

Western Digital[®]

Zoned Storage for the Zettabyte Age

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Forward-looking Statements

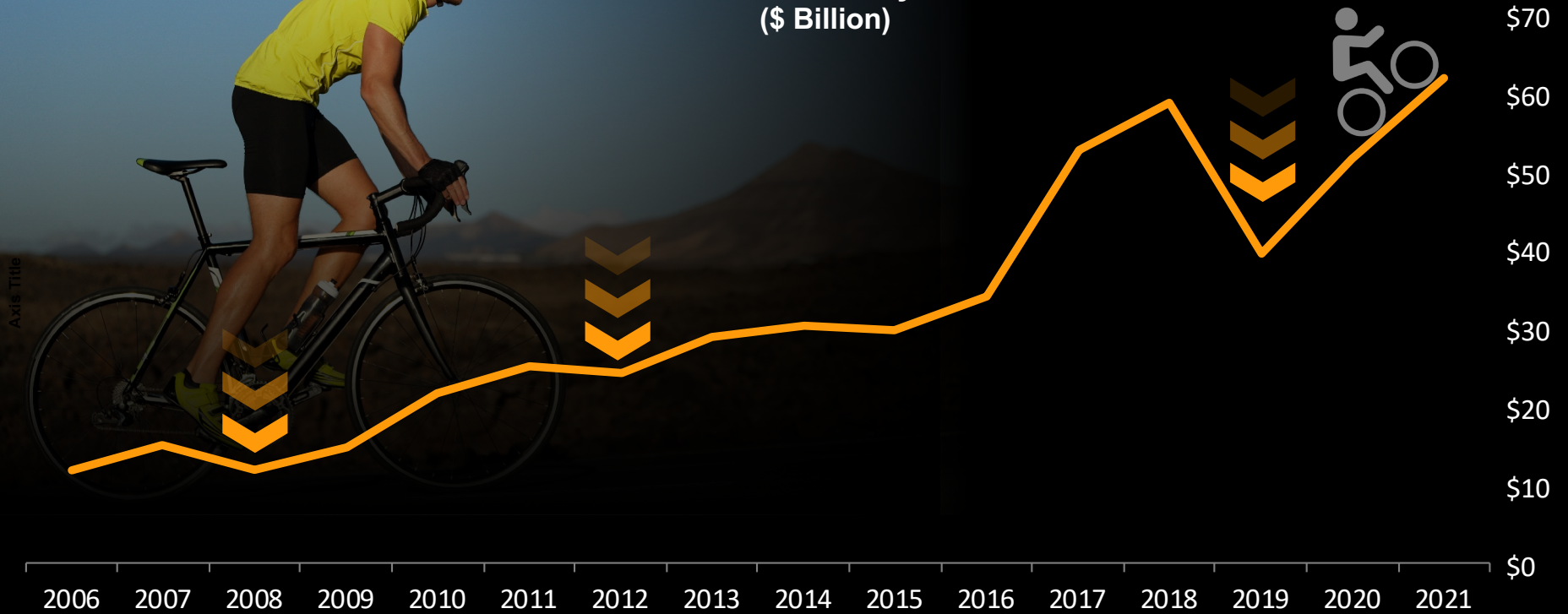
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This presentation contains forward-looking statements that involve risks and uncertainties, including, but not limited to, statements regarding our product and technology portfolio; business strategies and growth opportunities; capital expenditures; and market and data storage industry trends. Forward-looking statements should not be read as a guarantee of future performance or results, and will not necessarily be accurate indications of the times at, or by, which such performance or results will be achieved, if at all. Forward-looking statements are subject to risks and uncertainties that could cause actual performance or results to differ materially from those expressed in or suggested by the forward-looking statements.

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Tour De Flash: Back to Climbing

NAND Flash Industry Revenue
(\$ Billion)

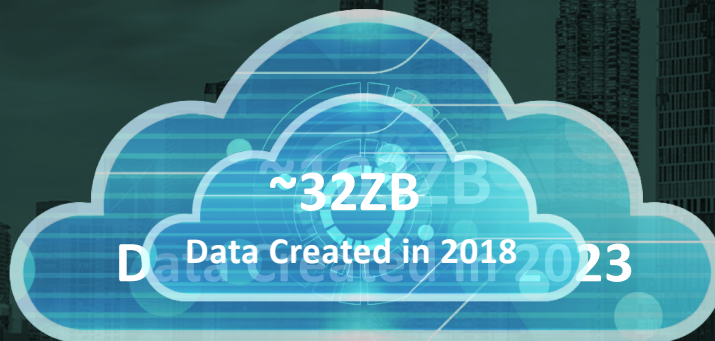


Have we Reached a Cyclical Trough?

Source: "NAND Quarterly Insights Q2/19," Forward Insights, May 2019

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Zooming into the Zetta-Zone

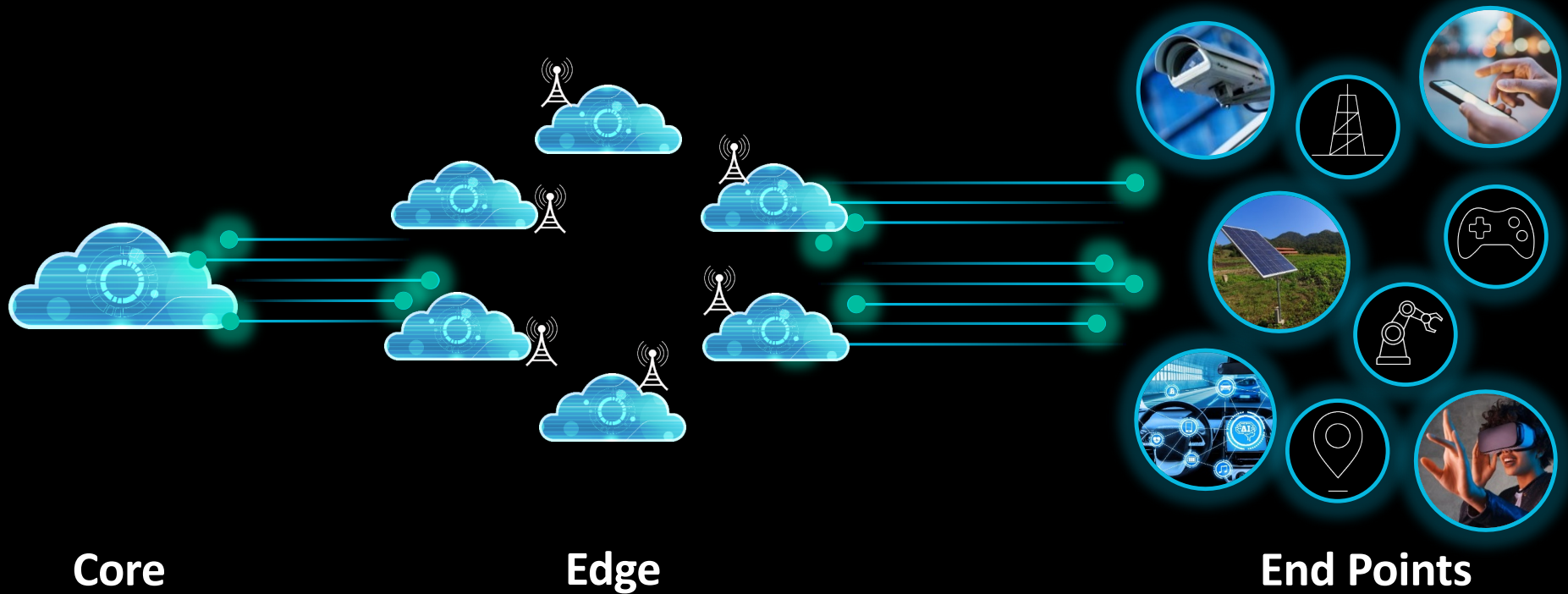


Source: IDC Global DataSphere Forecast, 2019-2023: Consumer Dependence on the Enterprise Widening, January 2019, DOC #US44615319

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Cloudy with a Chance of More Data



