

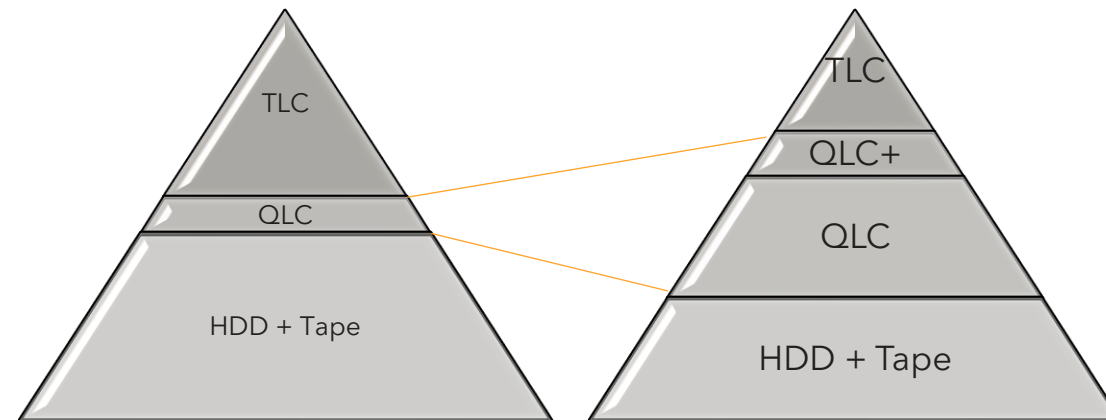
QLC SSD Readiness for Datacenter Mainstream

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Agenda

- What is QLC and how it compares with TLC NAND
- Considerations of QLC readiness for datacenter and enterprise
 - Technology maturity and flash vendor readiness
 - Datacenter workload evolution
 - Ecosystem
 - Economics
- Risks and challenges
- Conclusion



TLC vs QLC NAND Comparison



	TLC NAND	QLC NAND
Bits/Cell	3	4
P/E Cycle ¹	10k	>3k
I/O Speed ²	2-2.4Gbps	1.6Gbps
Areal Density (Gb/mm ²)	16.25 (Samsung V8 236L TLC)	18.6 (Solidigm N4PA 192L)
Die Size	512Gb-1Tb	1.368Tb

Compared to TLC (Triple-level-cell), QLC (Quad-level-cell) NAND provides:

- Instant 33% increase on areal density and 25% \$/GB cost saving
- Lower P/E cycle and I/O Speed
- No change to SSD quality and reliability







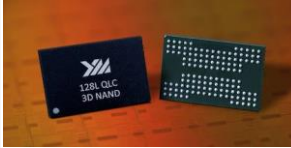
^{1,2} Number based on Solidigm™ N4PA NAND



