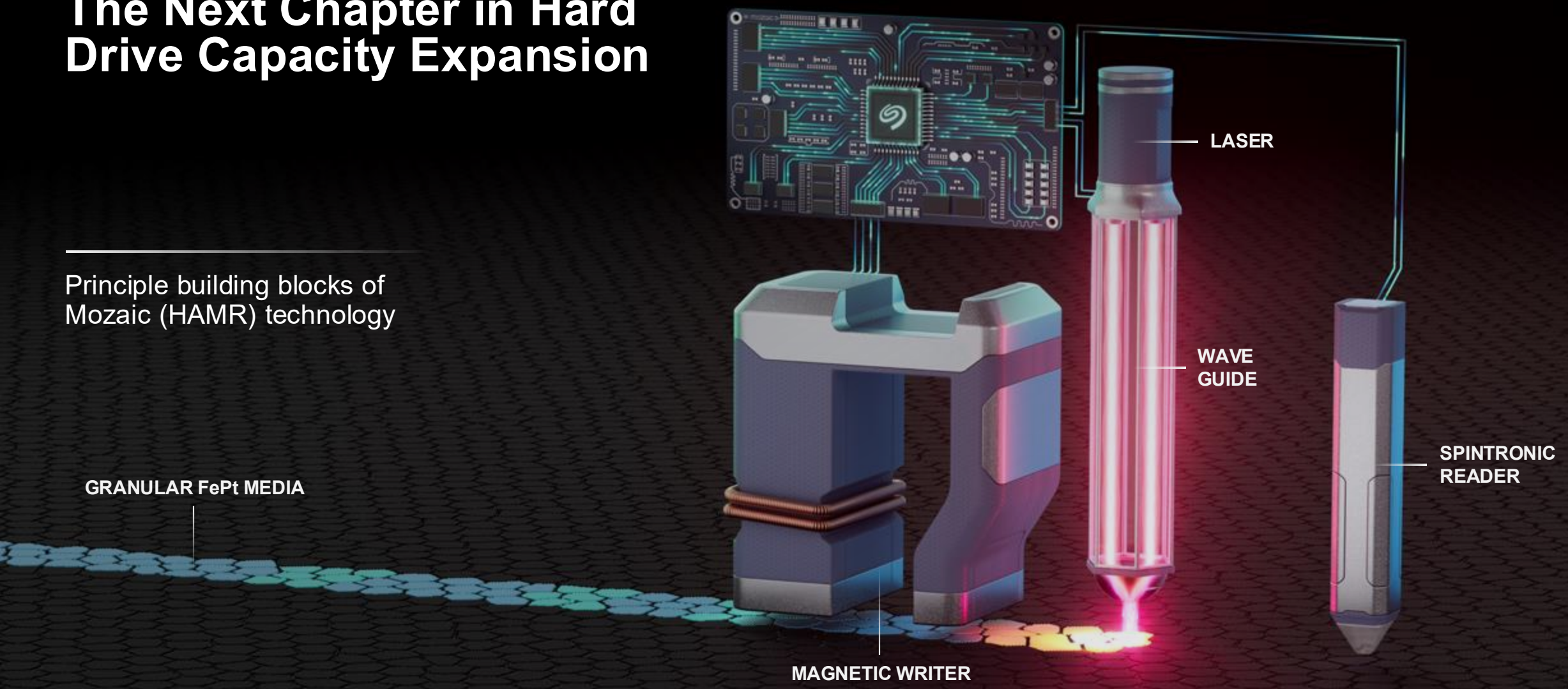




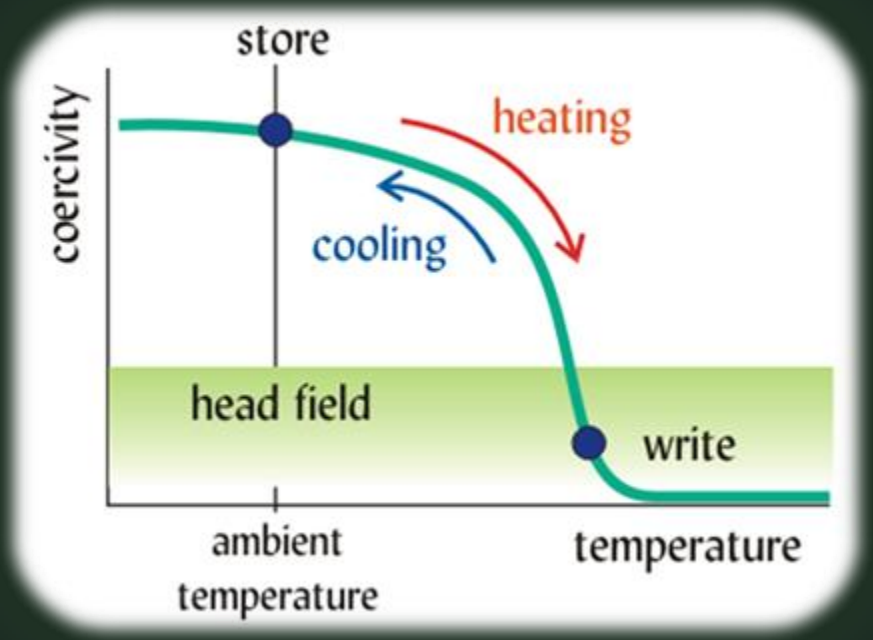
FROM PMR TO HAMR

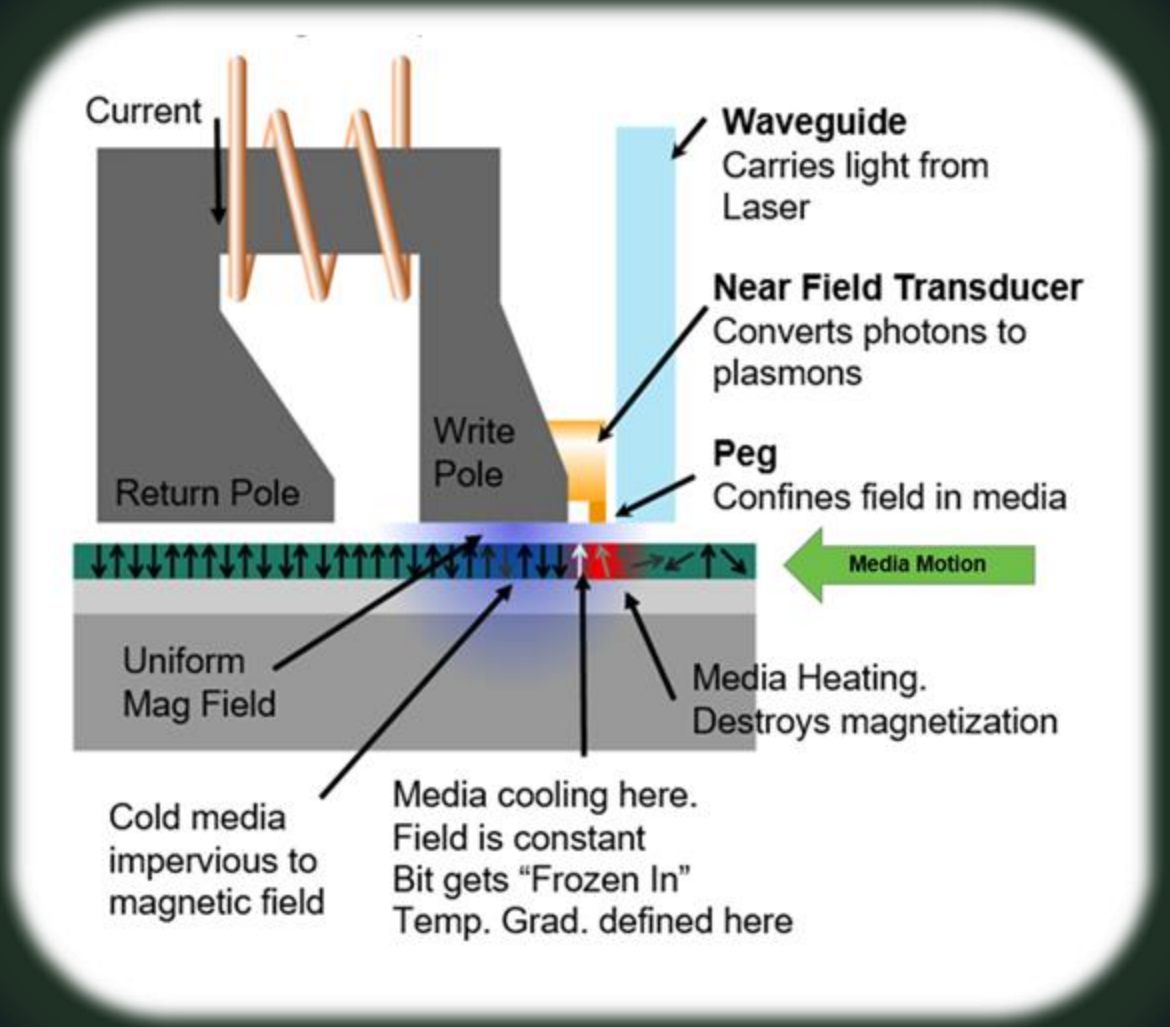
The Next Chapter in Hard Drive Capacity Expansion