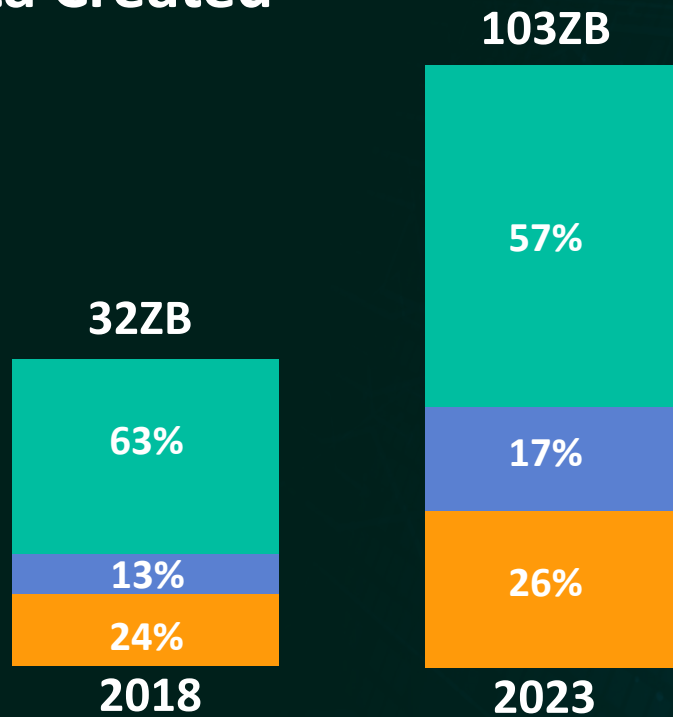
By 2023, >90% of data created will be generated by machines

Source: Applied Materials, SEMICON West, AI Design Forum, July 2019

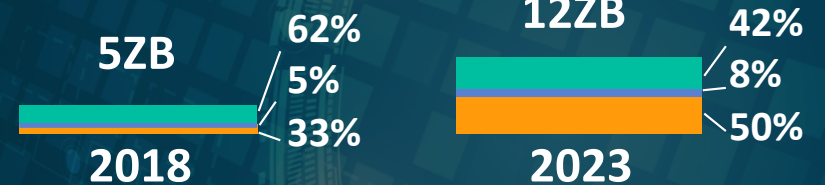
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'There's Gold in Them Thar' Bits

Data Created



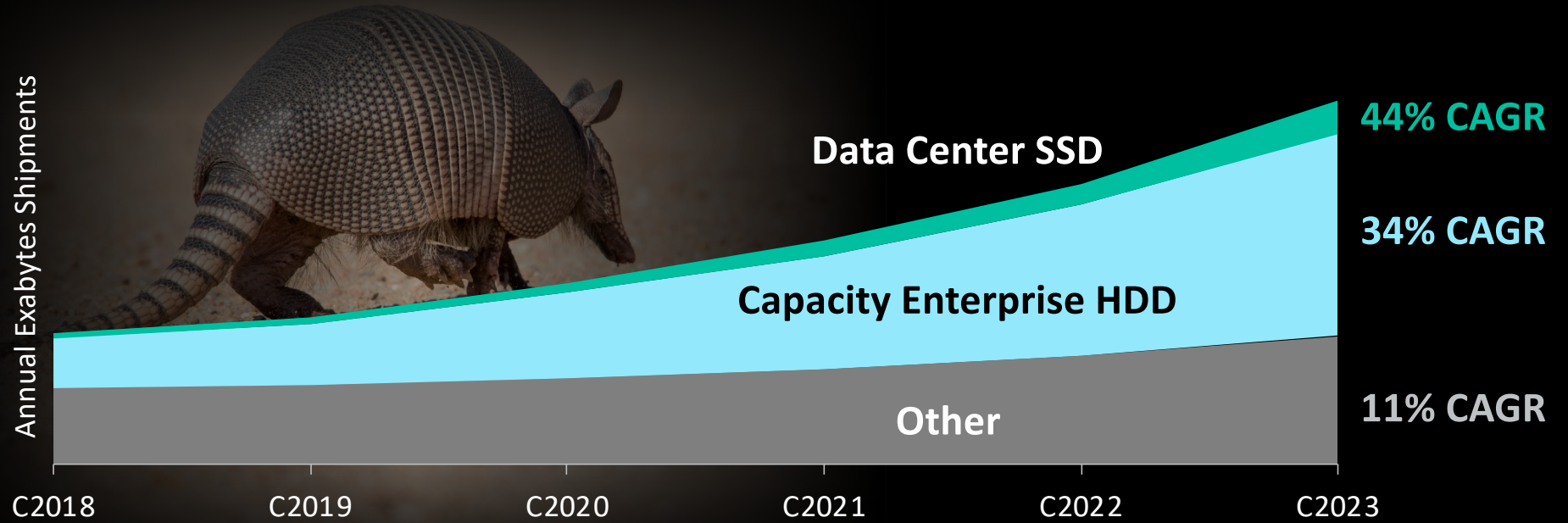
Data Stored



■ Core
 ■ Edge
 ■ Endpoint

Sources: 1) IDC Global DataSphere Forecast, 2019-2023: Consumer Dependence on the Enterprise Widening, January 2019, DOC #US44615319; 2) IDC, Worldwide Global StorageSphere Installed Base Forecast, 2019-2023: The Global StorageSphere Installed Base by Core, Edge, and Endpoint, April, 2019, DOC #US45009319; Percentages and numbers approximate, rounded off to whole number

Storage Darwinism



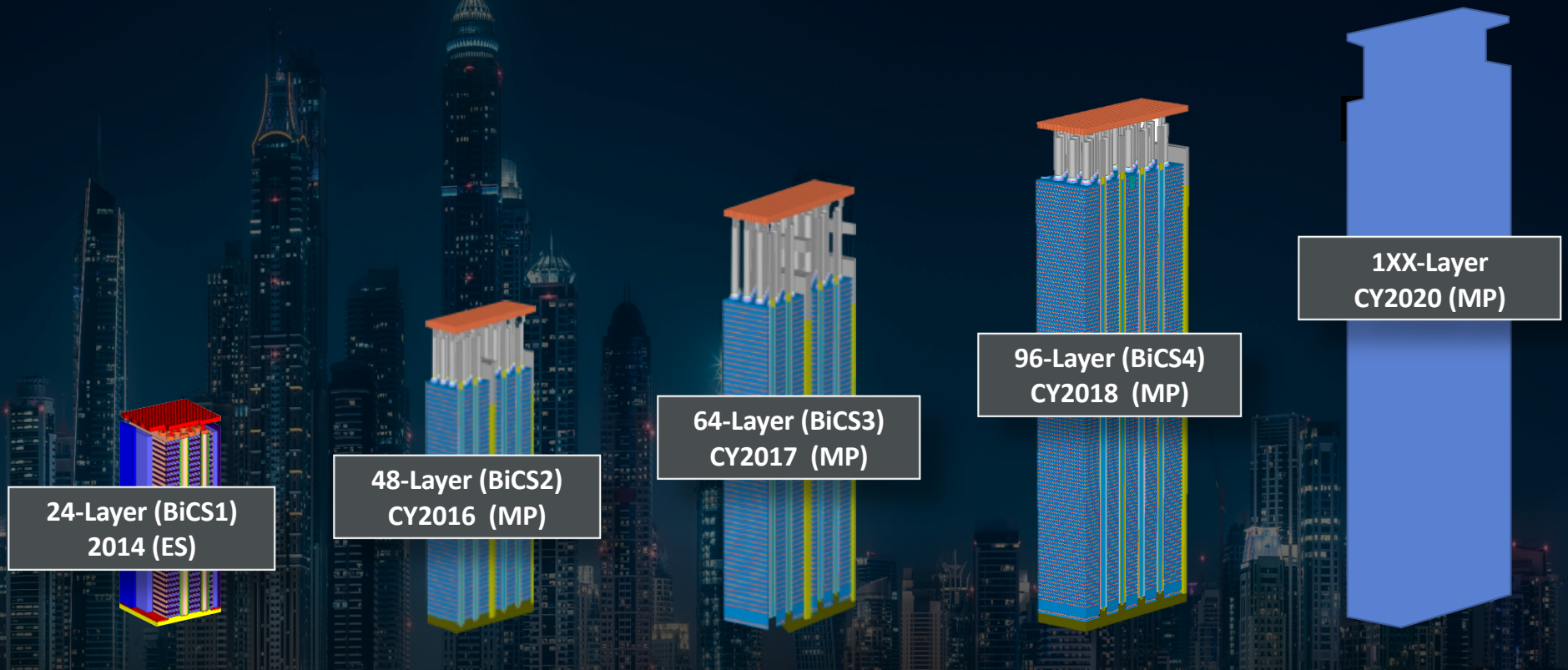
Don't Scale, Don't Survive!

