

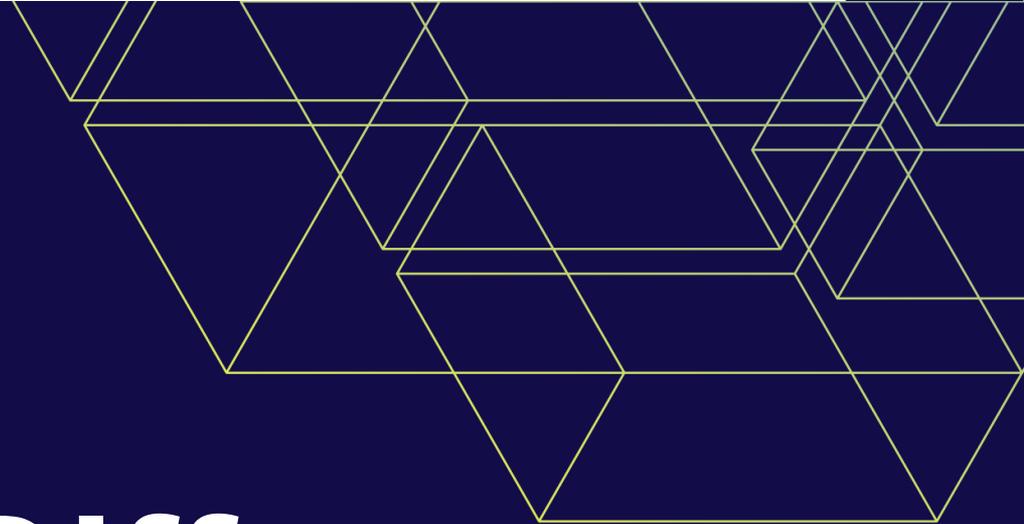


September 23-26, 2019  
Santa Clara, CA

# Emerging Memory Update 2019: What a Difference a Year Makes!

**Jim Handy, Objective Analysis**  
**Tom Coughlin, Coughlin Associates**



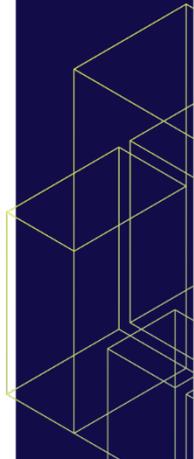


**What A Difference  
A Year Makes!**

# Outline

April 23-26, 2019  
Santa Clara, CA

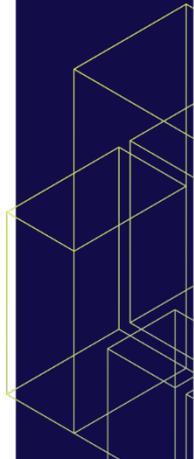
- Emerging Memory Update by Type
- Emerging Memory Support Update
- Hurdles & Outlook



# Outline

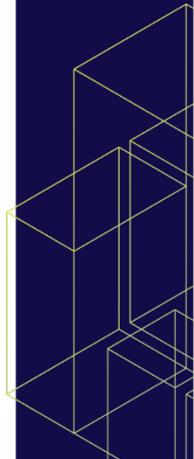
23-26, 2019  
Santa Clara, CA

- Emerging Memory Update by Type
- Emerging Memory Support Update
- Hurdles & Outlook