Principle building blocks of Mozaic (HAMR) technology



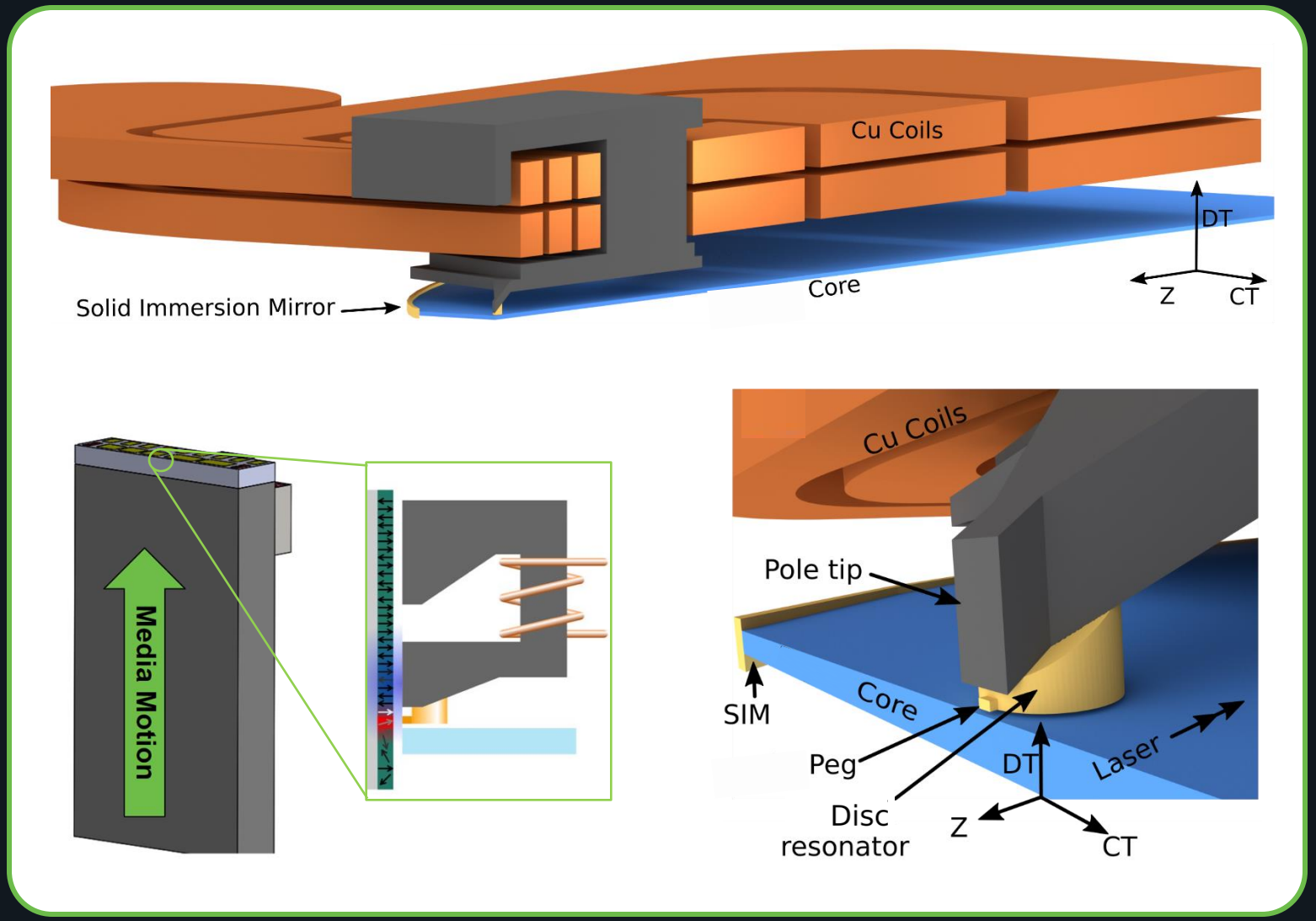
HAMR in Theory



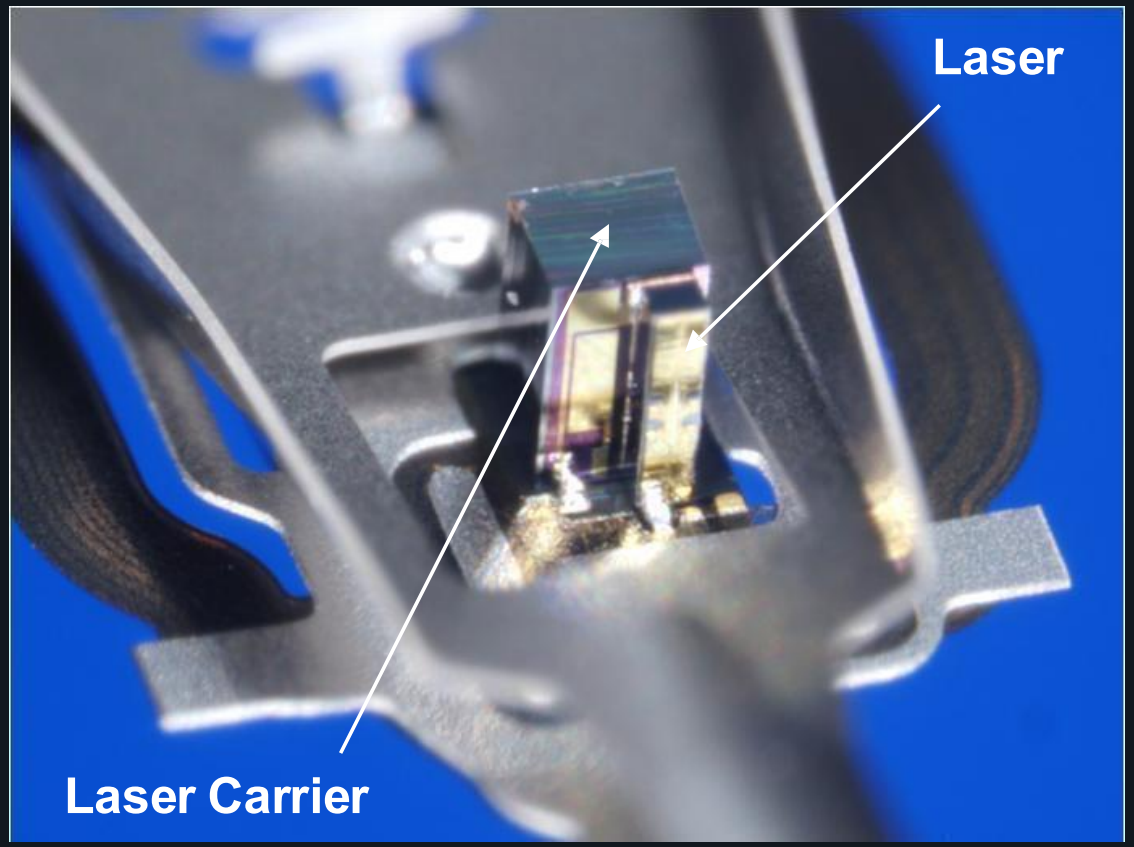


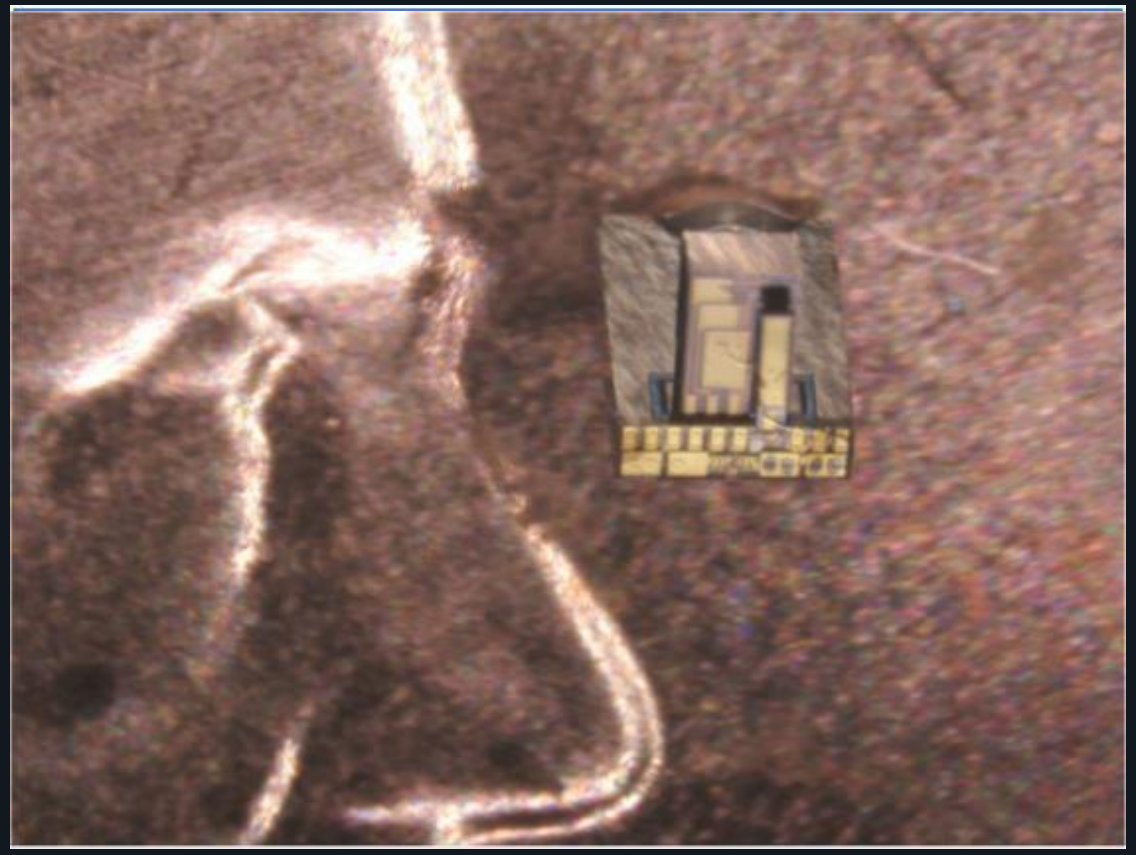
HAMR Head Architecture

- Electromagnet writer (old) + solid state laser (new) + optical lightpath (new) + nanofocusing optics (new)
- Laser → planar waveguide → solid immersion mirror → near field transducer
- Lollipop NFT for plasmon resonance – disc + antenna
- Sloped write pole to avoid power absorption from light tail