NAND Vendors QLC Readiness

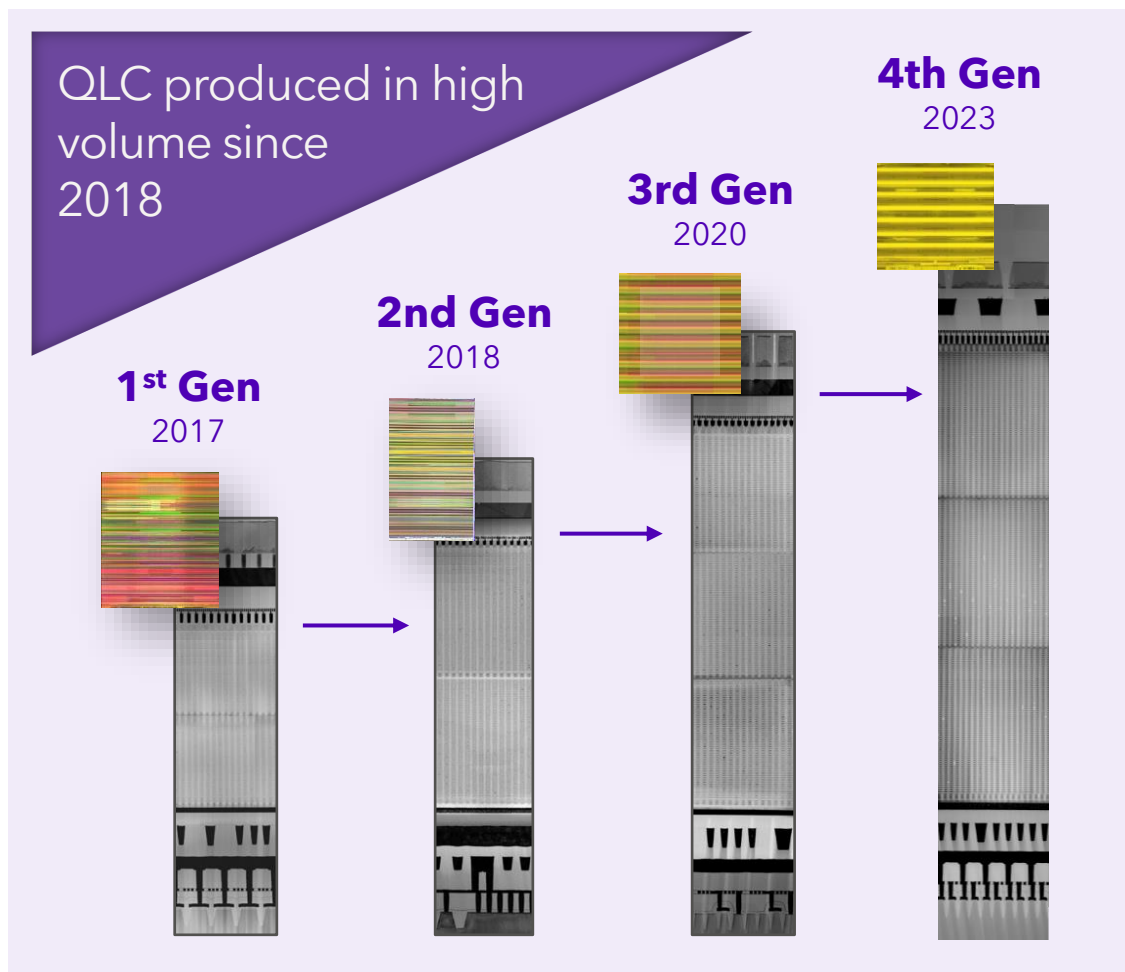


Broad range of QLC products offered in Client and Data Center

	Solidigm	Samsung	Micron	KIOXIA BiCS	Seagate	Western Digital	YMTC
							
Interface	PCIe 4	SATA	PCIe/SATA	N/A	PCIe 3	PCIe 3	N/A
Layers / NAND Type	192L FG, QLC	92L, QLC V-NAND	176L, QLC	162L, TLC/QLC	QLC	QLC	128L, QLC
Name	D5-P5336/P5430 P41 Pro	QVO 870	Micron 2400 5210 ION	BiCS	BarraCuda Q5	SN550	Xtracking
Capacities	3.84TB-61.44TB 512GB-2TB	1TB, 4TB	512GB-2TB 1.92TB -7.68TB	N/A	Up to 2TB	250GB-2TB	N/A
Type	DC/Client SSD	Client SSD	DC/Client SSD	Component	Client SSD	Client SSD	Component