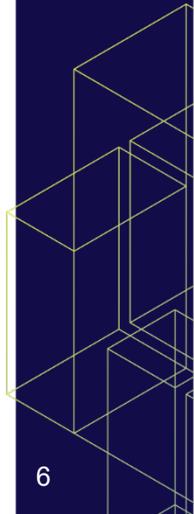
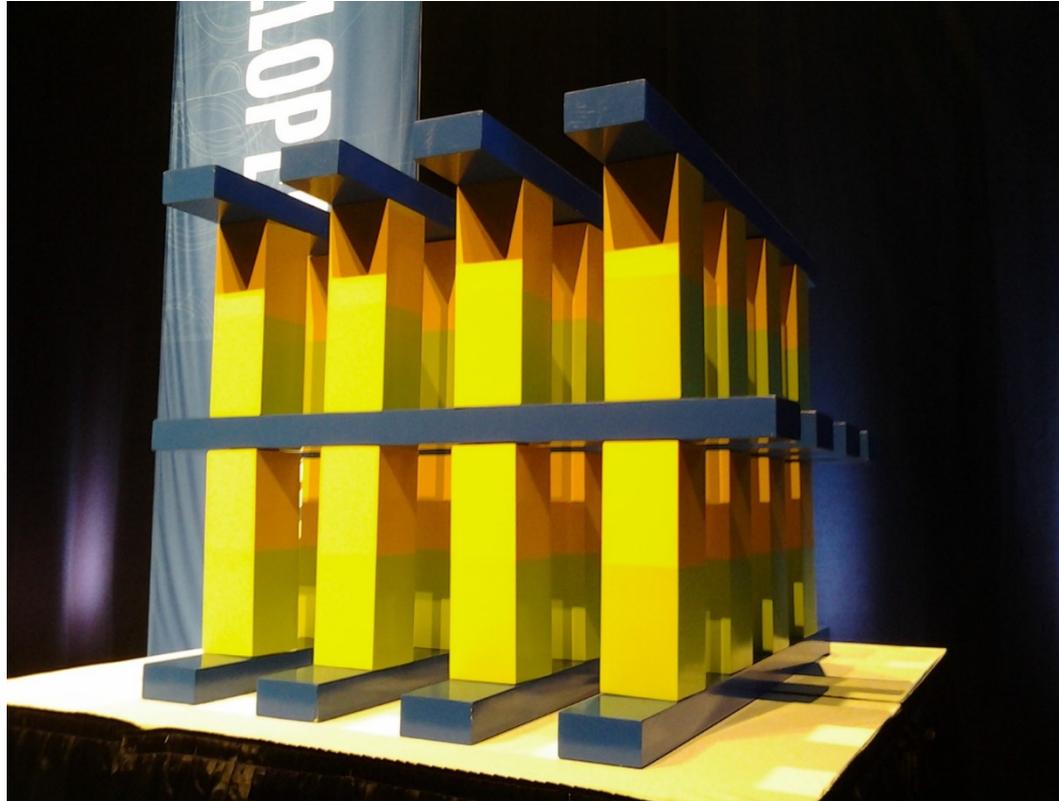
# Emerging Memory Types