Source: Western Digital

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Gordon Moore meets IM Pei

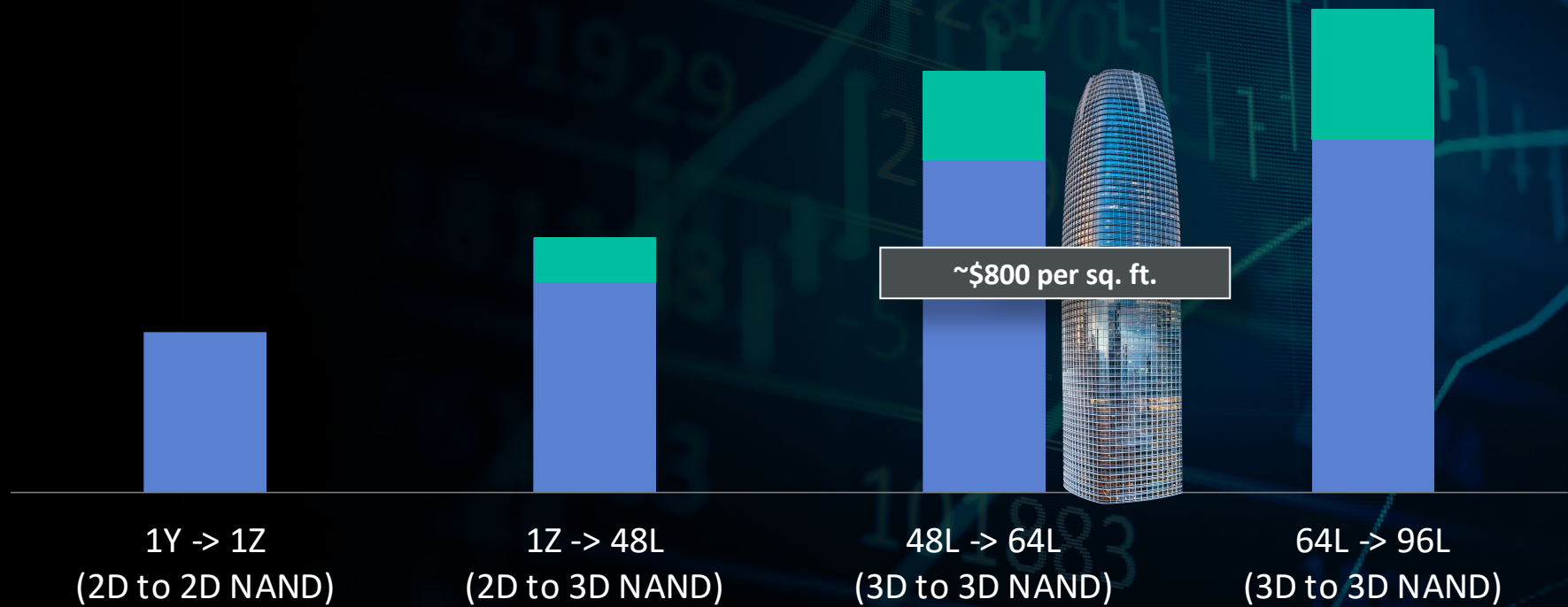


3D NAND: Scaling in the Z-Direction

Capital Intensity of Industry 3D NAND Generations

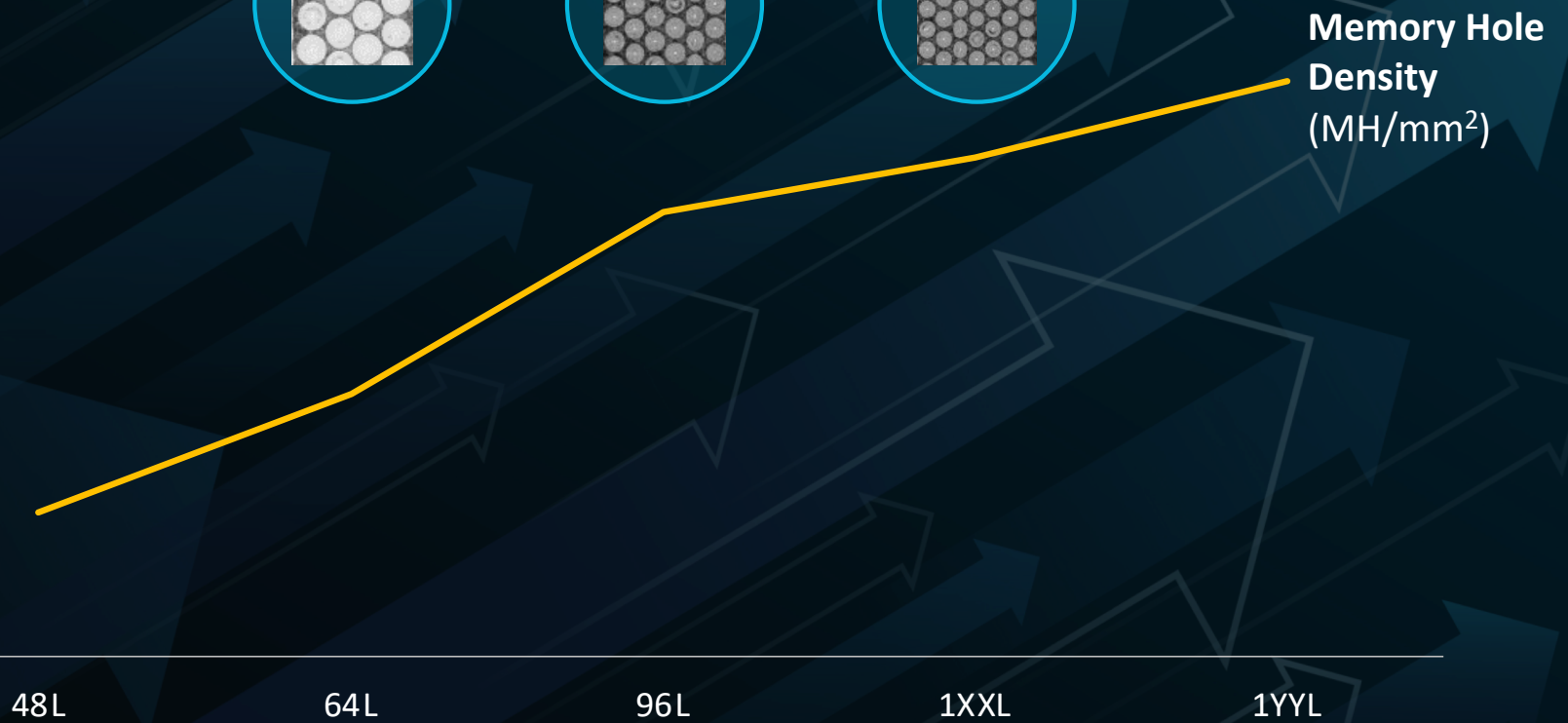
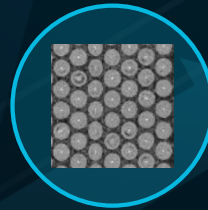
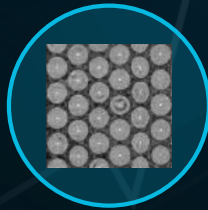
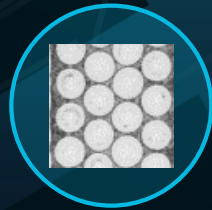
Capital Intensity
(Capex \$M / 1% bit growth)

