

RAMAC at 70 Kryder's Roadmap at 7

Vertical Market Failure in Magnetic Data Storage

Matthew B. Klusas | West Ox Advisors

Peter Faulhaber | BusinessConsult | Former President & CEO, FUJIFILM Recording Media U.S.A.

MSST · Santa Clara University, CA · June 1, 2026



Magnetic Data Storage Never Looked Better

Stock Performance



+1,190% since end of 2023



+835% since end of 2023

Stock Buybacks



\$6B announced



\$5B announced

Shortages

2026-2027 capacity sold out

Long-term agreements through 2028

Record Revenue and Margins FY Q3 2026



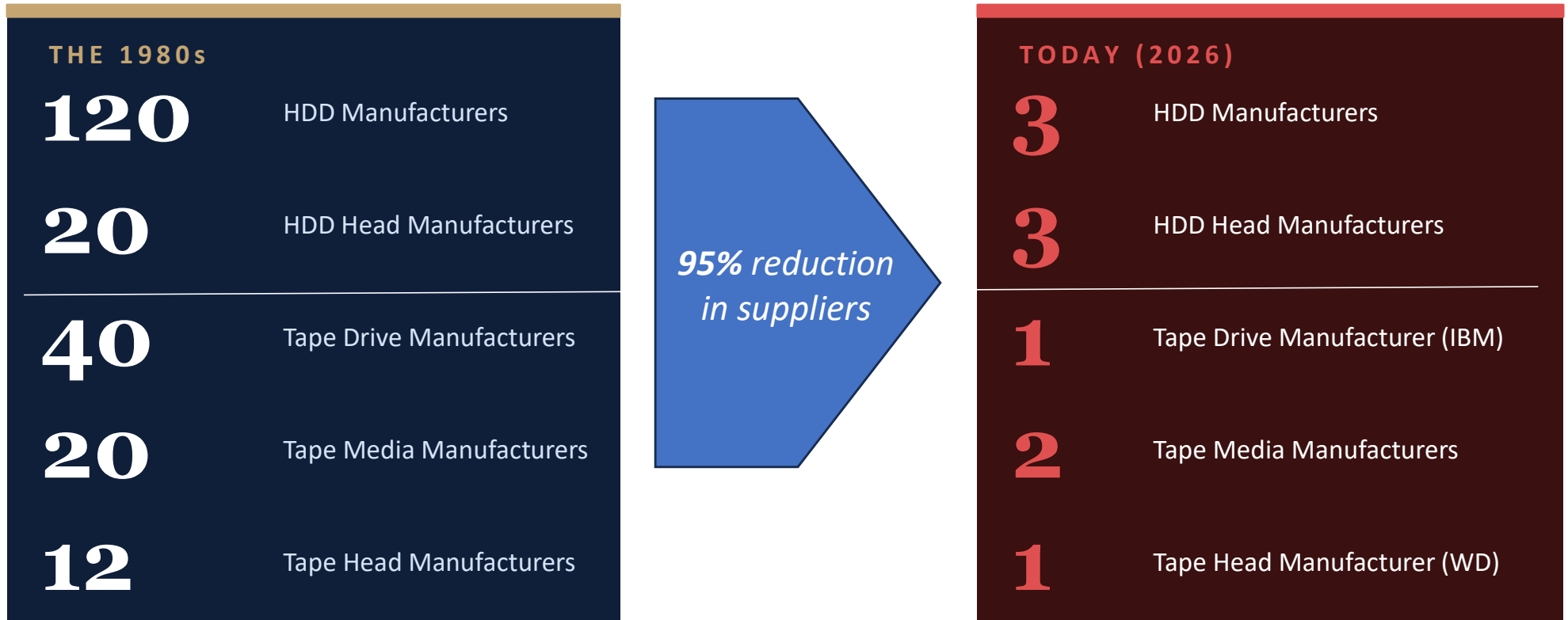
\$3.34B Revenue
50.2% Gross Margin



\$3.11B Revenue
46.5% Gross Margin

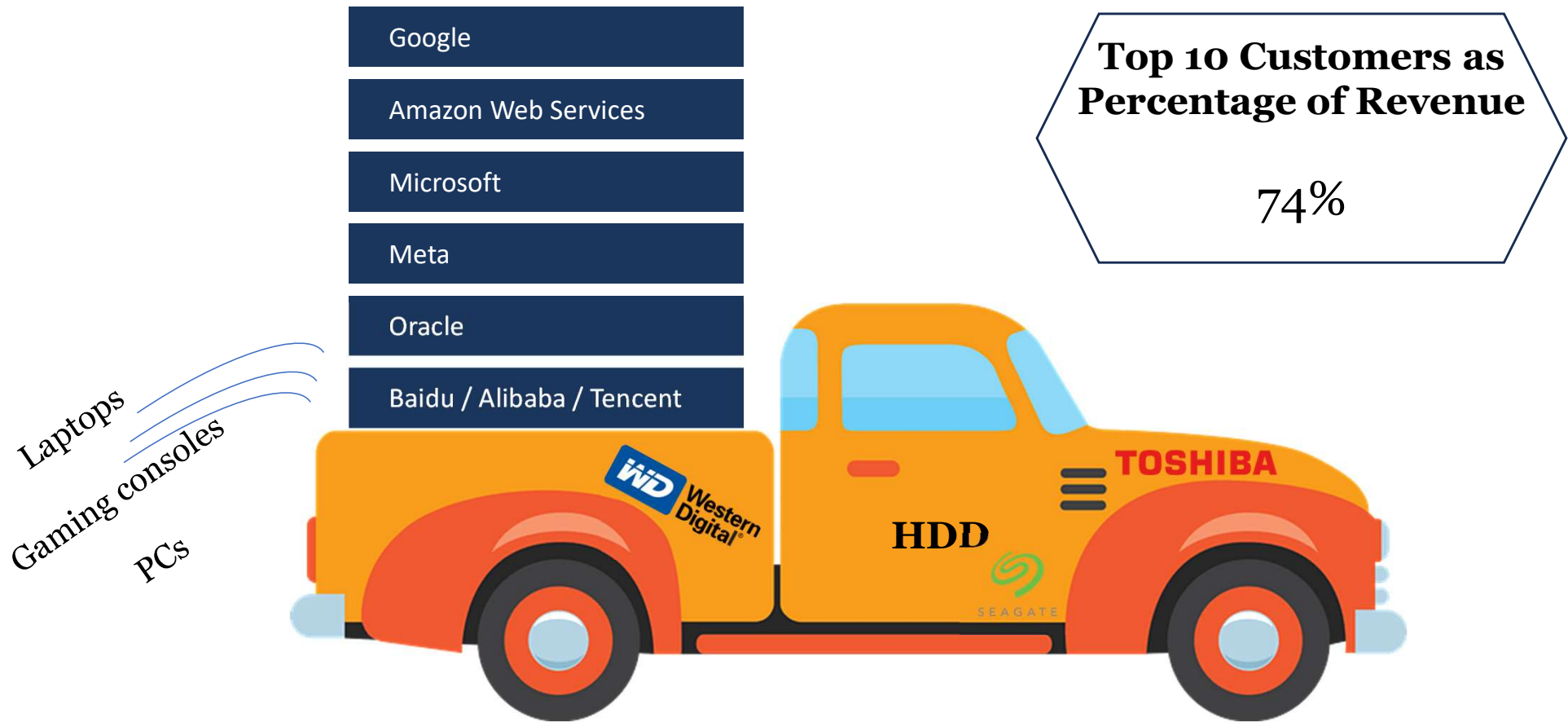
Four Decades of Supplier Attrition

Forming the bilateral oligopoly



Further Consolidation is Still Possible, Toward (More) Monopoly

HDD Buyer Concentration is Now Severe



"Just a Customer" Versus Majority of the Business?

