THE DEMISE OF SLC IN THE ENTERPRISE

Bernie Rub

SMART STORAGE™ SYSTEMS

Making NAND Better

INTRODUCTION

- SLC is no longer the best solution for write intensive SSDs
- There are emerging MLC solutions with better specs and lower cost
- Will show how to compare SLC and MLC solutions and quantify the MLC advantage
- Similar analysis suggests that TLC will replace MLC for entry level SSDs

IT'S ALL ABOUT DENSITY!

- It's the density, stupid!

- MLC density is driving innovation to displace SLC

HISTORICAL PERSPECTIVE

- Decades of innovations to increase the density of storage
- Not all innovations are readily accepted
- Ultimately the higher density solutions tend to prevail

HISTORICAL PERSPECTIVE (2)

United States Patent [19]

Rub et al.

[11] **Patent Number: 4,503,420**

[45] **Date of Patent: Mar. 5, 1985**

[54] **ARRANGEMENT FOR ENCODING AND DECODING INFORMATION SIGNALS**

[75] Inventors: **Bernardo Rub**, Marlborough; **Lih J. Weng**, Lexington, both of Mass.

[73] Assignee: **Digital Equipment Corporation**, Maynard, Mass.

[21] Appl. No.: **375,931**

[22] Filed: **May 7, 1982**

[51] **Int. Cl.**[3] **G11B 5/09**

[52] **U.S. Cl.** ..... **340/347 DD**; 360/40

[58] **Field of Search** ..... 340/347 DD; 360/39–44

[56] **References Cited**

U.S. PATENT DOCUMENTS

4,020,282	4/1977	Halpern	360/40 X
4,032,979	6/1977	Rice	360/40

OTHER PUBLICATIONS

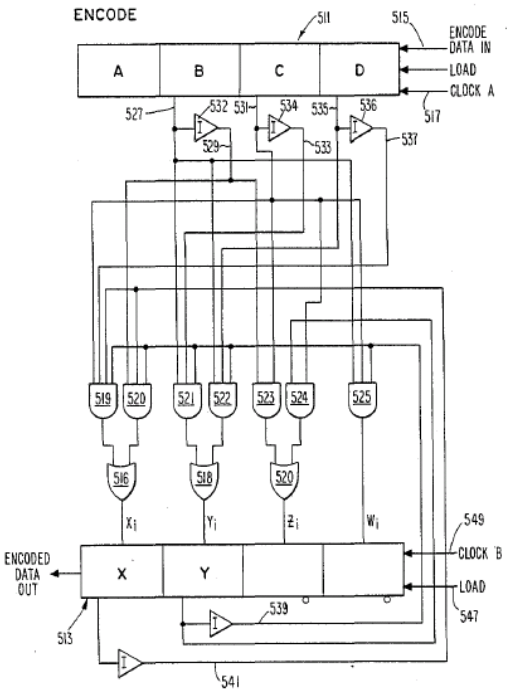
Horiguchi et al., An Optimization of Modulation Codes in Digital Recording, IEEE Transactions on Magnetics, vol. MAG–12, No. 6, 11/1976, pp. 740–742.

Primary Examiner—T. J. Sloyan
Attorney, Agent, or Firm—Vincenzo Pitruzzella; Albert Cefalo; Ronald Reiling

[57] **ABSTRACT**

The present invention provides translation circuitry, which in one mode of operation acts to encode variable length data words into fixed rate data coded words for use with a communication channel, or a recording means, such as a magnetic recording medium and which in another mode of operation acts to decode the coded words to data words. The translation circuitry functions such that in an encoding operation, the second and third bits of a three-bit coded word respectively have the same binary values as the first and second bits of the data word, which the coded word represents and the second and sixth bits of a six-bit coded word respectively have the same binary values as the third and fourth bits of the data word which the coded word represents.