■ Estimate range

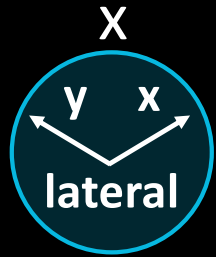


Sources: Western Digital Estimates; Salesforce Tower cost per sq. ft., https://en.wikipedia.org/wiki/Salesforce_Tower

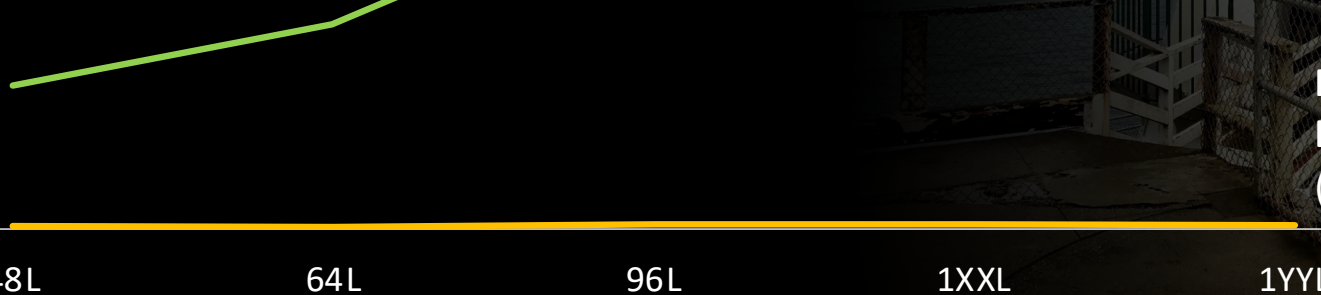
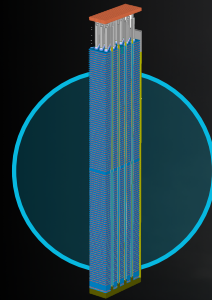
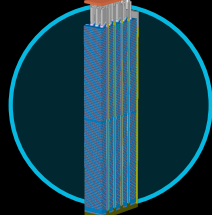
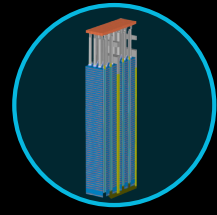
Honey, I Shrunk the Memory Holes



Scaling gets Vertigo



(Cell/mm²)xN



N = 48L

64L

96L

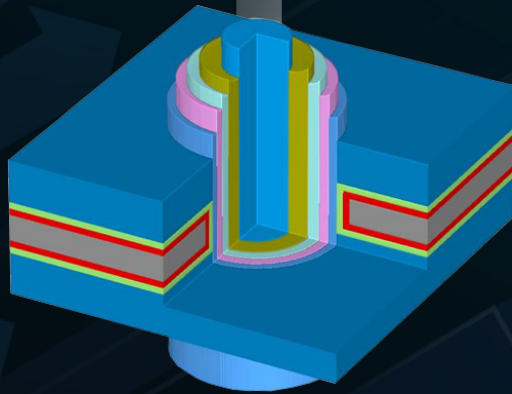
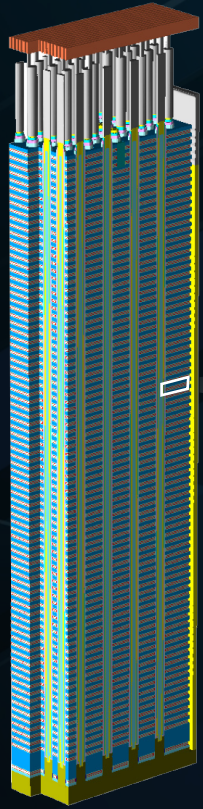
1XXL

1YYL

Three's Company

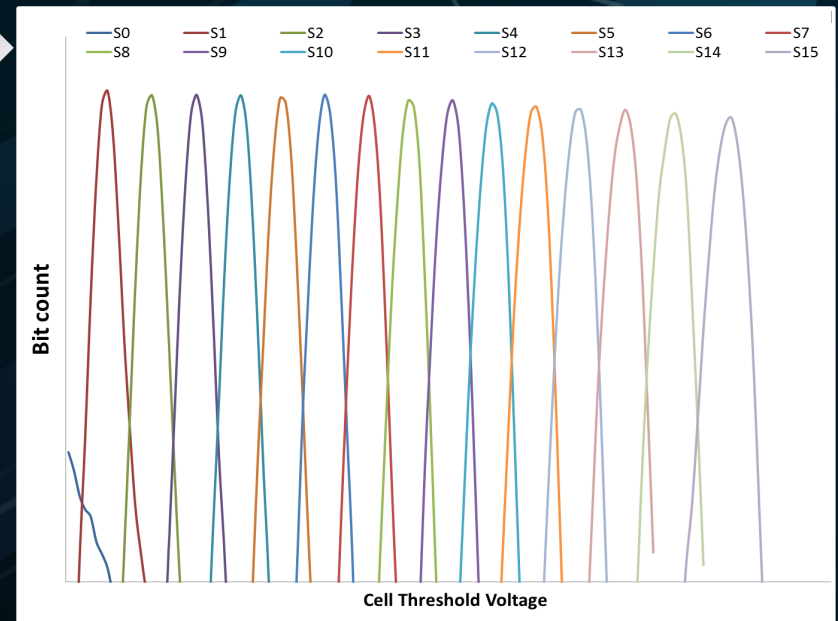


It is all Quite Logical: 4 Bits Per Cell



Single memory cell

16 Data Levels Per Cell

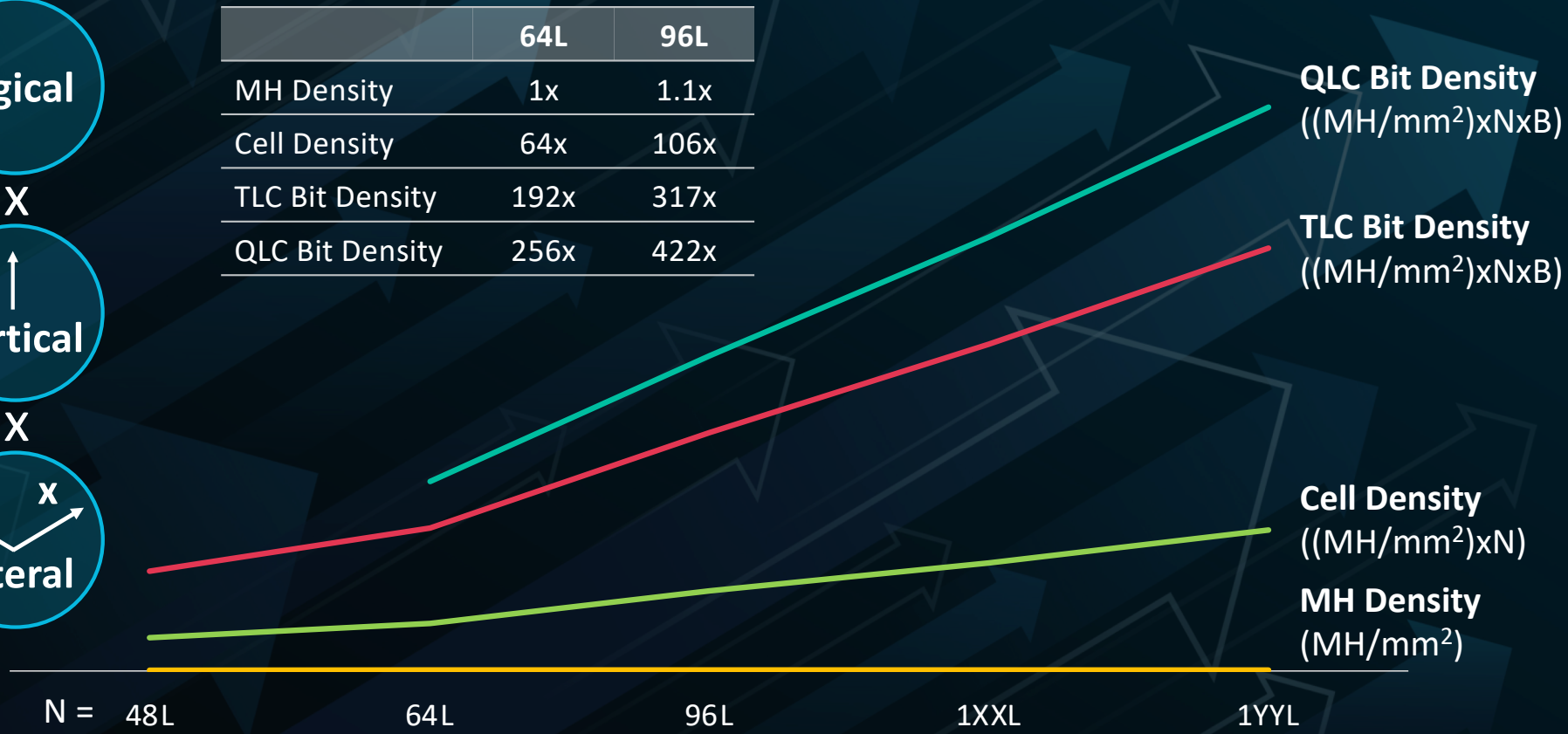


SSD based on 1.33Tb X4 (QLC)