Economists Have a Name for This

Markets with few buyers, few sellers, and long-cycle R&D don't "fail" randomly
They "fail" through a mechanism economists call Vertical Market Failure (VMF)

1

Few Buyers & Few Sellers

Bargaining power concentrates
Neither side can credibly commit
to long-term investments

2

High Asset Specificity

R&D investments have little value
outside the relationship, making
suppliers reluctant to invest in them

3

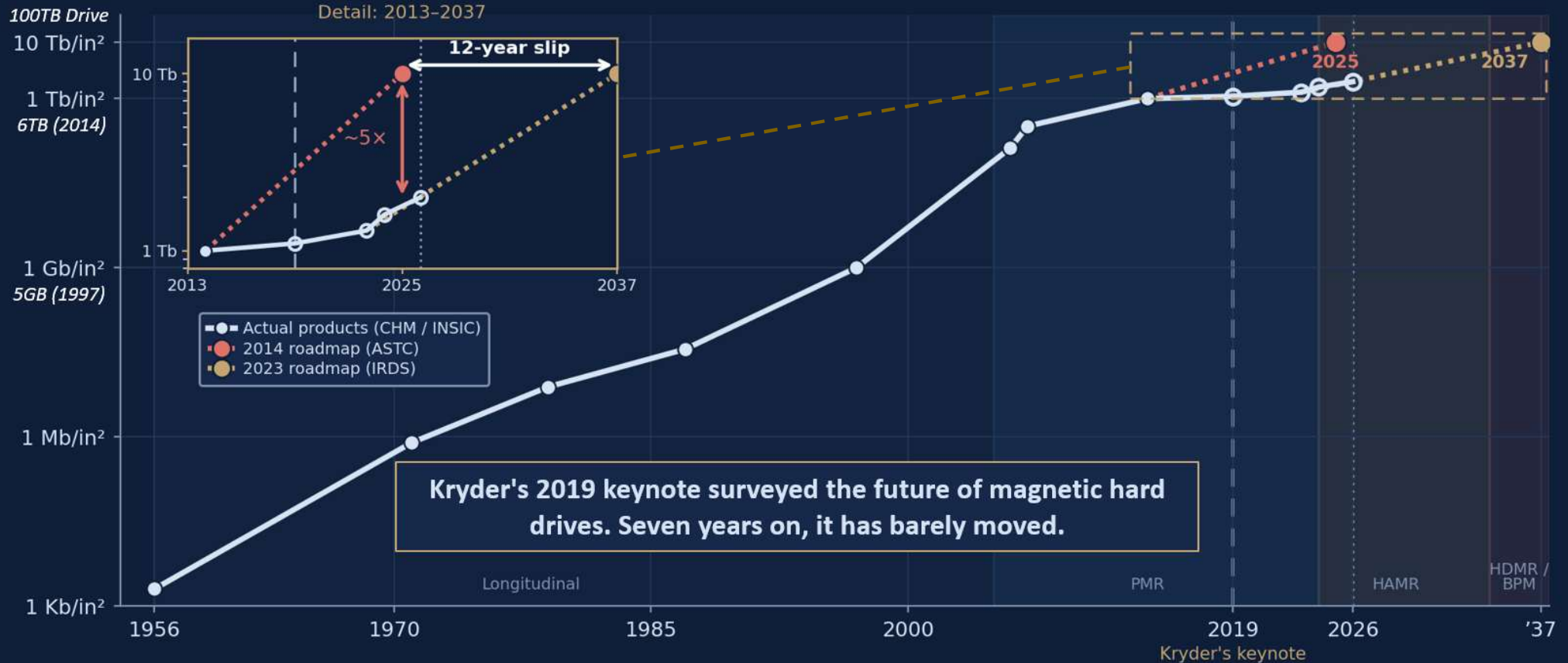
Frequent Transactions

Re-negotiation is constant
Every contract cycle is another
chance for opportunistic re-pricing

*Causes the "Hold-Up" Problem: Suppliers Rationally Avoid Investments in
Long-Cycle R&D They Cannot Guarantee Recouping*

RAMAC at 70, Kryder's Roadmap at 7

A Vertical Market Failure



Kryder's 2019 MSST Keynote Revisited

Two-Dimensional Magnetic Recording (TDMR)