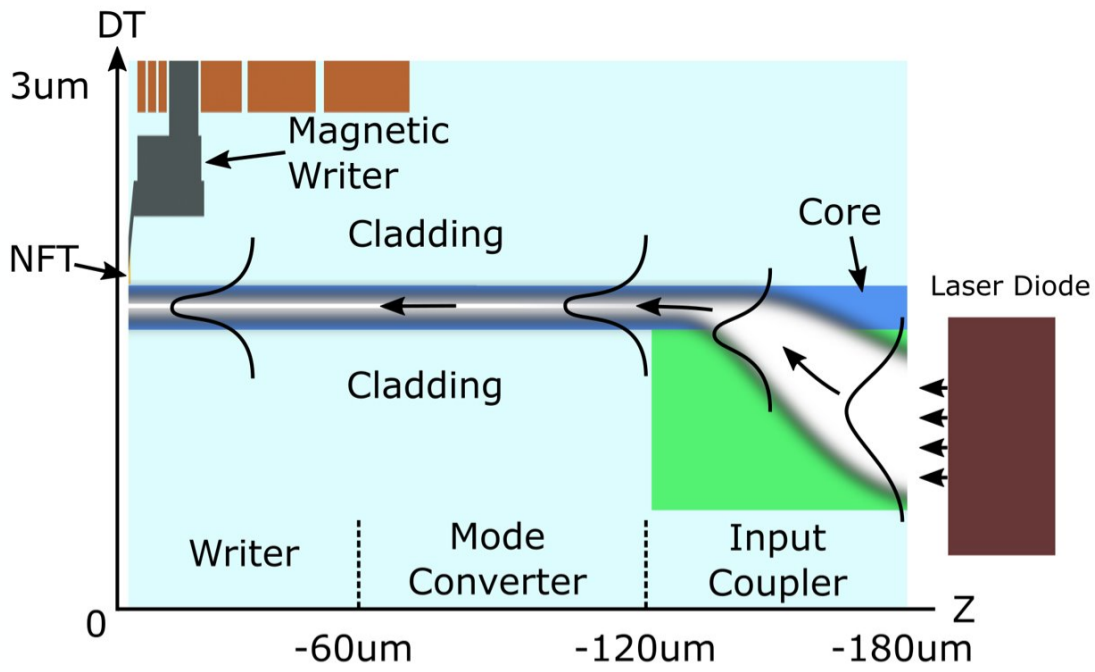


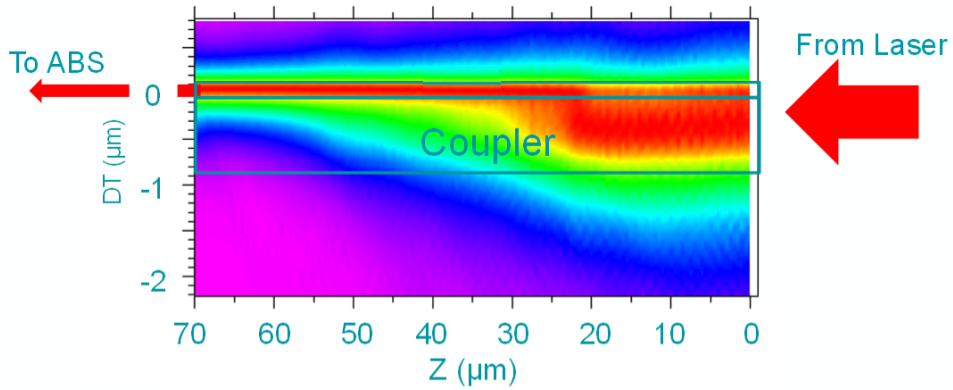
HAMR Head Architecture





Physics of HAMR Recording

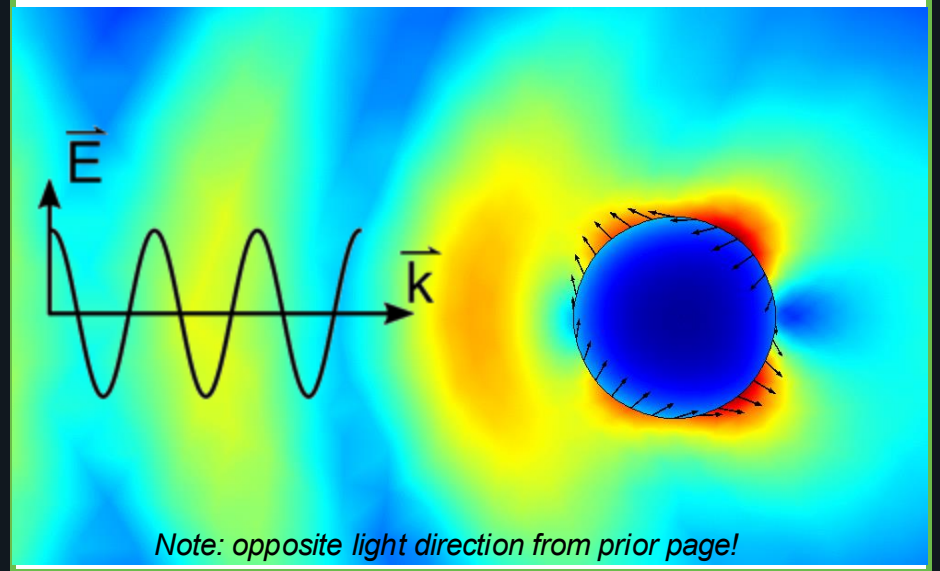




- 830nm solid state laser on back of slider
- Large-area input coupler to capture free space light
- Modify mode index to couple light into core ⇨ low-loss propagation

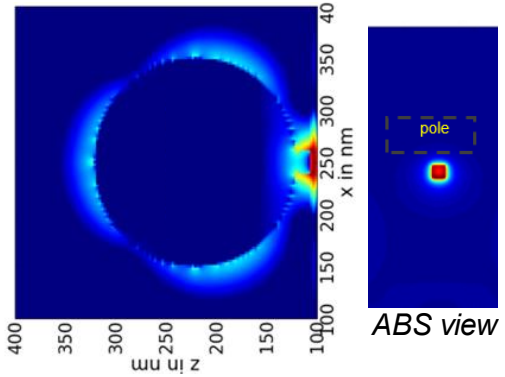
Physics of HAMR Recording

λ_{laser} + matched NFT disc size ⇨
Quadropole surface plasmon resonance



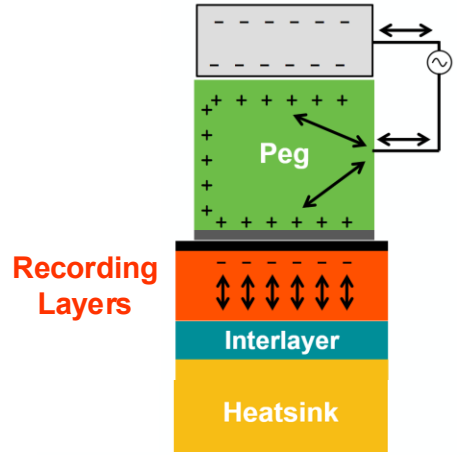
Note: opposite light direction from prior page!

Antenna ⇨
Field confinement



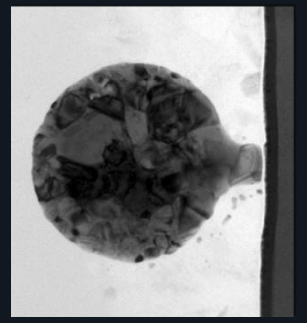
ABS view

Capacitive coupling ⇨
Media heating



Tiny size → low capacitance
low capacitance → High frequency

- Near field transducer has two components:
  1. NFT Disc – transduction of photons to plasmons AND extracting heat from peg
  2. NFT Peg – energy transfer from disc to media for heating