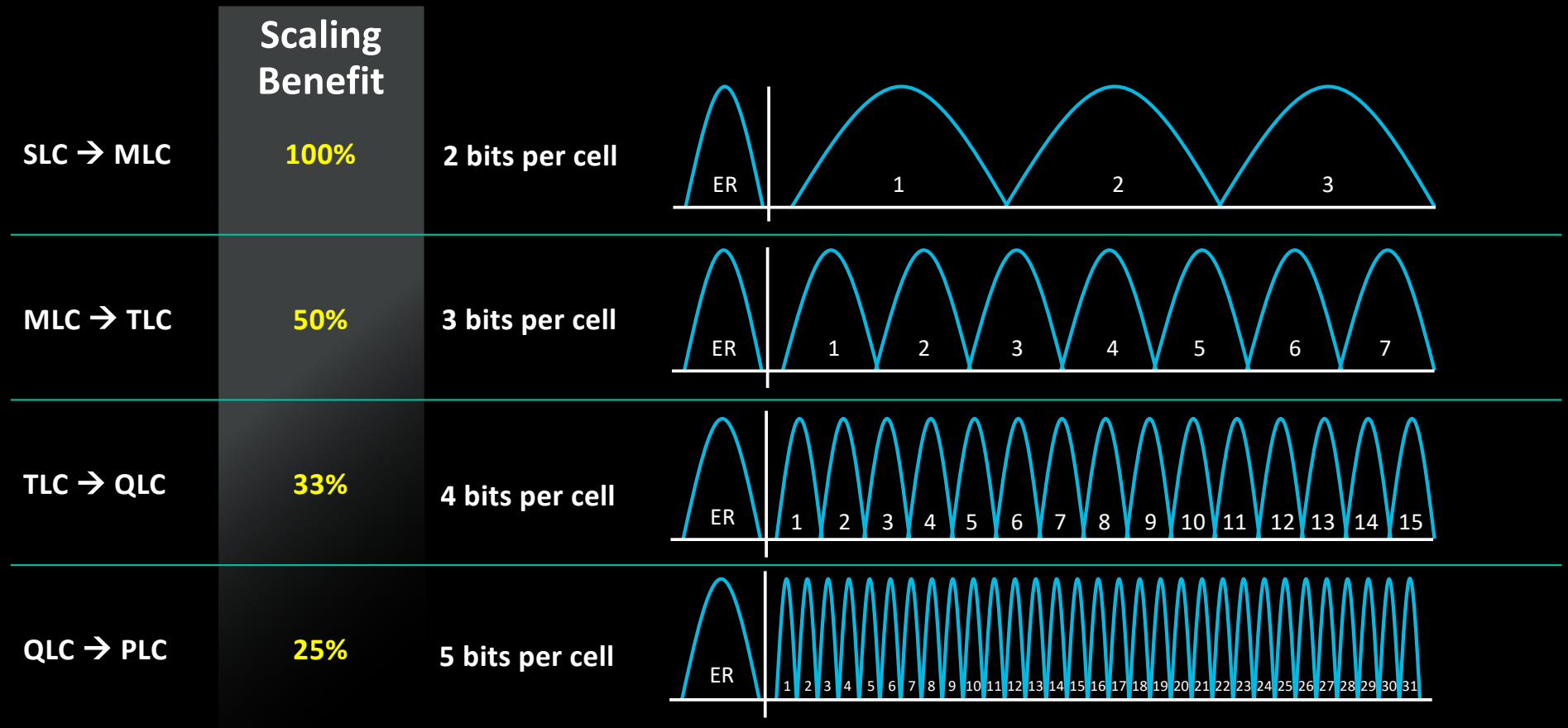
QLC: The New Logical Scaling Frontier



	64L	96L
MH Density	1x	1.1x
Cell Density	64x	106x
TLC Bit Density	192x	317x
QLC Bit Density	256x	422x