11 Claims, 10 Drawing Figures



1,7 RLL boosts density by 33%

- Deemed complex in 1982 → 8 Flip-Flops, 10 gates

HISTORICAL PERSPECTIVE (3)

Constant Density Recording Boosts Capacity by 30% to 40%

- Electronic Design, November 13, 1986 (Mark Young):
- …constant-density recording has been little used because of its high cost and the difficulty of putting it to work.
- Among those difficulties are the requirement for a phase-locked loop (PLL) capable of operating at any one of several different frequencies…

LESSONS LEARNED

- Not surprisingly, it didn't take long for 1,7 RLL Codes and Constant Density Recording to become widely adopted

- **Lessons Learned:**
- Tremendous innovation to store data more efficiently and increase storage density
- More efficient solutions usually prevail, even if they appear complex initially
- Complex today → simple tomorrow

EARLY ADOPTION OF SLC MAKES SENSE

- SLC has been the media of choice for write intensive applications
- SLC spec advantages appear compelling:
  - x33 Endurance: 100K vs. 3K
  - x3 Program Speed: Tprog = 0.5ms vs. 1.5ms
- But history suggests that the denser solution will prevail
- How?

ANALYSIS OF WRITE CAPABILITY

- Drive Writes Per Day (DWPD)
  - Amount of writing that can be sustained over the entire product life
  - Normalized to Drive Capacity
  - Assume random writes uniformly distributed over entire logical address space. This is much more stringent than sequential writing
- Typical SSD specs:
  - SLC: 25 DPWD
  - MLC: <1 DWPD

DRIVE WRITES PER DAY

$$DWPD = \frac{Endurance \bullet (1+OP)}{DaysPerLife \bullet WA}$$

$$OP = Overprovisioning = \frac{Physical\ Capacity}{Logical\ Capacity} - 1$$

WA = Write Amplification

WRITE AMPLIFICATION

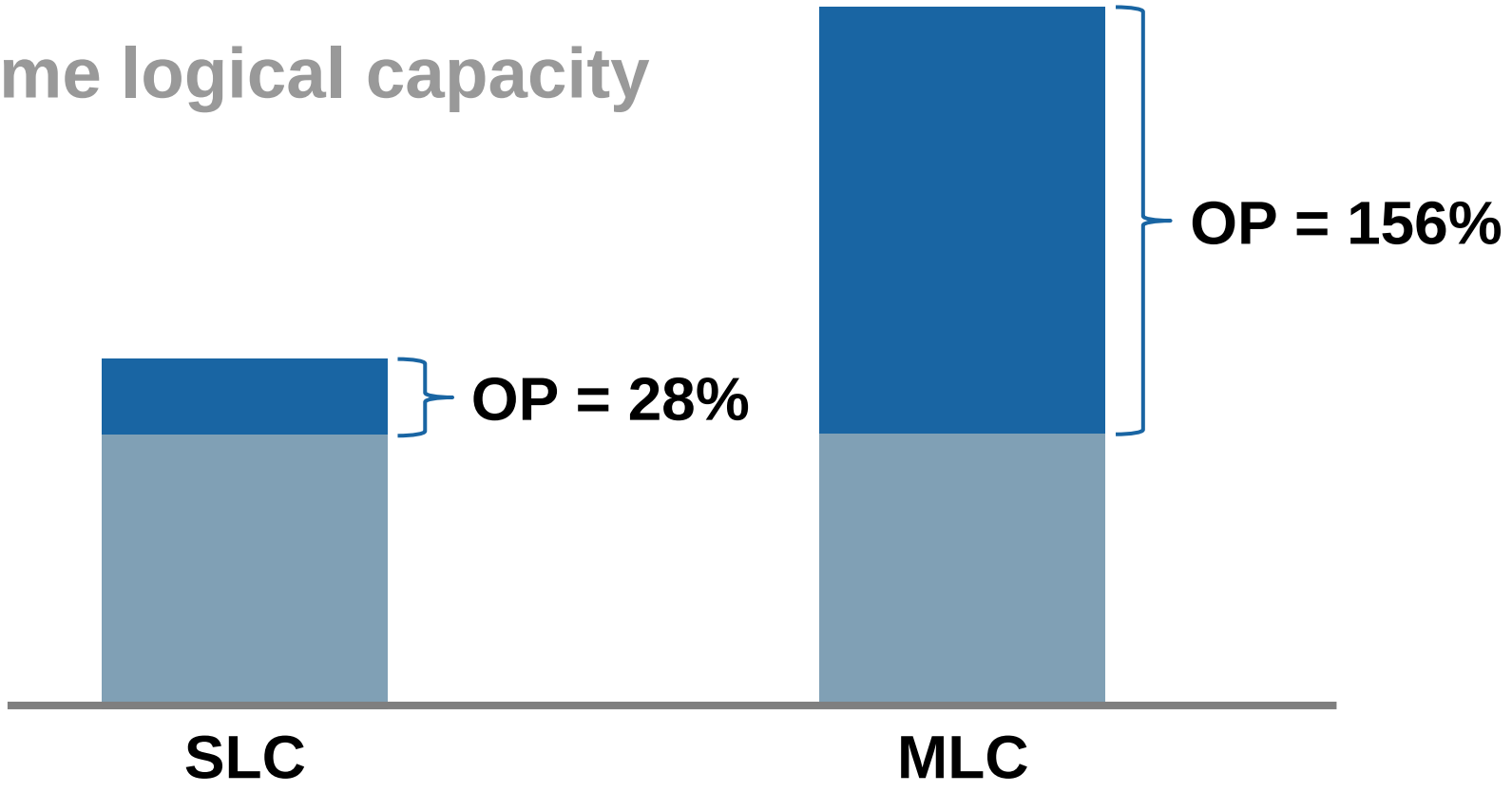
- Write Amplification is a measure of the extra writing required for garbage collection and other flash management functions
- Expressed as a ratio of the amount of data written to flash to the amount of data written by the host