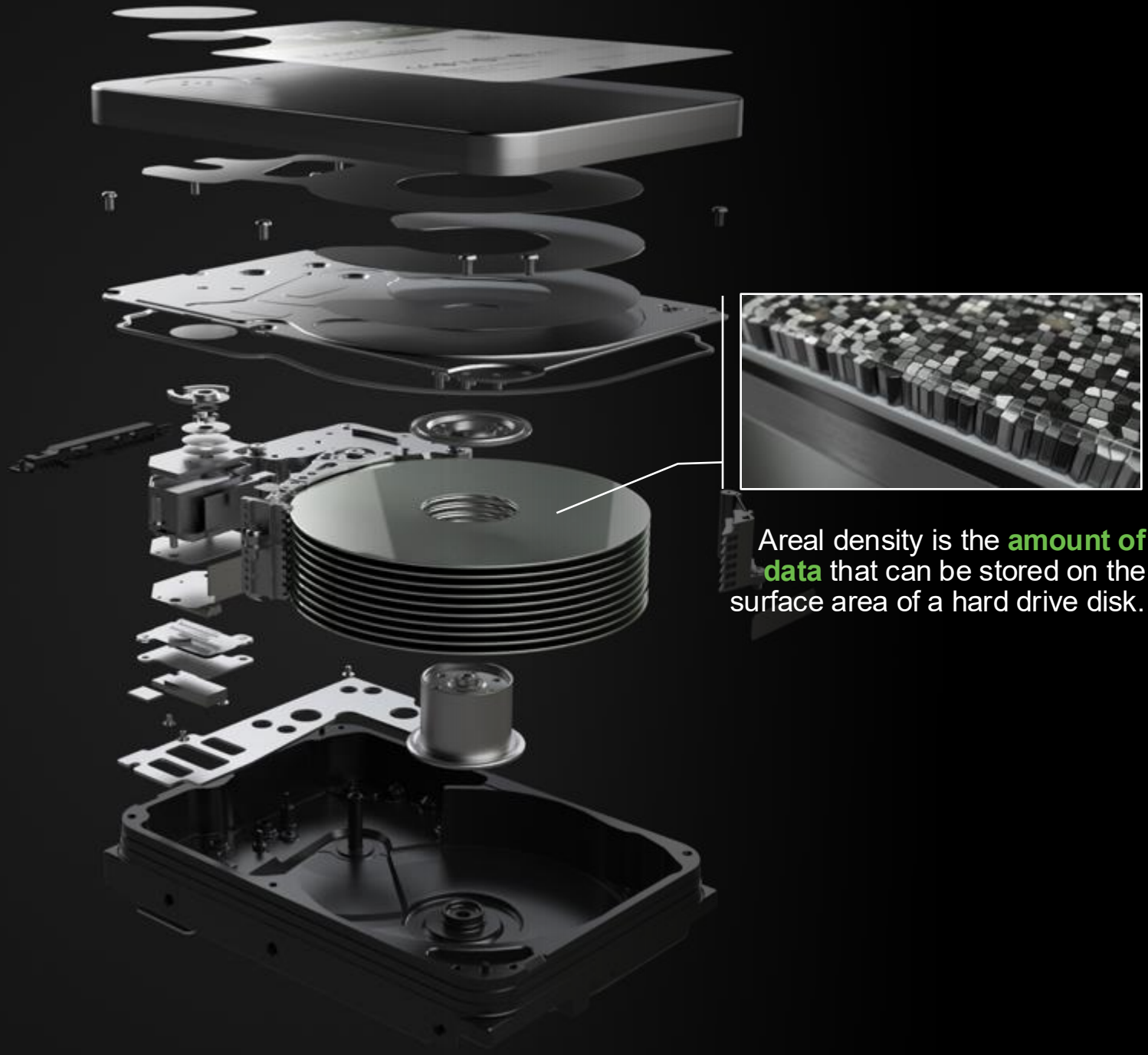


MOZAIC™ (HAMR)

The Value of Areal Density

Cost-efficient Capacity Scaling

We are scaling drive capacity by storing more data on every disk.



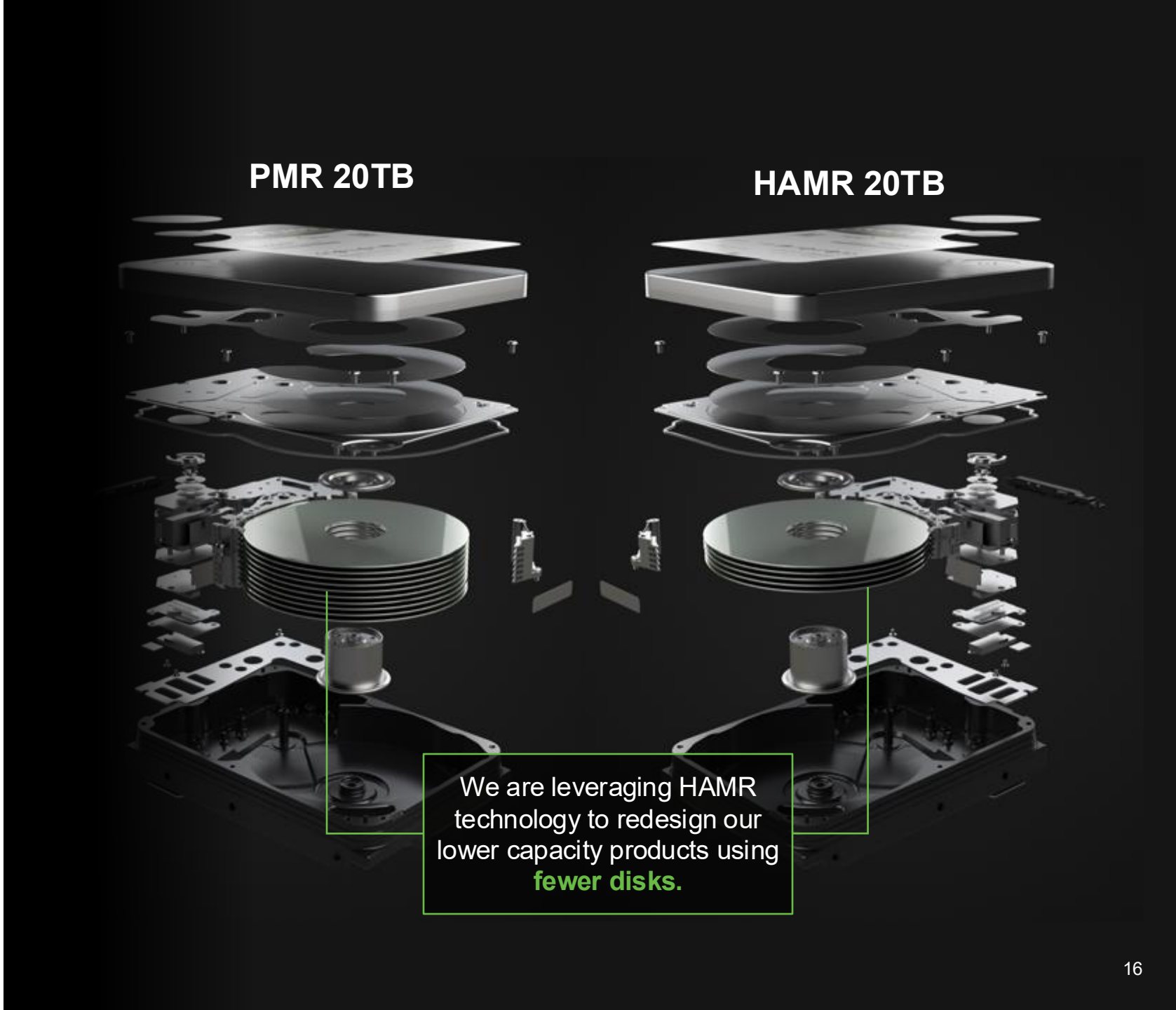
Areal density is the **amount of data** that can be stored on the surface area of a hard drive disk.

MOZAIC™ (HAMR)