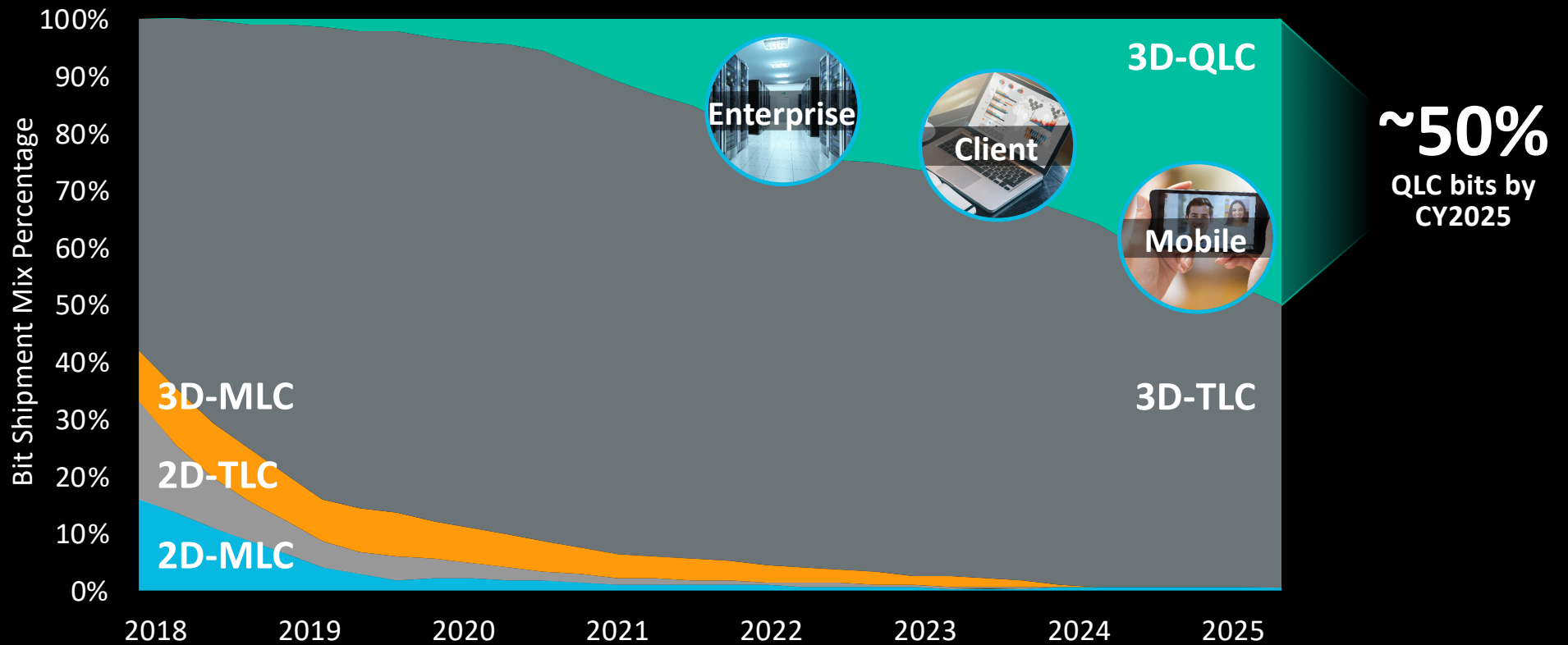


Too Much of a Good Thing



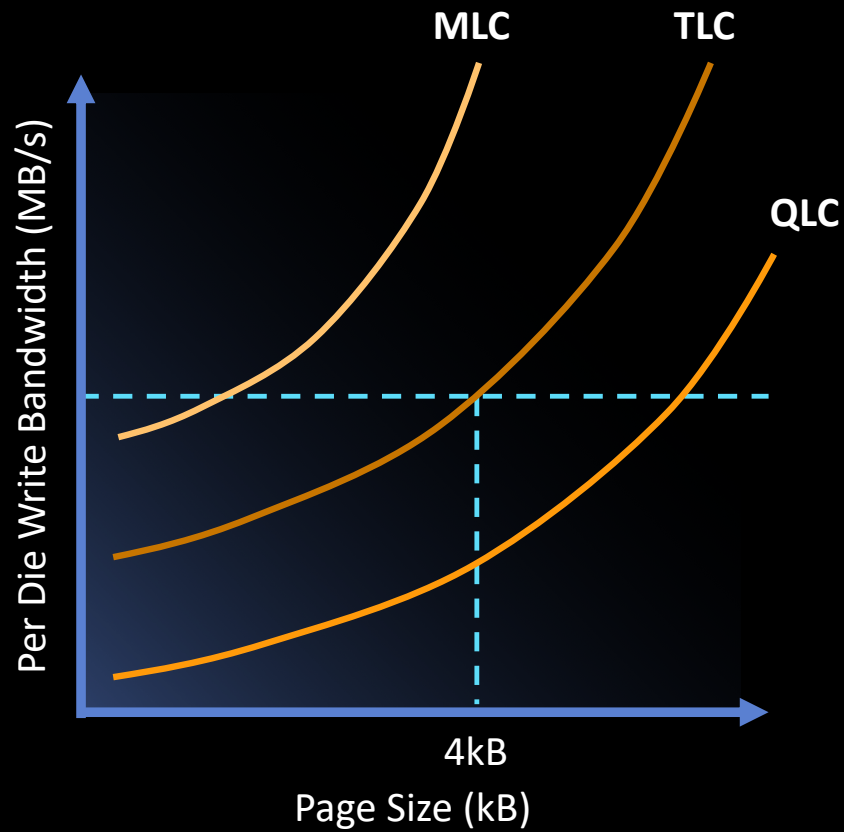
Fantastic 4: The Rise of QLC

Assuming same adoption rate as MLC→TLC

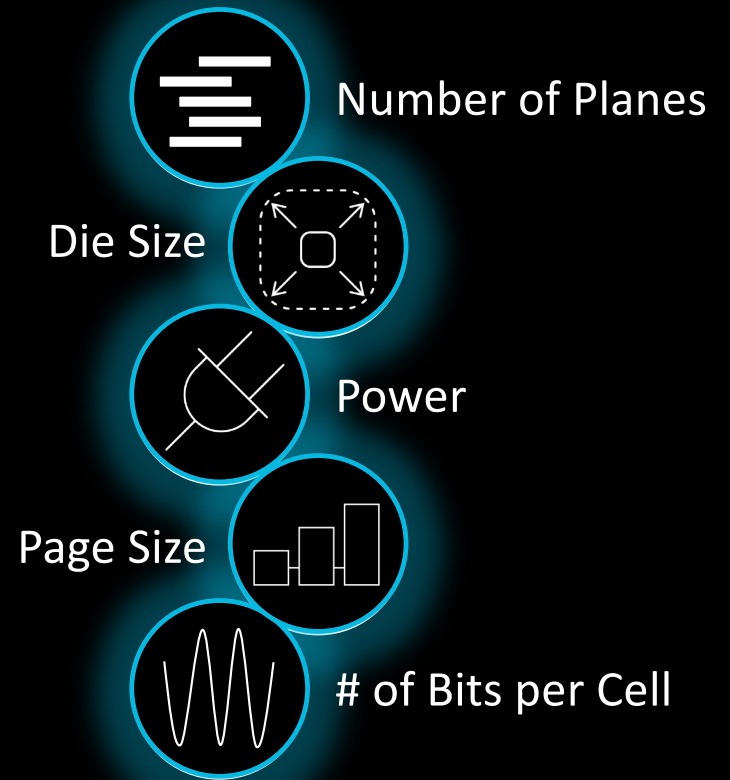


Sources: 1) Western Digital Data. 2) Forward Insights, NAND Quarterly Insights Q2/19, May 2019

'Something's Gotta Give'



Design Parameters



The Data Storage Approach for the Zettabyte Age

Is There a Problem?

01100111000
00101100101
01100101100
00110100110
10100110100

Enables scaling

QLC



Cost/TCO benefit



Great access/read performance



Write limitations



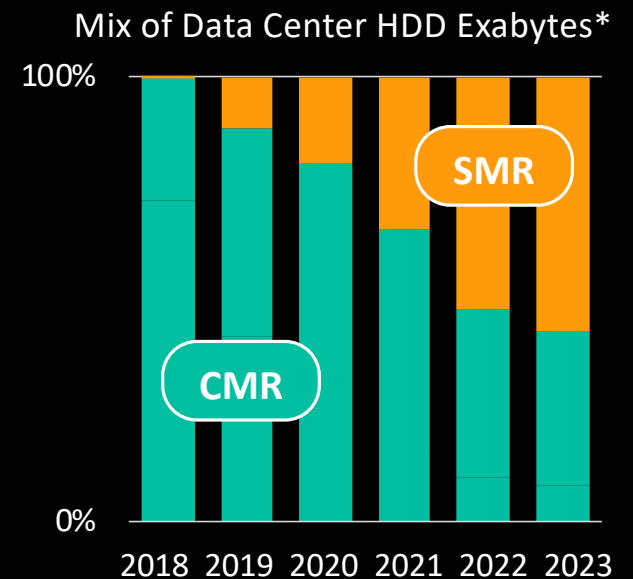
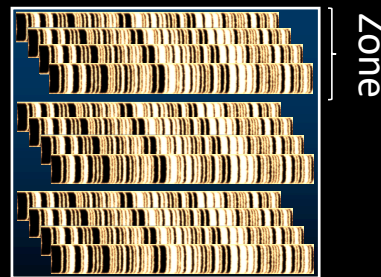
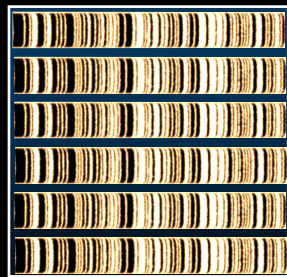
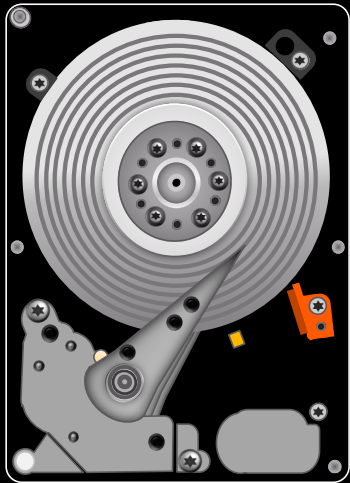
We Have Seen This Movie Before

	ZNS QLC	SMR HDD
 Enables scaling	✓	✓
 Cost/TCO benefit	✓	✓
 Great access/read performance	✓	✓
 Write limitations	✗	✗

What is SMR?