3D QLC SSD: Mature and Market-Aligned



QLC is a proven fit for today's value-based workloads

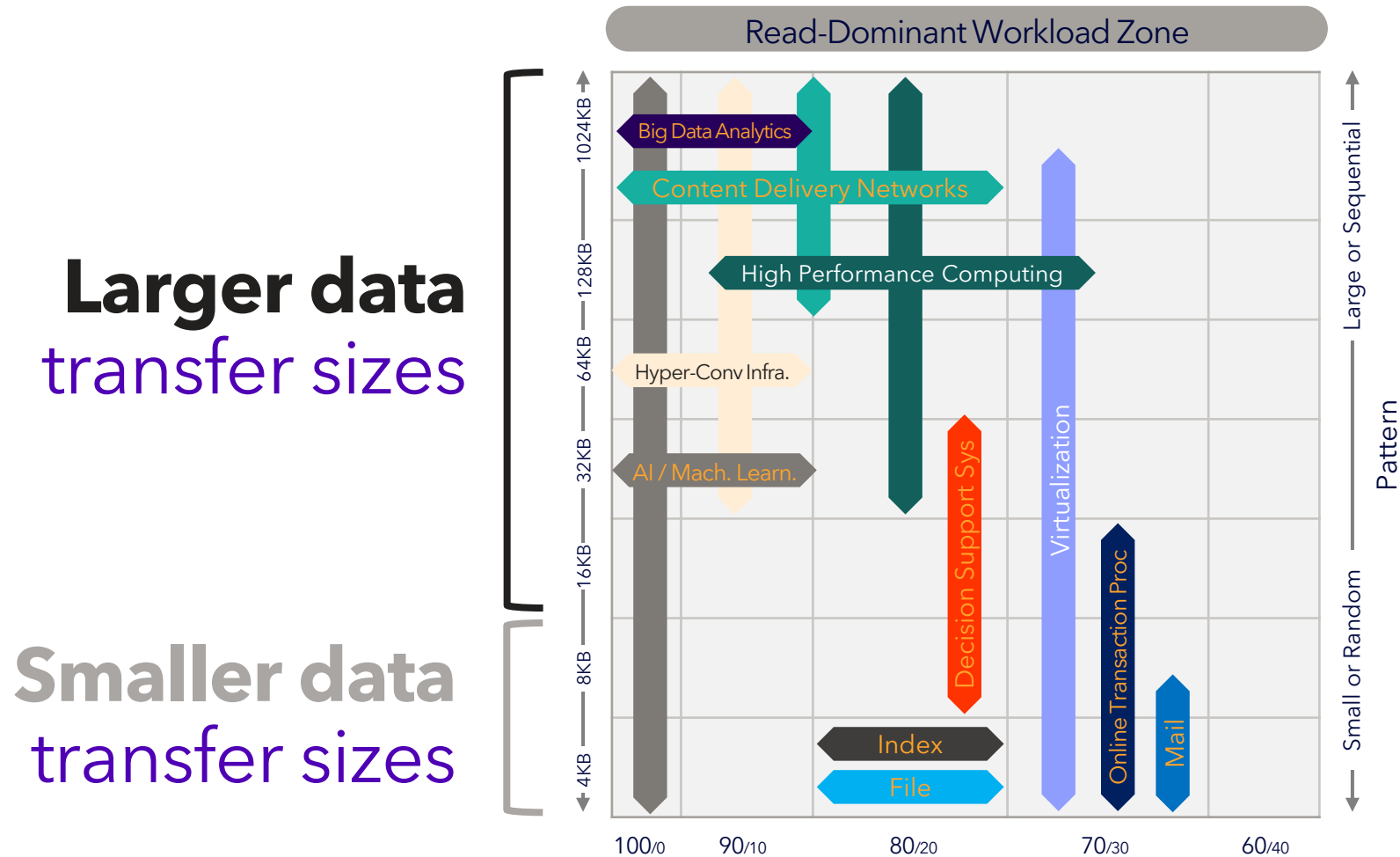
	Intel® SSD DC P4320/P4420 /P4326	Intel® SSD D5-P5316	Solidigm™ D5-P5336
NAND	N18A	N38A	N4PA
Layers	64	144	192
Bits per cell	4	4	4
Density (GiB)	128	128	171.4
# of Planes	4	4	4
Page Size (KB)	16	16	16
I/O (MT/s)	533	Up to 800	Up to 800
P/E Cycle	1K-3K	3K	3K+
Max Endurance (DWPD)	0.4	0.41 (64k)	0.58(16K)

¹Dates are based on Solidigm technology announcements.