$$\text{Write Amplification} = \frac{\text{Data Written to Flash}}{\text{Data Written by Host}}$$

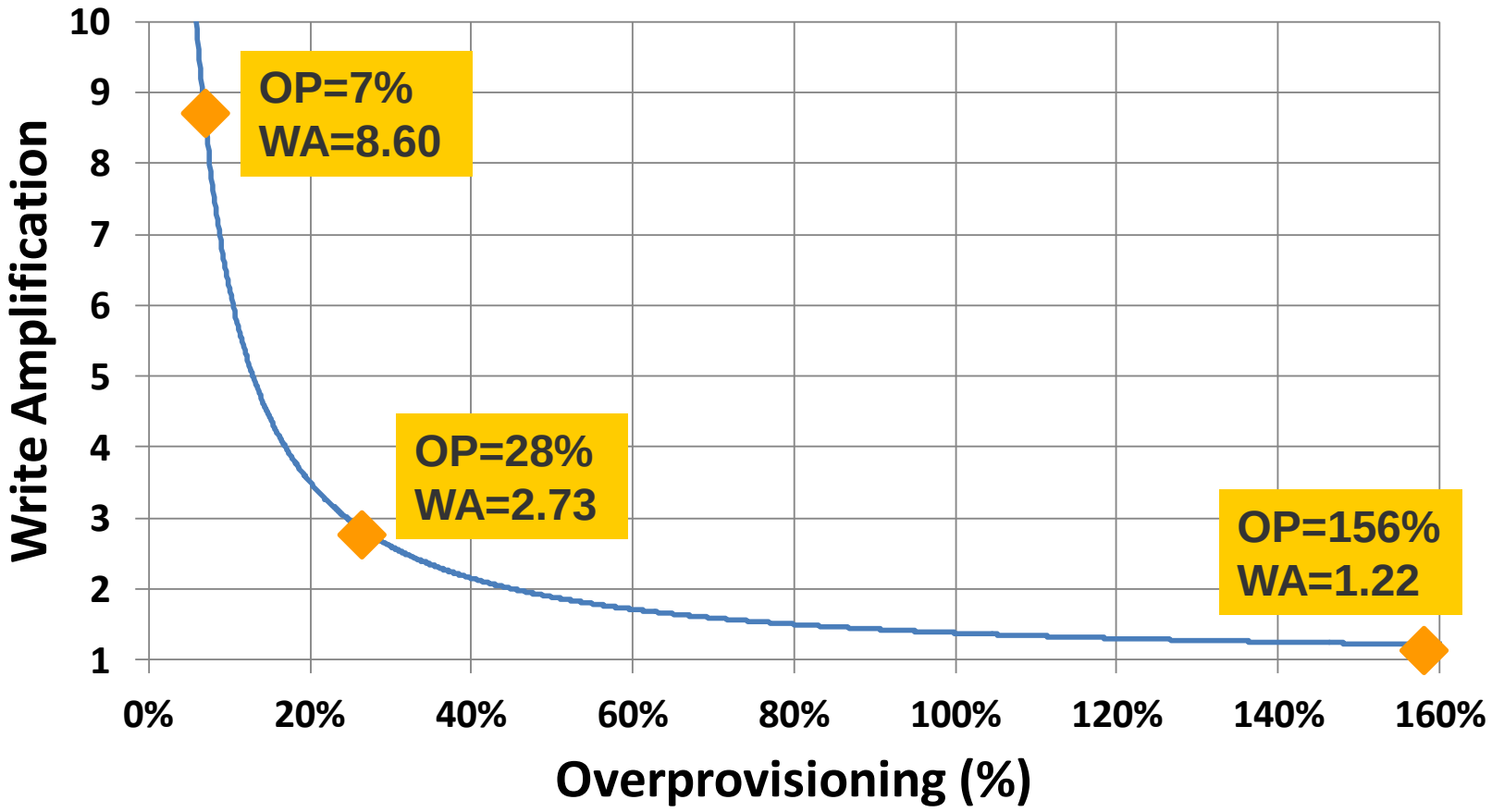
DENSITY ENABLES MUCH HIGHER OP

Same number of cells

Same logical capacity



WRITE AMPLIFICATION VS. OP



COMBINED BENEFIT OF OP AND WA

$$DWPD = \frac{Endurance \cdot (1 + OP)}{DaysPerLife \cdot WA}$$

	SLC	MLC
1+OP	1.28	2.56
WA	2.73	1.22
(1+OP) / WA	0.47	2.10

X 4.5

SMART STORAGE SYSTEMS
Making NAND Better