- PCM/XPoint
- MRAM
- ReRAM
- FRAM
- Others



# PCM/3D XPoint – “Optane”

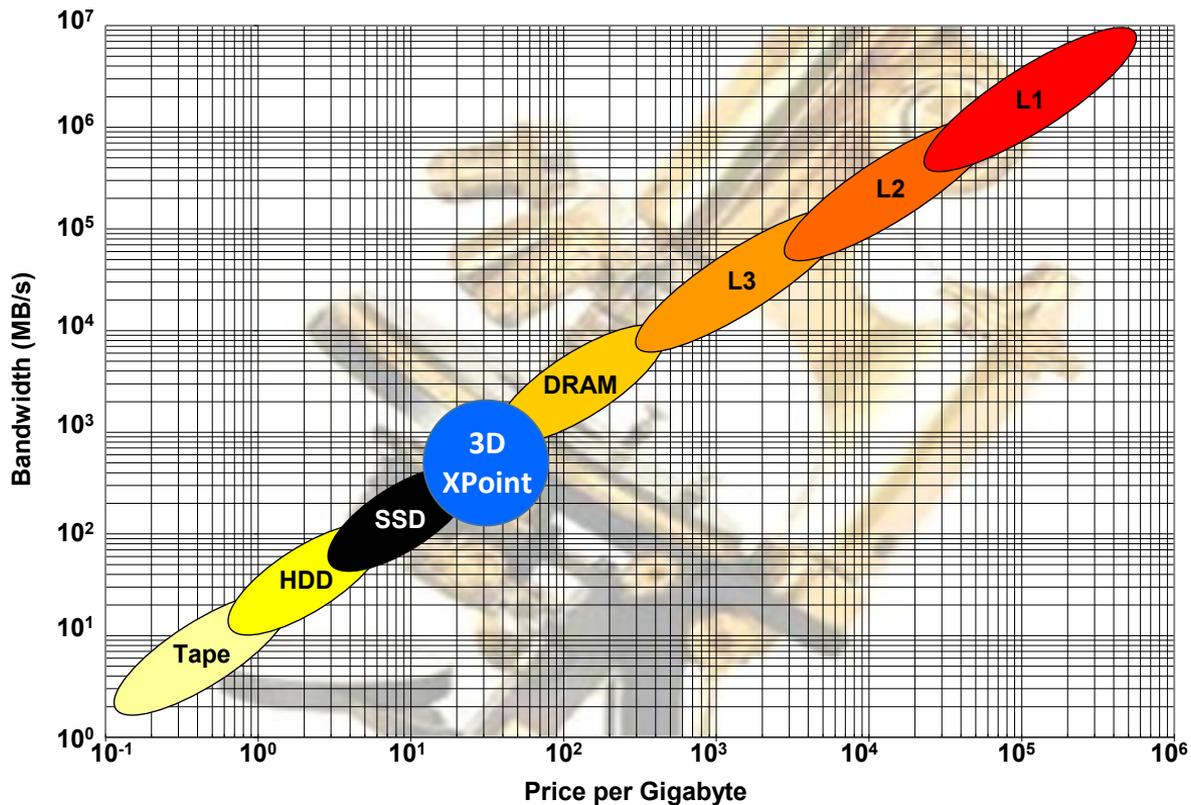
February 23-24  
Santa Clara, CA



# 3D XPoint Must Be Priced Below DRAM

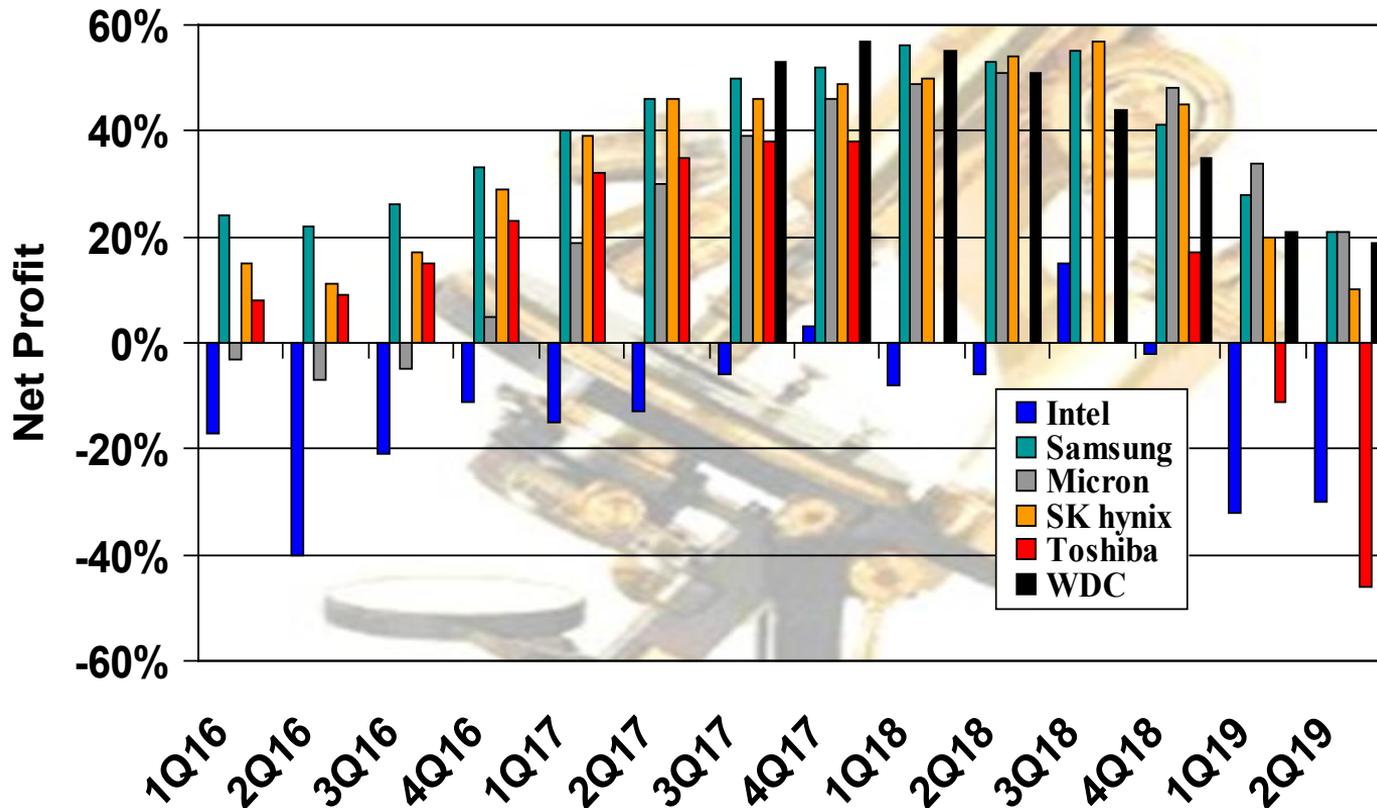
September 23-26, 2019

## Otherwise People will Just Buy DRAM



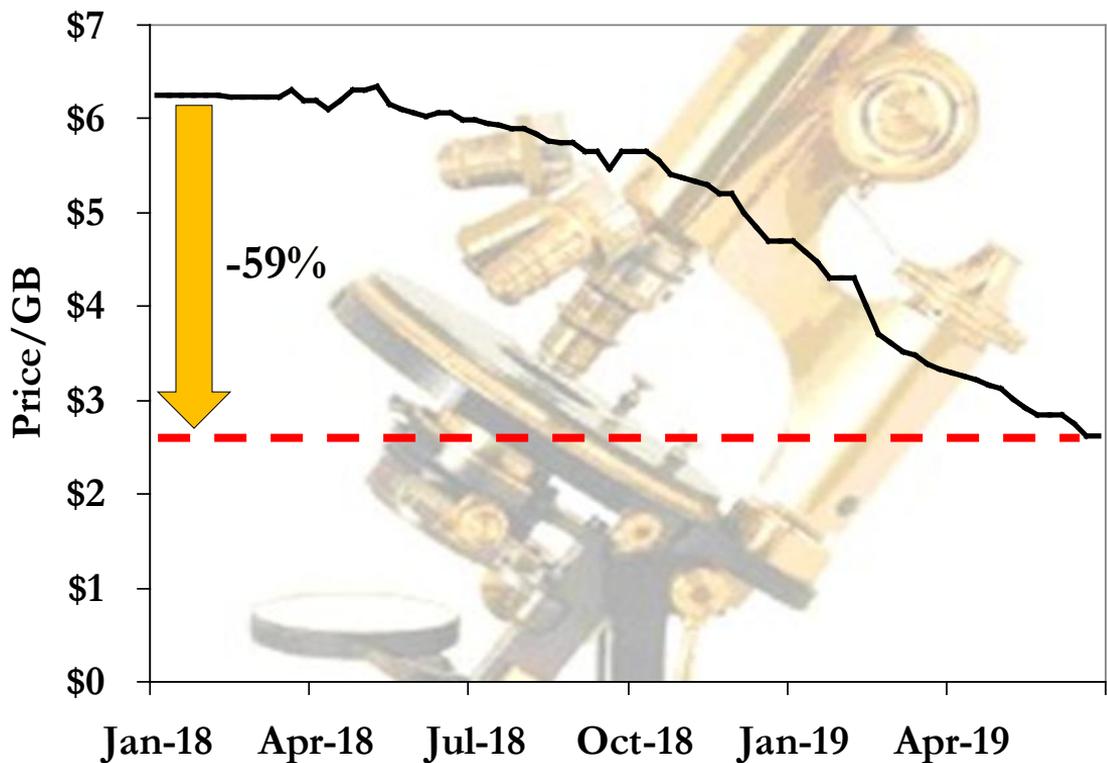
# Intel Incurring Significant XPoint Losses

Objective Analysis & Coughlin Associates  
Santa Clara, CA

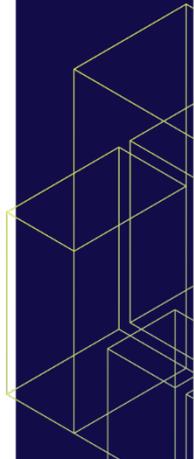