Datacenter Workload Evolution

Read intensive scenarios increase in the data center



- Characterize and Model I/O¹
 - Read-write mix
 - Transfer size
 - Queue depth
 - Random or sequential access
 - Idle vs active
 - Scenarios: everyday workload, backups, boot storm, periodic workload

Data Shows SSD DWPD Reduction Trend



Conventional ideas around endurance are out of date

Most SSDs ship with ≤ 1 DWPD...

...and most never approach DWPD rating

~85%

of projected worldwide DC SSDs shipments 2020-2023 **rated at ≤ 1 DWPD**¹



"...for the vast majority..., **a move towards QLC's PE cycle limits poses no risks**, as 99% of systems use at most 15%...rated life..."²

Total PBW³ is a better endurance metric:

D5-P5336
65 PBW

D5-P5430
32 PBW

Micron 6500 ION
16.8 PBW

HDD
2.5

¹ Source - Solidigm, based on available internal and 3rd party analyst data.
² Source - <https://www.usenix.org/conference/fast22/presentation/maneas>; *Operational Characteristics of SSDs in Enterprise Storage Systems: A Large-Scale Field Study*, Stathis Maneas and Kaveh Mahdavian, University of Toronto; Tim Emami, NetApp; Bianca Schroeder, University of Toronto Feb 2022
³ See Appendix 'PBW' for additional information.



Compare PCIe QLC SSD Tuned for Read | Data-intensive Workloads with popular TLC SSDs



Product	SR 128K QD256	RR 4K QD256	SW 128K QD256	RW 4K QD256	Max Endurance ¹ Lifetime Petabytes Written (PBW)	Max Cap.
Solidigm™ D5-P5336¹	1.03x up to 7000 MB/s	1x up to 1.005M IOPS	0.59x up to 3300 MB/s	0.10x up to 24K IOPS	2.3x 65 PBW	4x 61.44TB
Samsung PM9A3²	1.01x up to 6700 MB/s	1.1x up to 1.1M IOPS	0.73x up to 4000 MB/s	0.8x up to 200K IOPS	0.5x 14 PBW	0.5x 7.68TB
Micron 7450 Pro³	1x up to 6800 MB/s	1x up to 1.0M IOPS	1x up to 5600 MB/s	1x up to 250K IOPS	1x 28 PBW	1x 15.36TB
Micron 6500 ION⁴	1x up to 6800 MB/s	1x up to 1.0M IOPS	0.89x up to 5000 MB/s	0.8x up to 200K IOPS	0.6x 16.8 PBW	2x 30.72TB
Kioxia CD8-R⁵	0.97x up to 6600 MB/s	1x up to 1.05M IOPS	1.07x up to 6000 MB/s	0.78x up to 195K IOPS	1x 28 PBW	1x 15.36TB

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Similar or better read performance and higher endurance vs. TLC

1. Solidigm. D5-P5336 product specifications and current 5 quarter roadmap. Max endurance for D5-P5336 based on 100% 16K RW @ 61.44TB capacity.

2. Samsung. Performance and PBW from highest capacity drive available. https://image.semiconductor.samsung.com/resources/data-sheet/Samsung_SSD_PM9A3_Data_Sheet_Rev1.0.pdf

3. Micron. Performance and PBW from highest capacity drive available. https://media-www.micron.com/-/media/client/global/documents/products/product-flyer/7450_nvme_ssd_product_brief.pdf

4. Micron. Performance and PBW from highest capacity drive available. https://www.micron.com/-/media/client/global/documents/products/product-flyer/6500_ion_product_brief.pdf

5. Kioxia. Performance and PBW from highest capacity drive available. <https://americas.kioxia.com/content/dam/kioxia/shared/business/ssd/data-center-ssd/asset/productbrief/dSSD-CD8-R-U2-product-brief.pdf>



Innovation Powered by QLC Technology



Address the needs for both capacity and fast access at low cost



Democratize flash and build unified and containerized architecture to store and organize EB level of data on a single tier with QLC¹