The Value of Areal Density

Cost and Manufacturing Efficiency

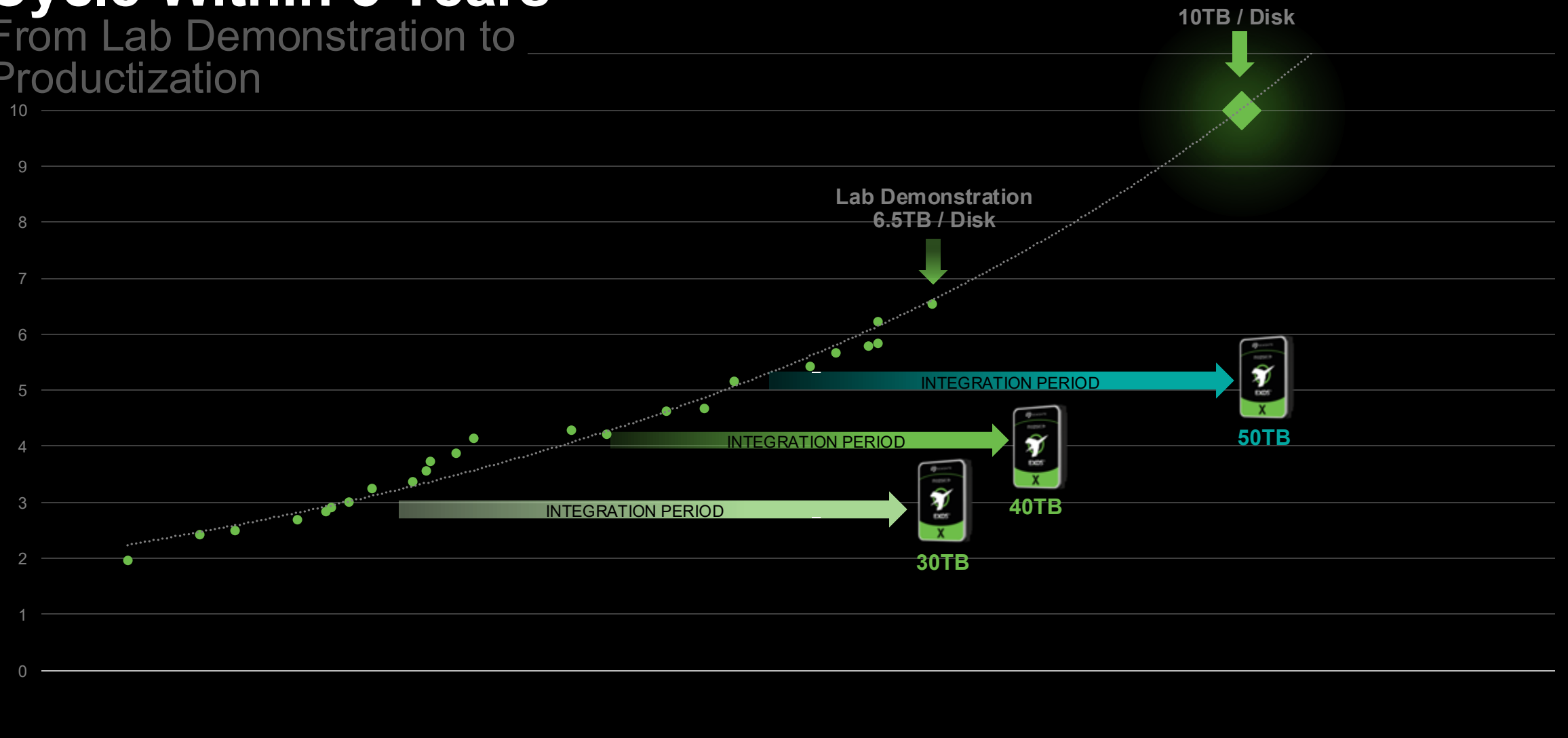
- Reducing unit cost by **10% - 15%**
- Reducing number of platforms



MOZAIC™ (HAMR)

Product Maturity Cycle Within 5 Years

From Lab Demonstration to Productization

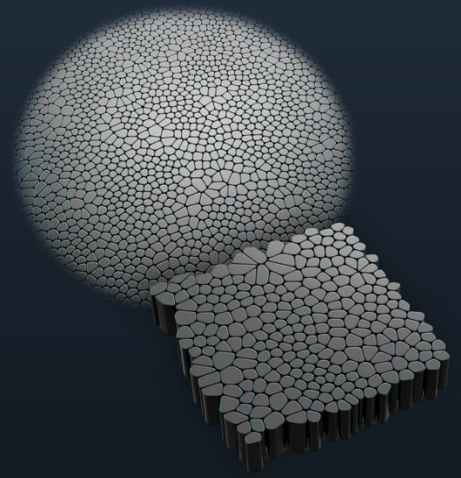
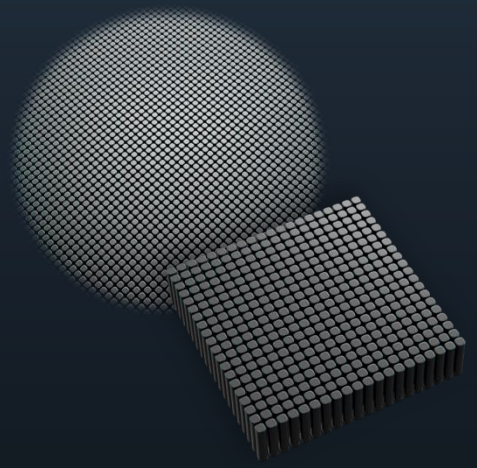


Beyond 10TB / Disk

Trailblazing the Path to Future Capacity Scaling

65TB

Based on **Maximum Demonstrated Areal Density**

	~100TB	100 - 150TB	>150TB
			
Media Type:	Enhanced Granular	Ordered-Granular or Advanced Architect: 3D	Low Cost & Mass Pro Patterning Technology (Innovation)
Areal Density Outlook:	**2 - 10TB / Disk**	**10 - 15TB / Disk**	**>15TB / Disk**