Shingled Magnetic Recording (SMR) and HDD scaling

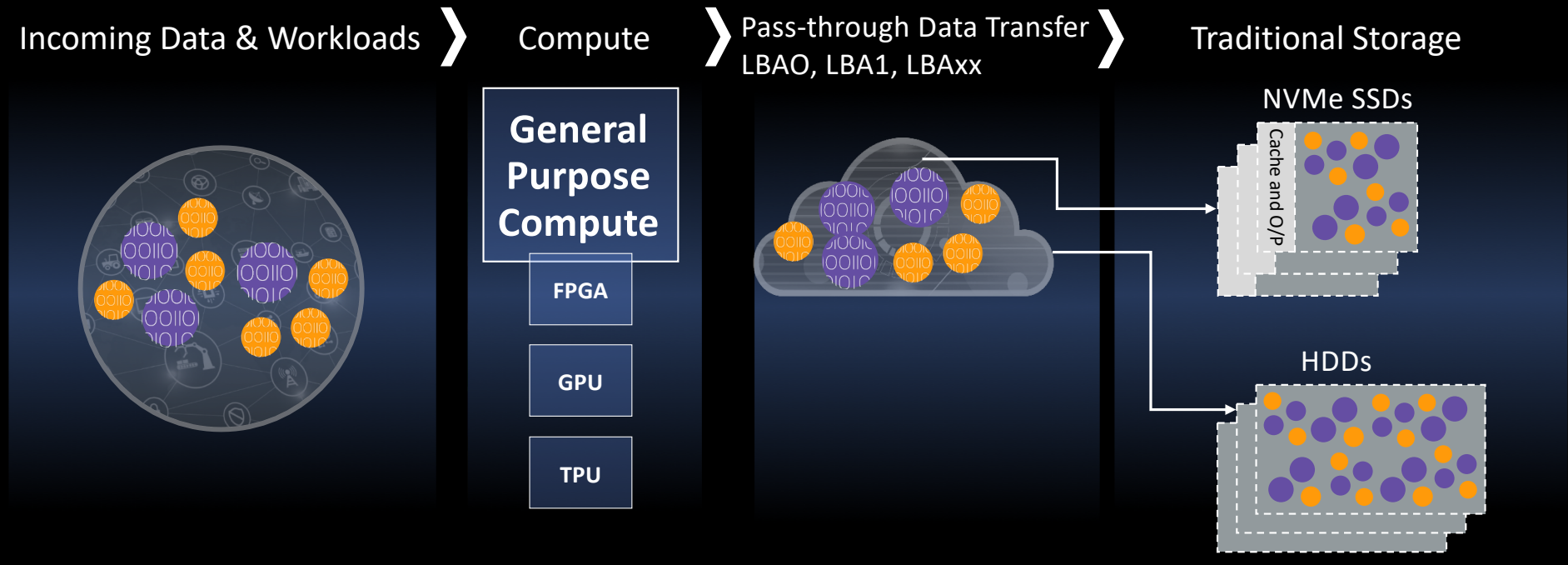
- Scale physically by adding disks, enlarging disks, and narrowing tracks
- Scales “logically” by shingling more tracks per zone
- SMR ecosystem enables access to highest capacities



* Source: Western Digital internal modeling data , February /April 2019

Evolution of the Existing Data Center

Data growth powers the need for purpose-built solutions



Storage architectures must become purpose-built

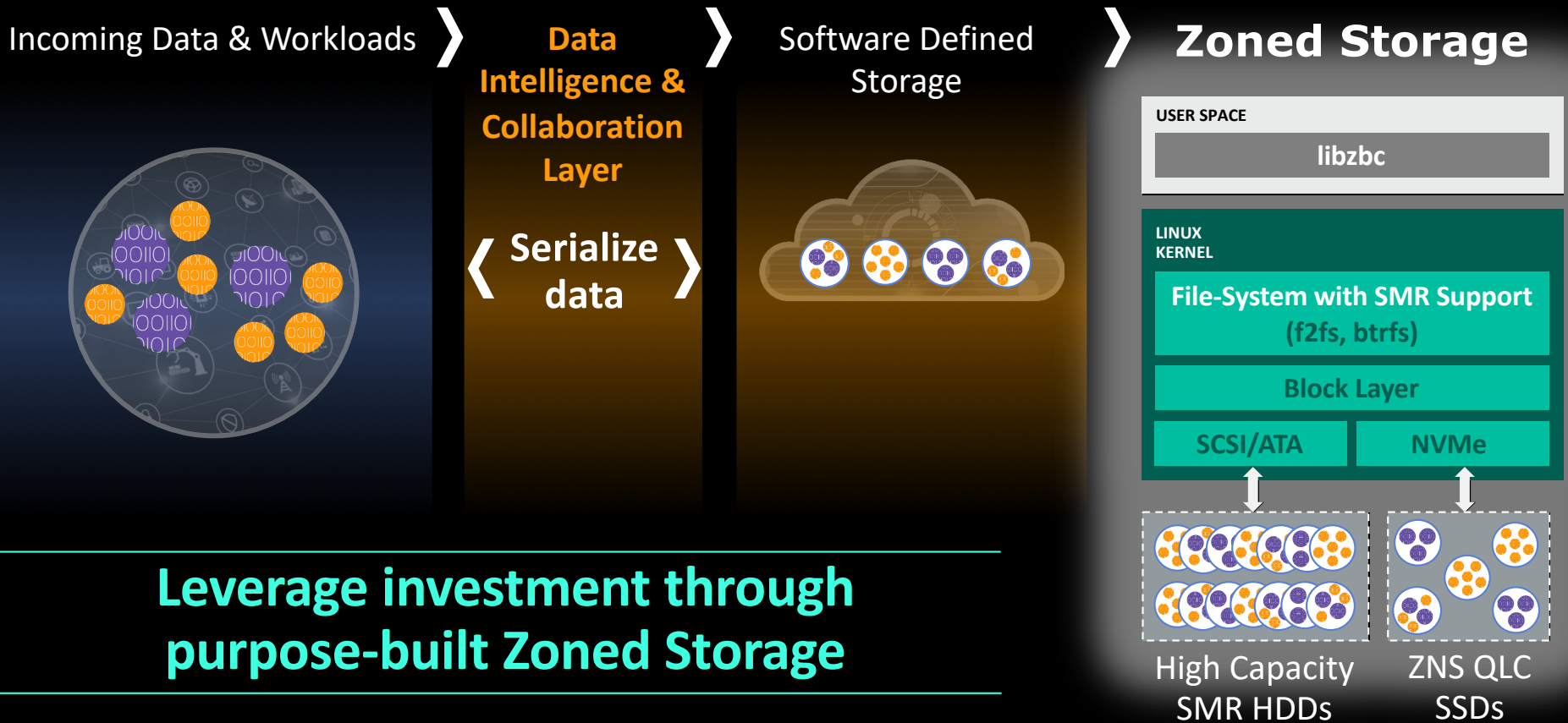


Zoned Storage

Data-Centric Architecture for the Zettabyte Age

Re-architecting for the Zettabyte Age

Zoned storage enables efficiency and intelligent data placement



Zoned Namespaces Enables Intelligent, Lean SSDs

ZNS provides host with system-level intelligence for data placement

Up to
8x
DRAM reduction



Up to
10x
Overprovision reduction

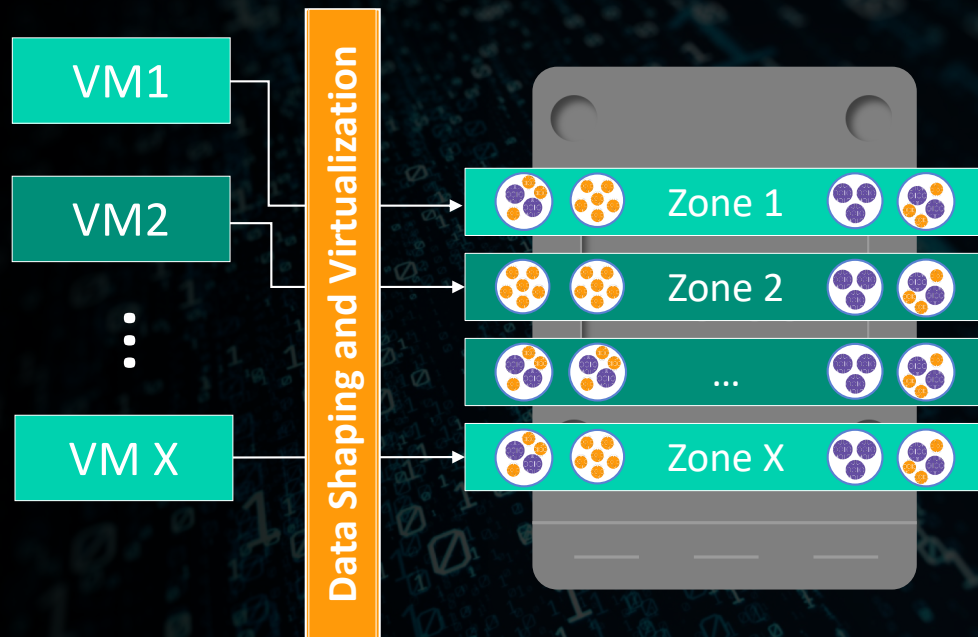
Source: Western Digital internal modeling data, 2019