Add QLC support to deliver twice the cluster capacity, node density and lower costs without any increase in power, cooling or floor-space requirement²



Flash translation layer (DFS) to interact with flash media directly and optimize QLC media endurance, capacity and cost to compete with SATA HDD and HFA³



Replace HDD with QLC SSD with 2x performance by leveraging open-source CSAL (Cloud Storage Acceleration Layer) into ECS D3C local-disk instance⁴

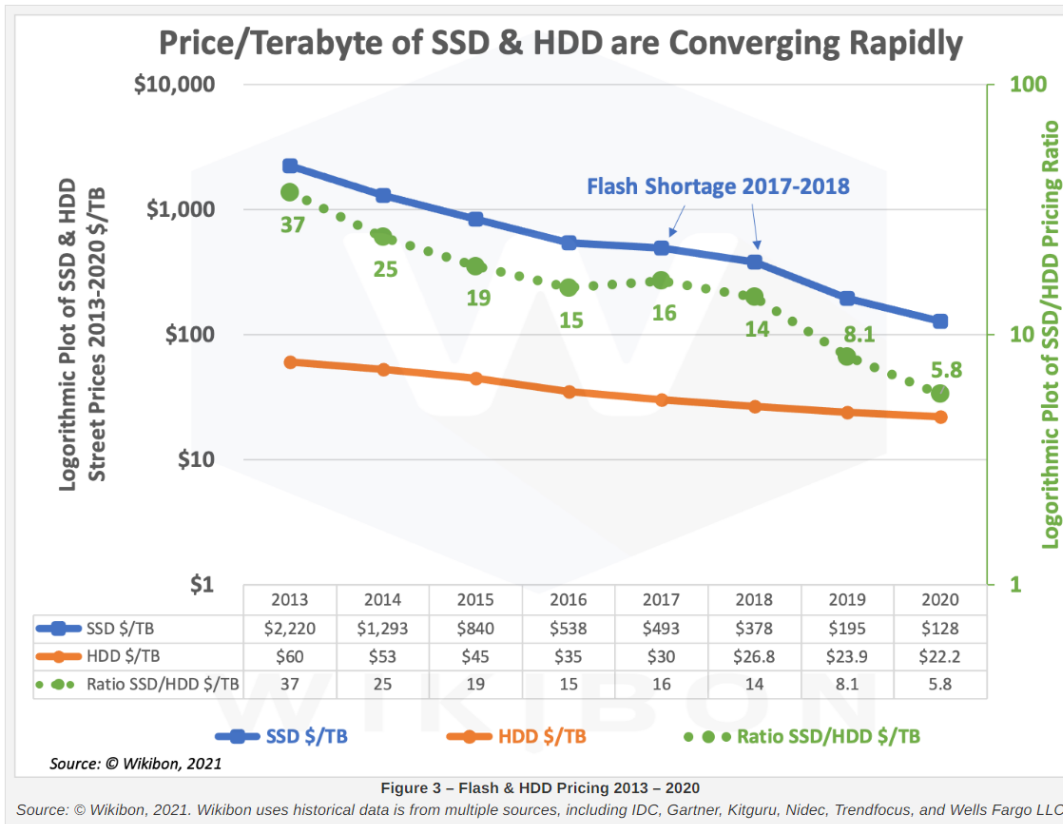
¹ Source - The VAST Platform White Paper (vastdata.com) ² Source - PowerScale | Dell UK ³ Source - FlashArray//C for Capacity-Optimized Storage Workloads Paper | Pure Storage ⁴ Source - A Media-Aware Cloud Storage Acceleration Layer