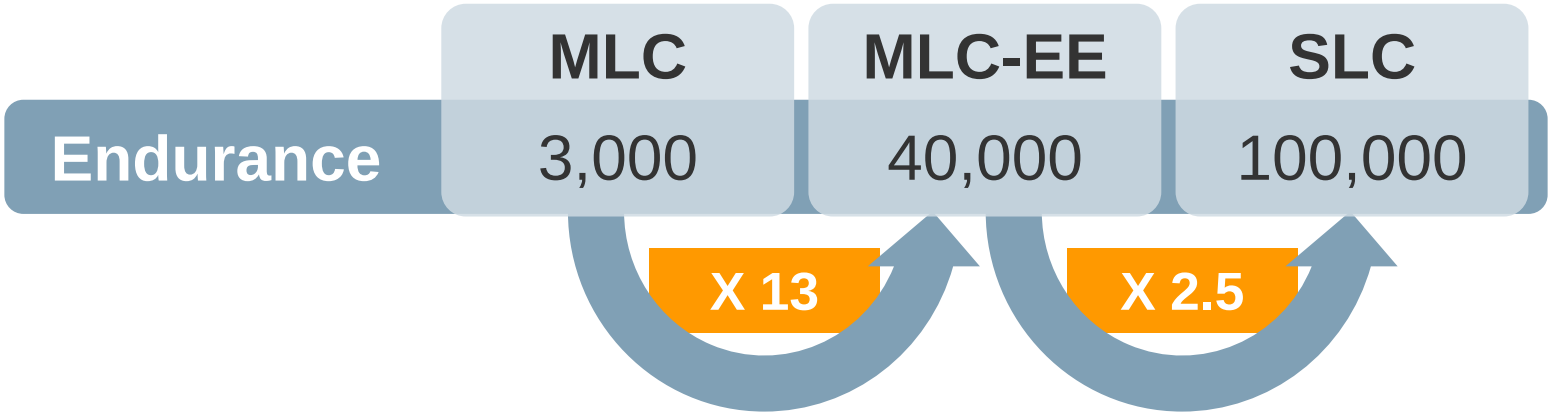
MLC ENDURANCE ENHANCEMENTS

- The gains from Overprovisioning and Write Amplification are not sufficient to bridge the gap between SLC and MLC
- However, the advent of technology to extend the endurance of MLC is a game changer
- For example, technology that won the “Best-of-Show” award at FMS 2011 for extending the endurance of MLC from 3K to 40K PE cycles
- We refer to Endurance Enhanced MLC as MLC-EE