Path to 10TB / Disk & Beyond

Mozaic (HAMR) vs. PMR

- At the Disk Level

mozaic	4TB / Disk
vs	
PMR	2.4TB / Disk

Mozaic (HAMR) vs. PMR

mozaic | 40TB / Drive

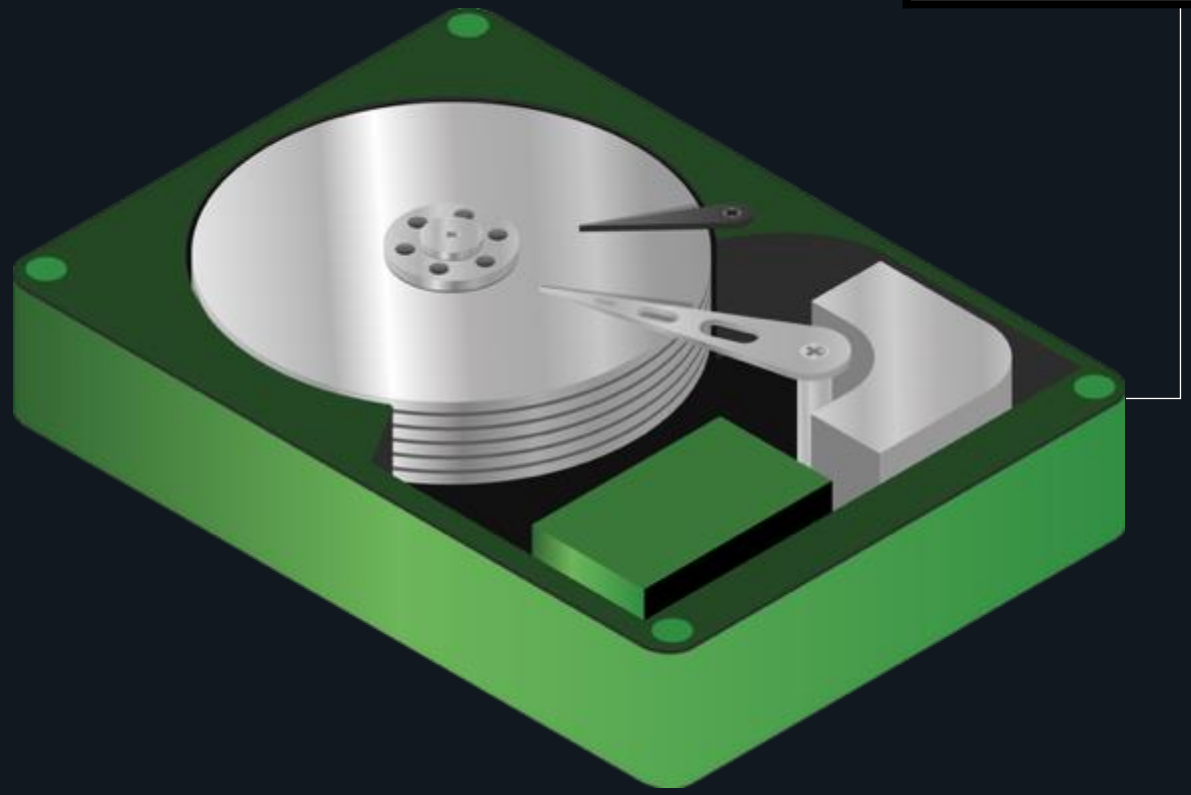
vs

PMR | 24TB / Drive

At the Disk Level

4TB / Disk vs. 2.4TB / Disk

At the Drive Level



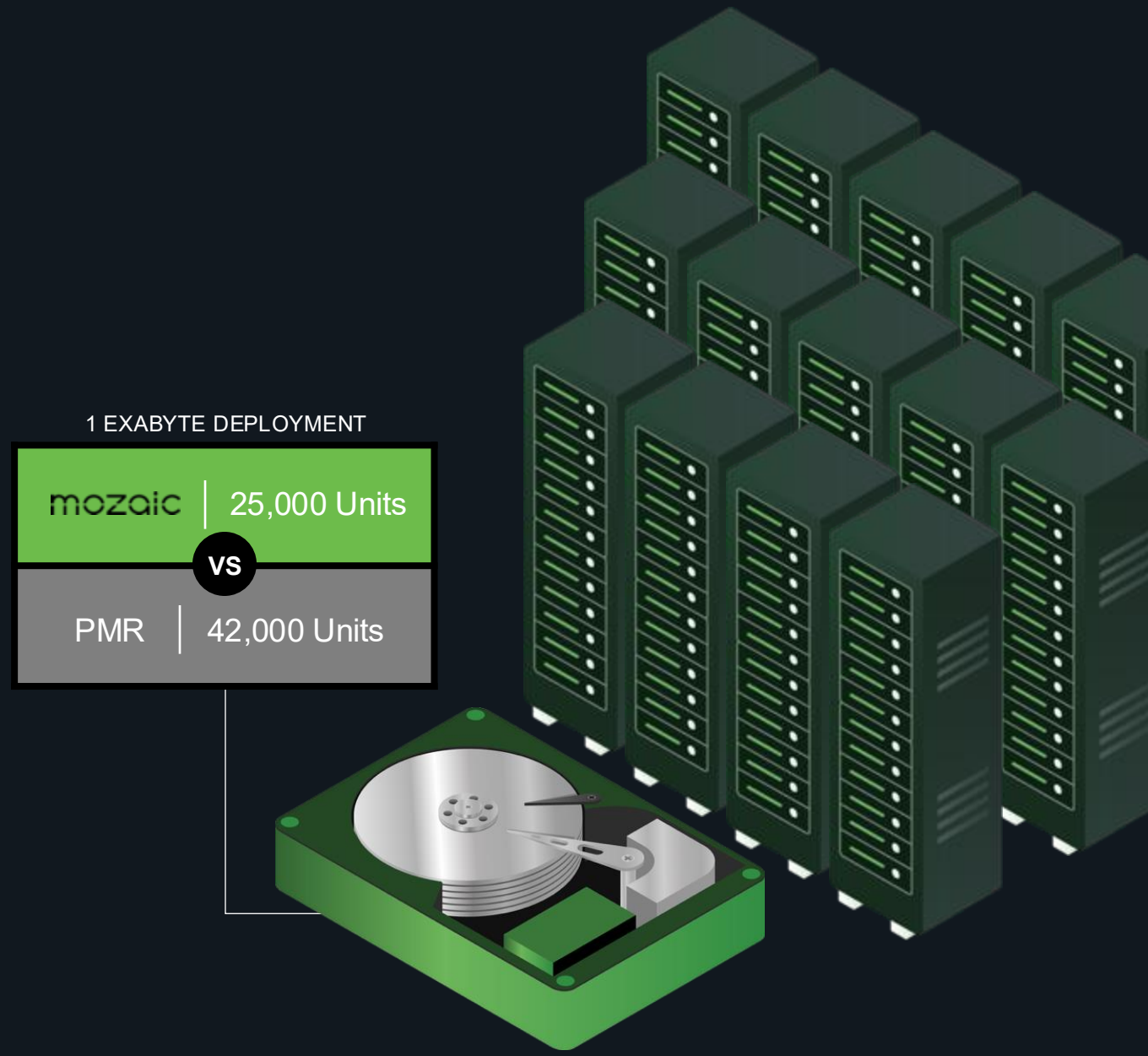
THE POWER OF AREAL DENSITY AT SCALE

Mozaic (HAMR) vs. PMR

At the Disk Level
4 TB / Disk vs. 2.4 TB / Disk

At the Drive Level
40 TB / Drive vs. 24 TB / Drive

At the Data Center Level



THE POWER OF AREAL DENSITY AT SCALE

Mozaic (HAMR) vs. PMR

At the Disk Level
4 TB / Disk vs. 2.4 TB / Disk

At the Drive Level
40 TB / Drive vs. 24 TB / Drive

At the Data Center Level
25,000 Units vs. 42,000 Units
240 Sq. Ft. vs. 400 Sq. Ft.
~2.0M kWh / Year vs. ~3.3M kWh / Year

1 EXABYTE DEPLOYMENT

mozaic	240 Sq. Ft. ~2.0M kWh / Year
VS	
PMR	400 Sq. Ft. ~3.3M kWh / Year

Based on 1.2-meter racks housing 8 Seagate Exos 4U106 (848 drives per rack) in constant use.
Square footage excludes aisle space, which would result in a larger improvement.

AT THE DISK LEVEL	AT THE DRIVE LEVEL	AT THE DATA CENTER LEVEL		
4TB / Disk *10 Disks*	**40TB / Drive**	**25,000** Units	**240** Sq. Ft.	**~2.0M** kWh / Year
2.4TB / Disk *10 Disks*	**24TB / Drive**	**42,000** Units	**400** Sq. Ft.	**~3.3M** kWh / Year

40% Improvement with Seagate Mozaic 4+ (HAMR)