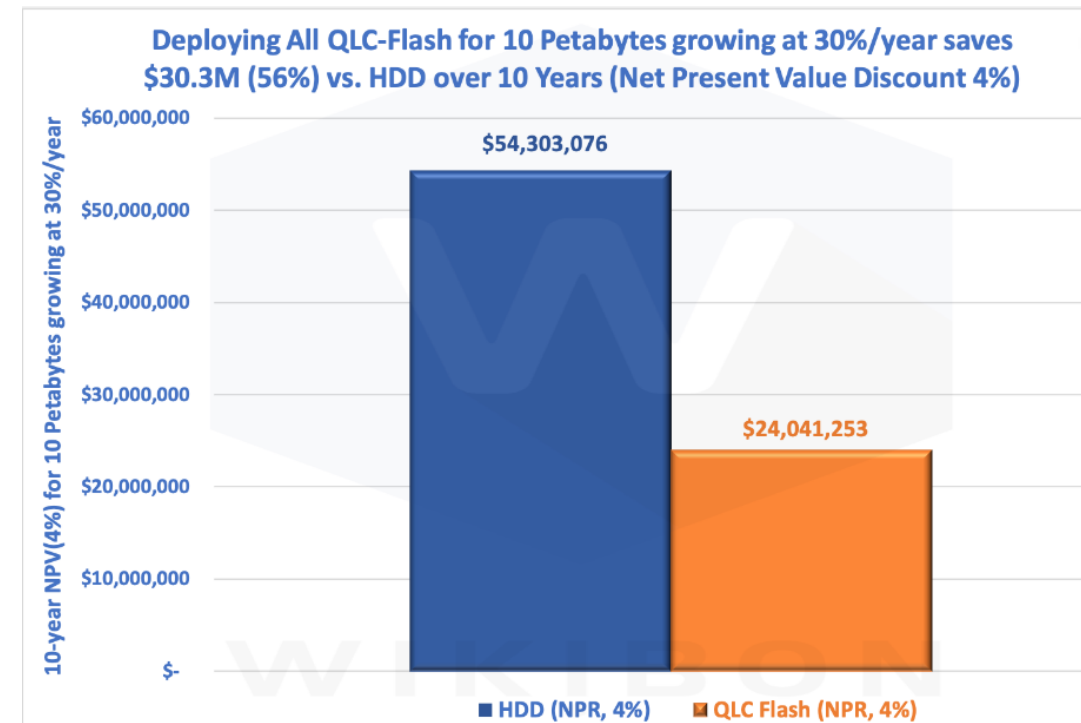
IDC Predicts Flash Raw Cost per GB Will Continue to Drop at a Compound Annual Rate of 16.6%* from 2020-2024



\$/GB and SSD/HDD Price Ratio Trends



QLC Cost Benefit over 10-years with in-line data-reduction factor of 2.0 for QLC Flash



Wikibon Research Showed the historic CAGR 2013-20 for the SSD/HDD price ratio is -23%**



61.44TB QLC SSDs Provide 47% Lower TCO and Sustainability Benefit over 20TB HDDs



Total Cost of Ownership Value When Solving for **100PB** Object Storage Solution

All-HDD Array
3.5" 20TB HDD @ 70% Util.

Solidigm D5-P5336
U.2 61.44TB @ 95% Util.

# of capacity drives	21,429	3,427	6.3x fewer drives
Total # of servers	1,786	143	12.5x fewer servers
Total racks	106	9	11.8x smaller rack footprint
TBe/W	3.03	9.05	3x better power density
5-year energy cost	\$1.19M	\$244K	4.9x lower energy cost
5-year total cost	\$26.4M	\$14.1M	47% LOWER TCO