SMART STORAGE SYSTEMS
Making NAND Better

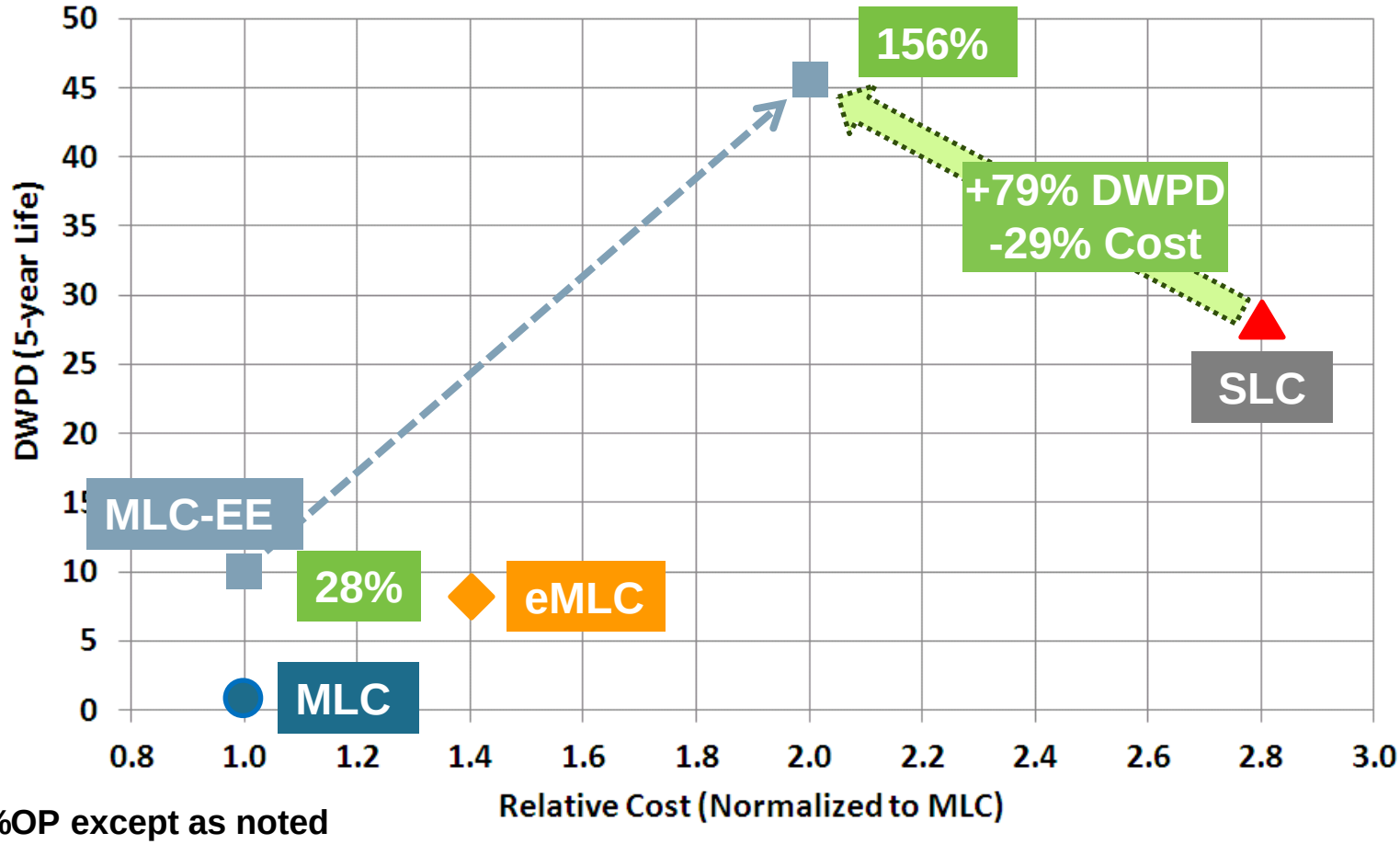
BENEFIT OF MLC ENDURANCE ENHANCEMENT TECHNOLOGY