With a 1 exabyte deployment

Mozaic at Hyperscale

Cloud Data Center

30+TB, 40+TB,… CAPACITIES

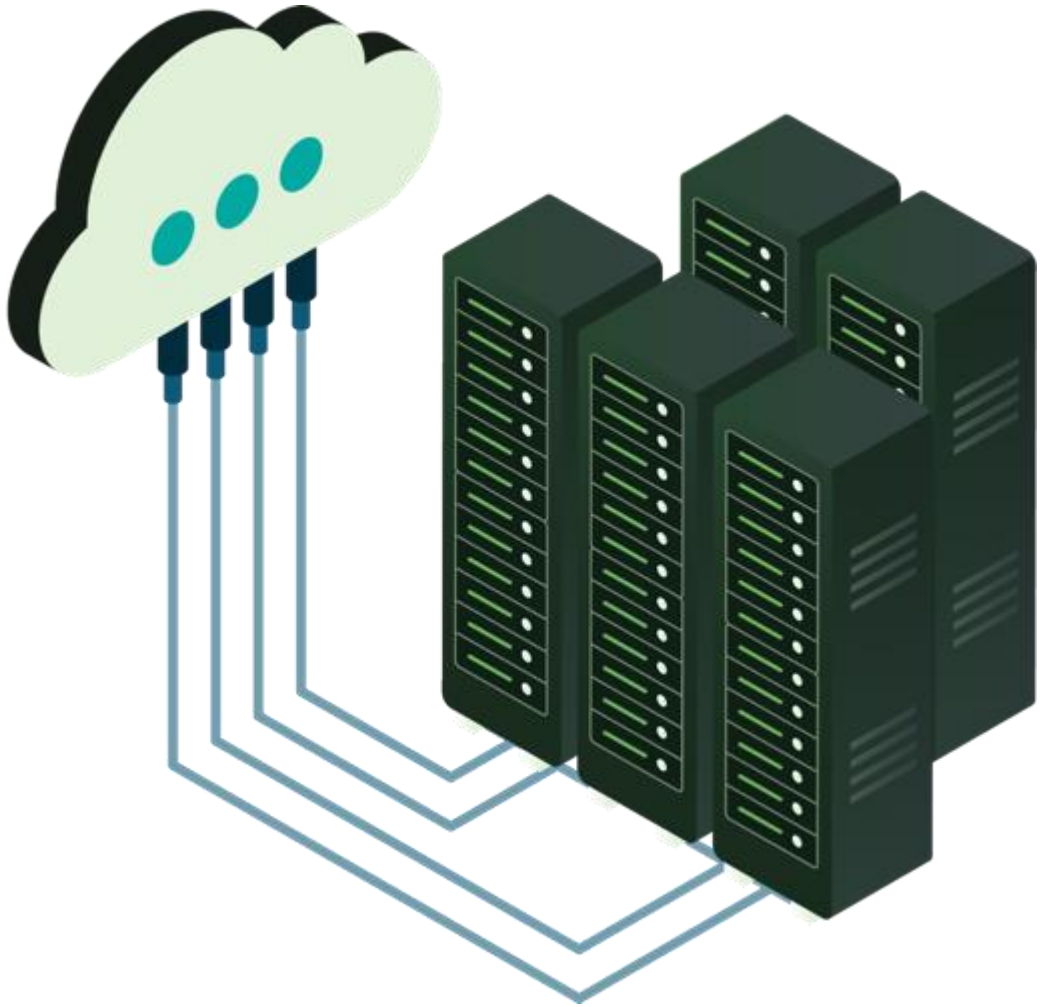
- ✓ Exabyte-scale storage pools
- ✓ Context-rich machine learning
- ✓ Trustworthy data retention

Maximum density storage for optimal space, power, and carbon efficiency.

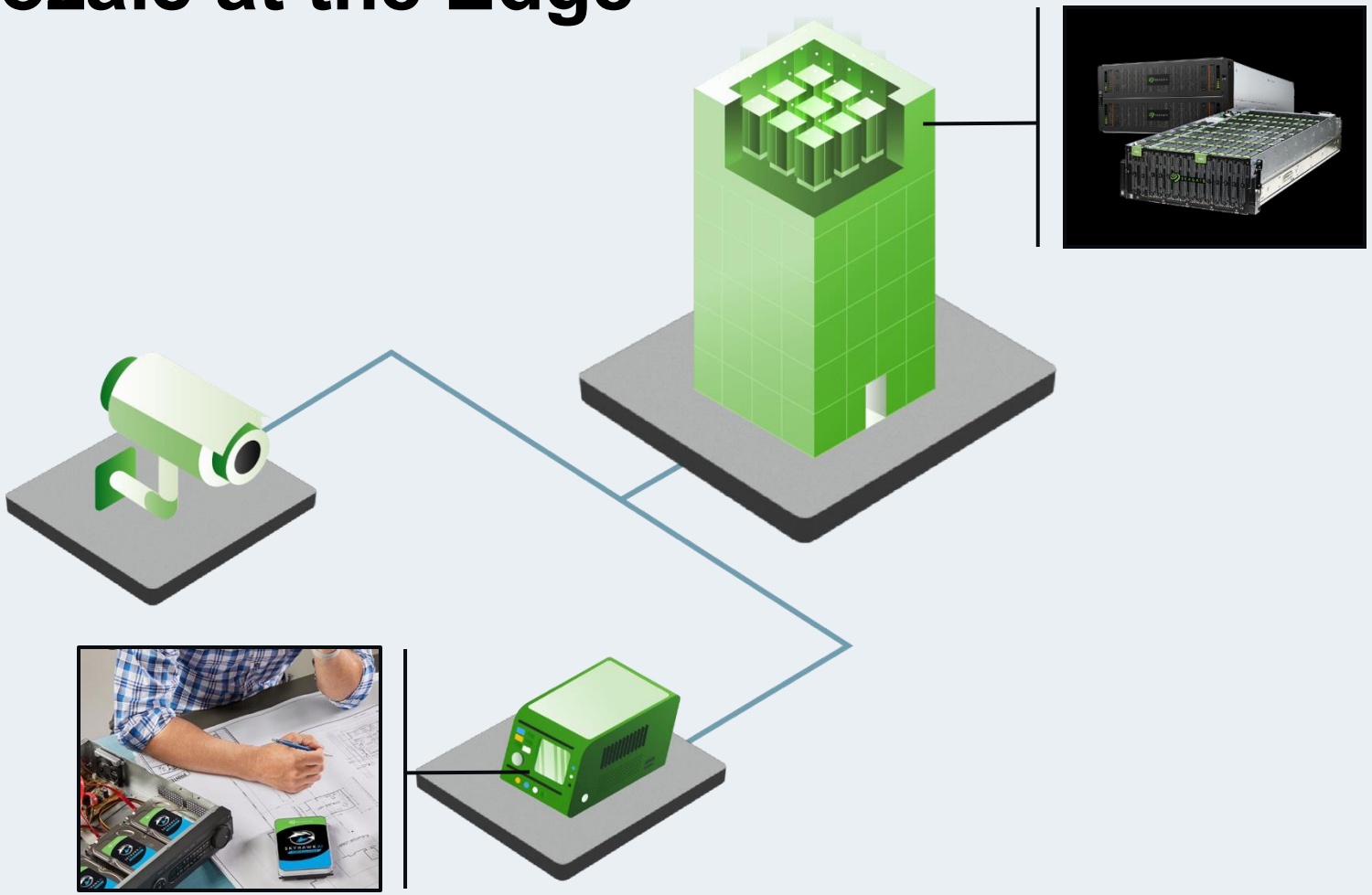
3.3×
the data center capacity in the same footprint[1]

3.5×
better power efficiency per TB[1]

3.7×
reduction in embodied carbon per TB[1]



Mozaic at the Edge



Edge Data Center

20+TB CAPACITIES

- Edge servers
- Network-attached-storage

General-purpose and network-attached high-density storage and server platforms deployed at the edge and on premises.

Edge IoT

10+TB CAPACITIES

- Video and image applications
- Smart cities
- Smart factories

Scalable storage solutions deployed at the edge and on premises for write-intensive video workloads.

Innovating in a Data-Driven World

Today

HAMR technology leadership. First to market. First to scale.

Tomorrow

Proprietary vertically-integrated laser enables capital-efficient production at scale.

In The Future

5TB / disk development is underpinned with path to 10TB / disk.

Thank you

Seagate is Leading Mass Capacity Storage Innovation With HAMR Technology

Areal Density Leadership

Most cost-efficient way to scale drive capacities

Economies of Scale

Reducing customers' total cost of ownership (TCO)

Broad Data Storage Portfolio

Delivering solutions to diverse markets