Quietly incorporated as a read-channel enhancement, not the density step-change envisioned

Heat-Assisted Magnetic Recording (HAMR)



The lone success, commercialized well behind early projections and only now scaling

Microwave-Assisted Magnetic Recording (MAMR)



Never scaled in form intended; WD retreated to energy-assisted PMR, a narrower approach

Bit-Patterned Media Recording (BPMR)



The named successor to HAMR, still with no credible development timeline today

Vertical Market Failure as a Possible Explanation

Tape: All Demos, No Cartridges

Year	Sponsors	Media	Areal Density	Native Cartridge Capacity
2015	 	Barium Ferrite (BaFe)	123 Gb/in ²	220 TB
2017	 	Sputtered media (vacuum-deposited thin film)	201 Gb/in ²	330 TB
2020	 	Strontium Ferrite (SrFe)	317 Gb/in ²	580 TB

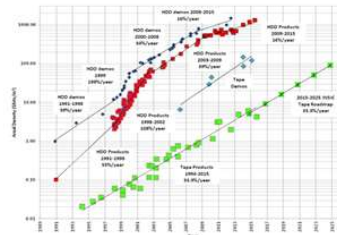
LTO-10 (2025): 40 TB Native Capacity

Tape Roadmaps



INSIC 2015-2025 Tape Roadmap

Parameter/Year	2015	2017	2019	2021	2023	2025	
1. Capacity (TB)	8	16	32	63	125	248	41.00%
2. Data rate per channel (MB/sec)	10.0	13.2	17.5	23.1	30.6	40.5	15.00%
3. Total data rate (MB/sec)	320.0	480.2	720.6	1081.4	1622.7	2435.1	22.50%
4. FC Speed Roadmap (MB/sec)**	3200	6400	12800	12800	25600	25600	
5. Number of channels	32	36	41	47	53	60	6.52%
6. Tape thickness (um)	5.20	4.79	4.42	4.07	3.75	3.46	-4.00%
7. Data capacity reserve	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	
8. Tape length that is recordable (meters)***	969	1051	1141	1238	1343	1457	3.90%
9. Tape length total (meters)****	1041	1129	1225	1330	1443	1565	4.17%
10. Track density (TPI)	10,686	15,652	22,868	33,543	49,372	72,891	21.17%
track pitch = 25400/tpi (um)	2.38	1.62	1.11	0.76	0.51	0.35	
11. Linear bit density (kfc)*****	480	581	703	850	1029	1245	10.00%



INSIC 2015 Roadmap

2021: 63 TB
2025: 248TB

INSIC | Whitepaper

INSIC International Magnetic Tape Storage Technology Roadmap 2024

PARAMETER/Year	2024	2026	2028	2030	2032	2034	
1. Capacity (TB)	45	78	137	238	415	723	32% per year
2. Maximum data rate per channel (MB/sec)	12.5	8.3	10.9	14.5	19.1	12.6	
3. Maximum streaming drive data rate (MB/s)	400.0	529.0	699.6	925.2	1223.6	1618.2	15% per year
4. Minimum streaming drive data rate (MB/s)	90.7	200.0	220.5	243.1	268.0	591.0	1.2 m/s min
5. FC Speed Roadmap (GB/sec*)	128	256	256	512	512	1024	
6. Number of channels	32	64	64	64	64	128	

INSIC 2024 Roadmap

2024: 45 TB
2030: 238TB

The Stalemate Is Breakable

1

Risk-Share Agreements

Hyperscalers co-fund specific breakthrough R&D programs with contractual commits, eliminating the hold-up problem at the source: The ASML model, applied to storage

2

Pre-Committed Procurement

Long-term purchase commitments tied to technology milestones give suppliers the revenue visibility required to justify long-cycle investment; reduces contract uncertainty

3

Vertical Integration

Hyperscalers develop proprietary storage technology or acquire existing manufacturers; eliminates bilateral dependency entirely

4

Consortium Restructuring

Replace rent-collection mechanisms like the LTO Consortium with direct R&D funding models; fees must reach the lab