$$DWPD = \frac{Endurance \cdot (1 + OP)}{DaysPerLife \cdot WA}$$



INNOVATIONS TO EXTEND MLC ENDURANCE SIGNIFICANTLY SHRINK NATIVE SLC ADVANTAGE

CHANGING LANDSCAPE



28%OP except as noted

SMART STORAGE SYSTEMS
Making NAND Better

IT'S NOT ALL ABOUT DENSITY!

- It's the density, stupid!
- And endurance enhancements too!

SMART STORAGE SYSTEMS
Making NAND Better

MLC DELIVERS ONE-TWO PUNCH

29% Cost Savings

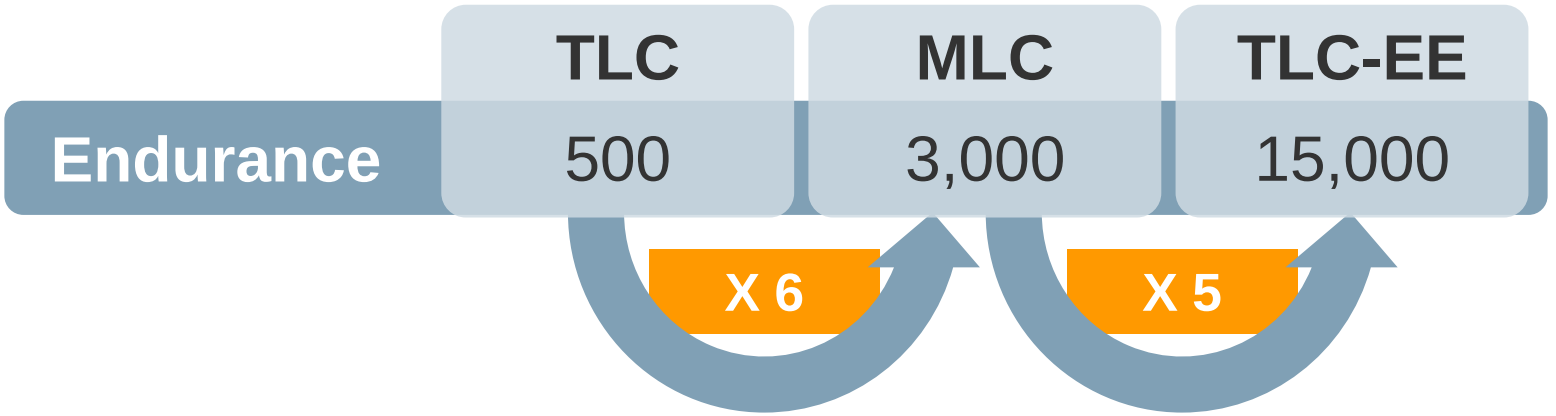
SMART STORAGE SYSTEMS
Making NAND Better

WHAT'S NEXT?

- Continued innovation will push endurance enhancements even higher
- Line of sight for additional factor of 2-3 resulting in endurance gains 25x to 40x
- Opportunities to migrate to denser solutions
- TLC?
- Likely to displace MLC in entry level applications