Sustainability
Benefit



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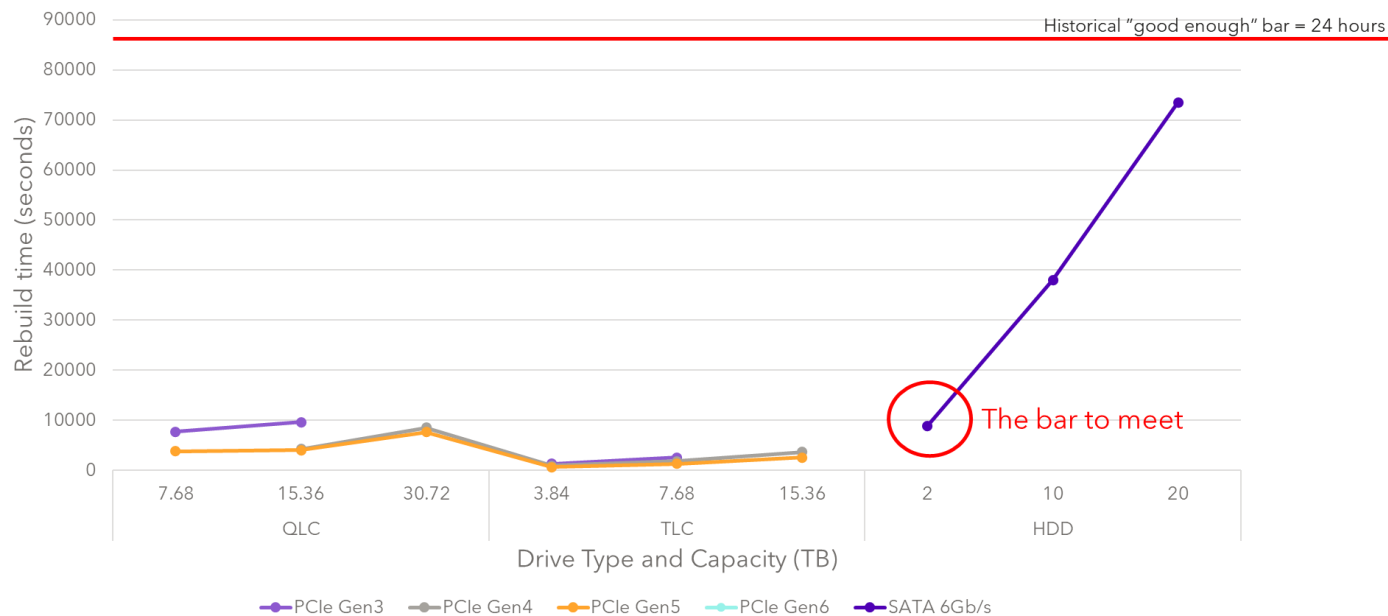


Mindset Change Takes Time

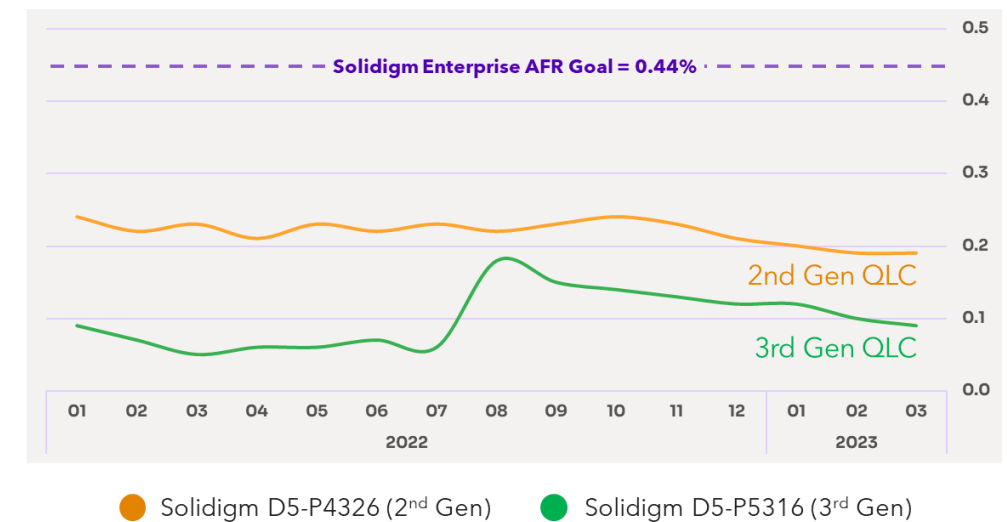


- Lack of awareness
 - Reliability & blast radius
- Conservatism on DWPD
- Infrastructure, interface transition etc.