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Zoned Namespaces Enables Intelligent, Lean SSDs

ZNS provides host with system-level intelligence for data placement



Every virtual machine can be assigned a zone

Zoned Storage Enables Zettabyte Scale

	ZNS QLC	SMR HDD
 Enables scaling	✓	✓
 Cost/TCO benefit	✓	✓
 Great access/read performance	✓	✓
 Write limitations management	✗	✗
 Data orchestration with enhanced control	✓	✓

The Power of Data at Zettabyte Scale

Zoned Storage enables tomorrow's data needs

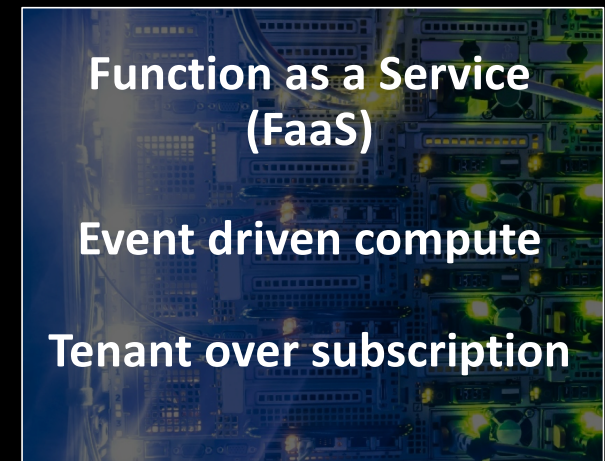
Sensor Data Analysis



Artificial Intelligence/ Machine Learning



Server-less



**Unified approach to manage naturally
serialized data at scale**

**Enables predictable
performance**

Leading the Way with Zoned Storage

ZNS NVMe SSD Platform

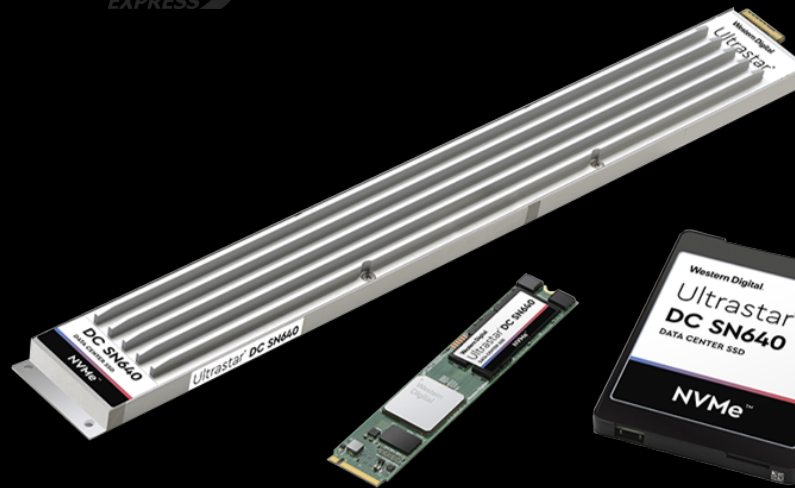
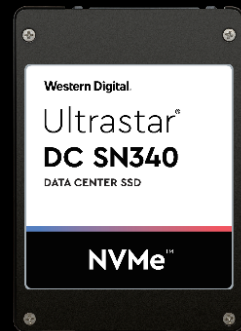


Leading the Way with Zoned Storage

ZNS NVMe SSD Platform

Western Digital
ZNS NVMe SSD
Development Platform

New Purpose-built NVMe SSDs



Leading the Way with Zoned Storage

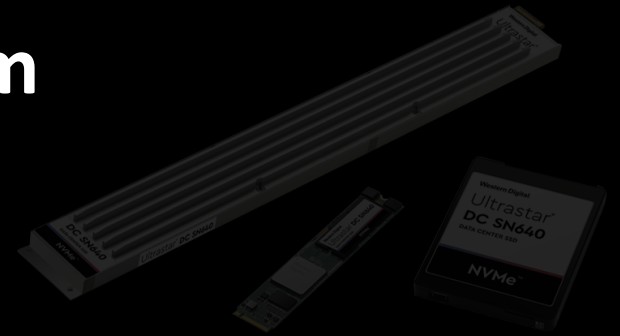
ZNS NVMe SSD Platform

New Purpose-built NVMe SSDs

SMR HDD Platform



nvm
EXPRESS



Leading the Way with Zoned Storage

ZonedStorage.io Home About Documentation ▾

ZonedStorage.io

Zoned Storage is a class of storage devices that enables host and storage devices to cooperate to achieve higher storage capacities, increased throughput, and lower latencies. The zoned storage interface is available through the SCSI Zoned Block Commands (ZBC) and Zoned Device ATA Command Set (ZAC) standards on Shingled Magnetic Recording (SMR) hard disks today and is also being adopted for NVMe Solid State Disks with the upcoming NVMe Zoned Namespaces (ZNS) standard.

[Learn more about Zoned Storage Devices »](#)

[Learn more about Linux® Software Support »](#)

QUICK START GUIDE

Learn how to setup a Linux system supporting zoned block devices and start experimenting with physical and emulated zoned storage devices.

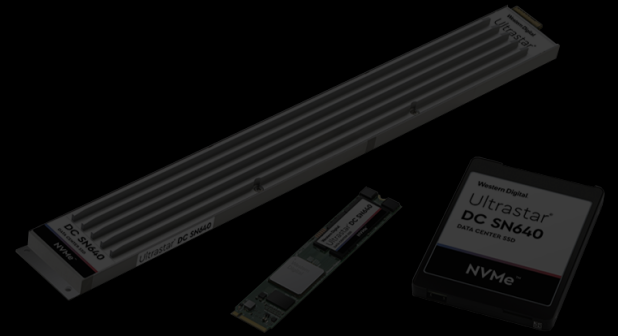
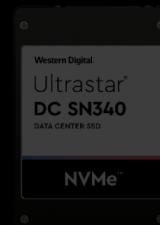
[Get Started »](#)

Leading the Way with Zoned Storage

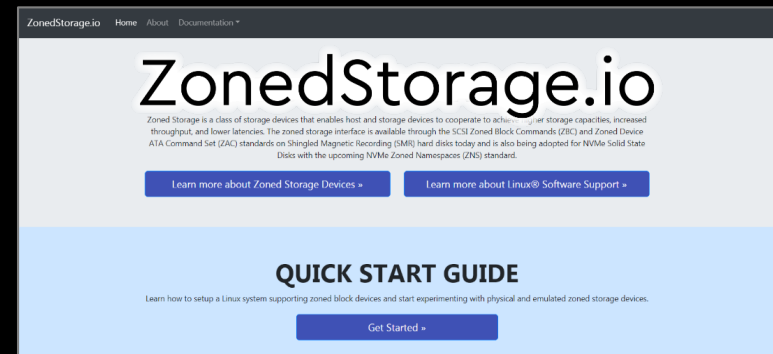
ZNS NVMe SSD Platform



New Purpose-built NVMe SSDs



SMR HDD Platform



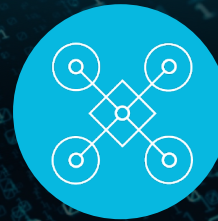
Zoned Storage

SMR Built and supported via open source

ZNS Extends Flash Scaling & QLC for the Data Center



Improves
TCO



Increases
Data Storage



Based on
Industry Standards

Innovation Through Intelligent Data Placement



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