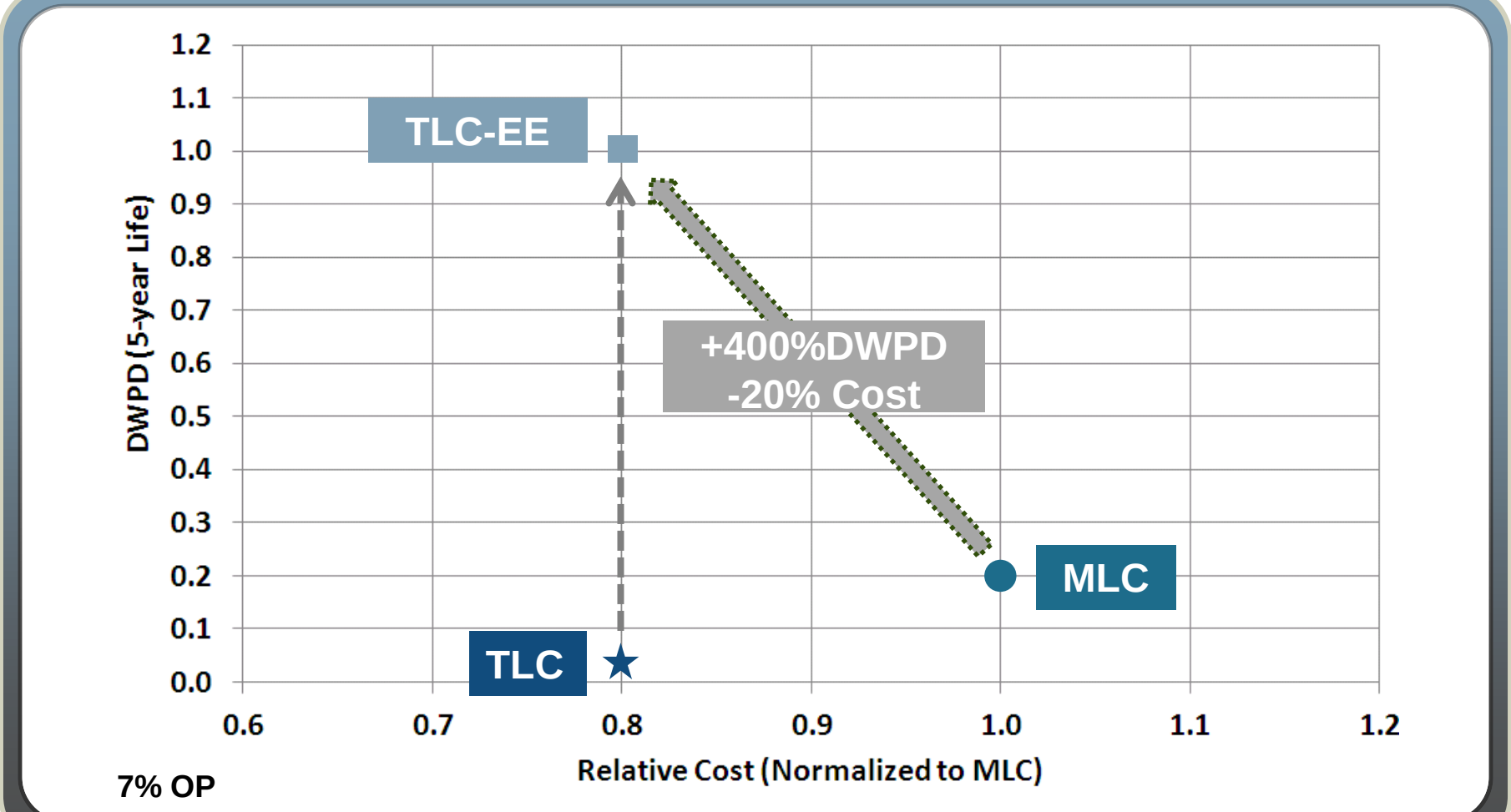
SMART STORAGE SYSTEMS
Making NAND Better