Local RAID rebuild time across Interfaces - TLC vs QLC vs HDD



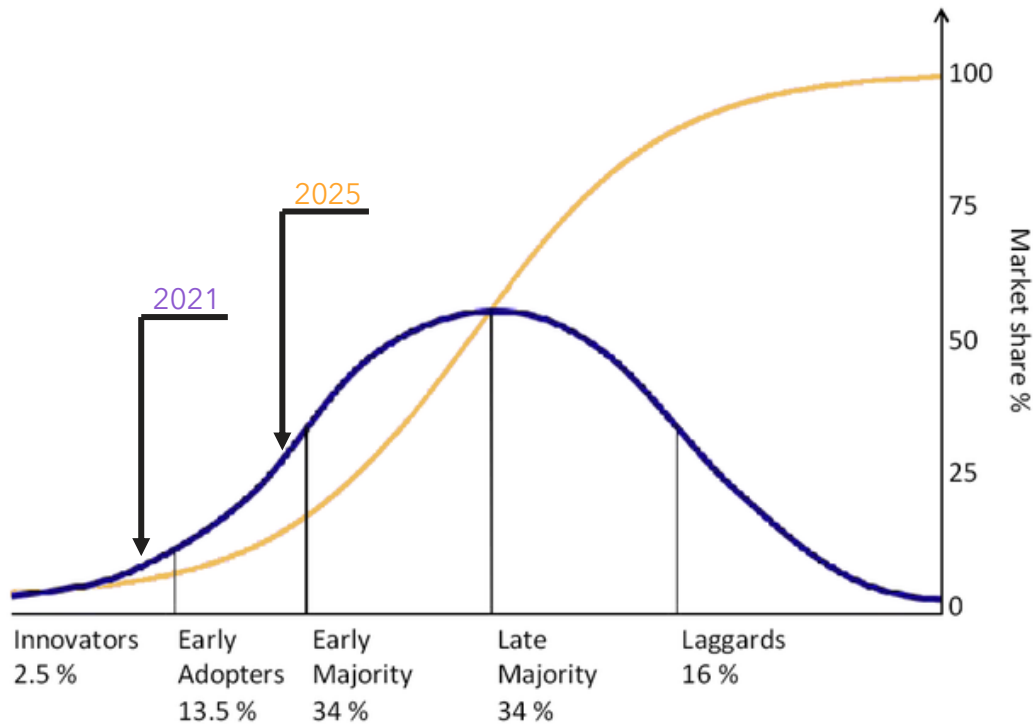
Annual Failure Rate (AFR) Goal vs Actual Performance¹



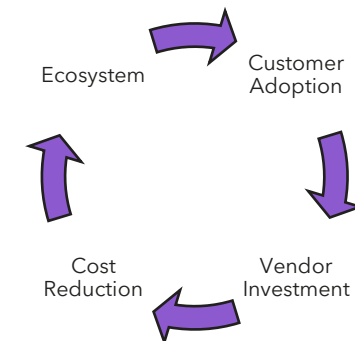
QLC is Moving toward Datacenter Mainstream



Forward Insights projects QLC to grow to 30% by 2025¹



- TLC will still likely be the majority flash media in the data center for the short future
 - QLC has started to displace performance and NL HDD and TLC based SSD in
 - Standard and Nearline Storage, active archive
 - Tiered/Hybrid clusters
 - Exascale NAS, software defined scale out
 - Cloud
- Will further expand with
- Cost driven down by economy of scale and layer increase
 - Flexibility on perf and endur. complemented by SLC, OP, etc.
 - Improvement on software stack, eco system and innovations



¹KIOXIA QLC Accelerates into the Mainstream Infographic





The World's Highest Capacity PCIe SSD



For Massive Data Storage
from Core to Edge



Solidigm™ D5-P5336

Learn more at Booth 107