Stalemate Has Been Broken Before

THE ASML / EUV PRECEDENT

ASML

The stalemate

EUV lithography required physics breakthroughs no single company would fund alone; suppliers doubted returns; chipmakers doubted delivery

The break

Intel, Samsung, and TSMC collectively committed ~€5.2 billion (~\$6.4B) through equity stakes and direct R&D funding in exchange for early access to EUV technology; risk-sharing replaced hold-up

The result

EUV now enables every leading-edge chip; the trillion-dollar semiconductor industry runs on technology that only materialized through coordinated customer investment

THE PARALLEL IN STORAGE

Hyperscalers are the analog of chipmakers: the concentrated buyer with the most to gain from breakthrough innovation

HDMR, ceramic substrates, holographic: Technologies exist in research; the path to manufacturing does not

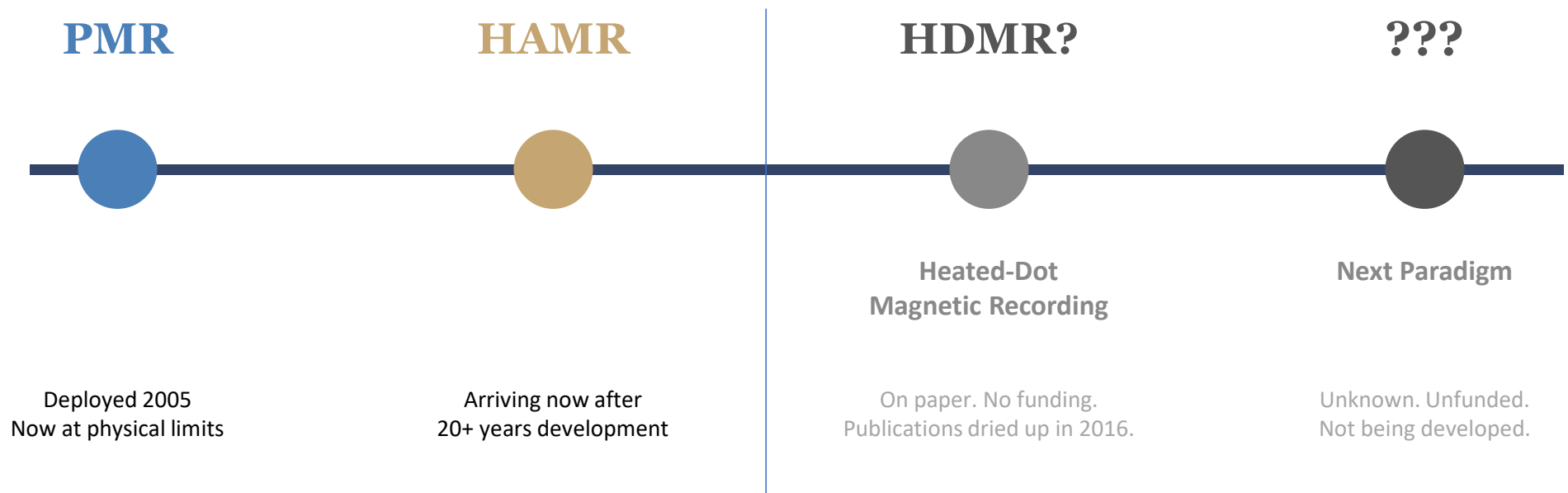
Combination of risk-sharing agreements, pre-committed procurement, and co-investment

Customers moved from arms-length transactions to integrated partners

No Clearly Defined Next Generation Technology for Data Storage

Magnetic Storage Has a Future — If Anyone Funds It

The roadmap beyond HAMR only exists on paper; the R&D investment to get there does not



Not Clear What – If Any – Investments Support Areal Density Growth Beyond Mid-2030s

Summary

Bilateral oligopoly

**Market shifts from
aggressive price takedowns
to rent-seeking price increases**

**Under-investment in
breakthrough R&D**



Vertical Market Failure (VMF)



High Profitability in a Bilateral Oligopoly Does Not Incentivize Breakthrough Investment

Who is Building the Future of Data Storage?