EVOLUTION OF ENTRY LEVEL SSDS



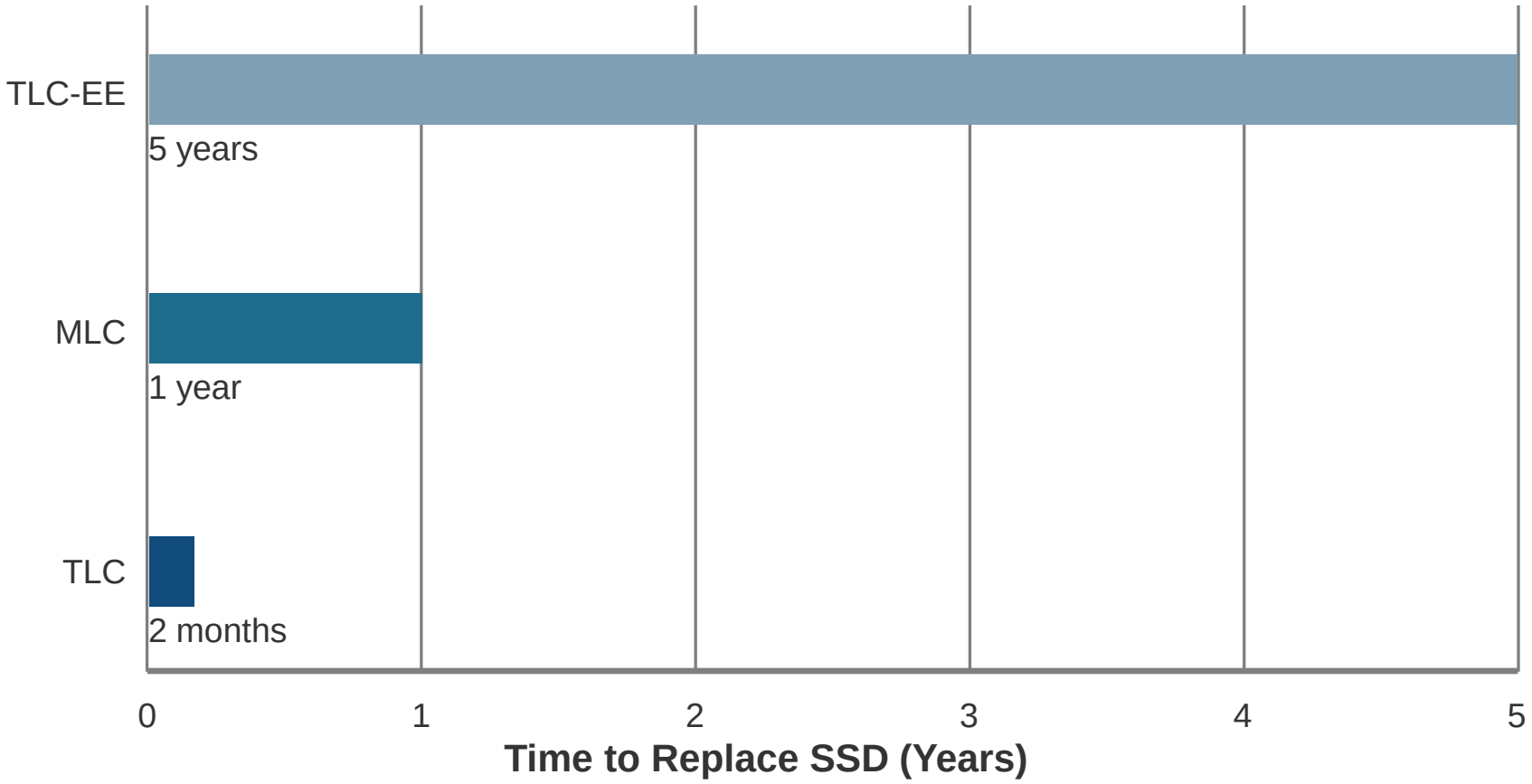
CONTINUED ENDURANCE ENHANCEMENT INNOVATIONS WILL ENABLE COMPELLING TLC SOLUTIONS

ENTRY LEVEL PRODUCTS MOSTLY READ WORKLOADS



SMART STORAGE SYSTEMS
Making NAND Better

CONSUMPTION MODEL TIME TO REPLACE SSD @ 1.0 DWPD



SMART STORAGE SYSTEMS
Making NAND Better

SUMMARY

- SLC is no longer the best solution for write intensive SSDs
- Compelling MLC advantage when combining endurance enhancements and higher overprovisioning
  - +79% Drive Writes per Day
  - -29% Cost
- Future endurance enhancements will enable TLC products vastly superior to today's MLC-based value SSDs

THANK YOU