# Meanwhile, DRAM Prices are Collapsing

Objective Analysis & Coughlin Associates  
Santa Clara, CA



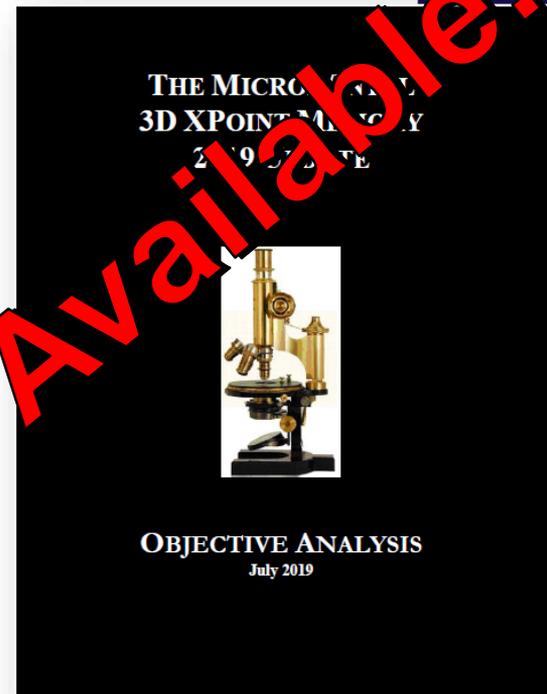
- Optane SSDs gaining modest acceptance
  - NAND makers countering with fast SLC SSDs
- Optane DIMMs key selling point for next-generation server CPUs



# 3D XPoint Report

- 2019 Update from Objective Analysis
- The Why, How, and When of 3D XPoint Memory
  - Why Intel wants it
  - How it fits into the memory hierarchy
    - Impact on DRAM
  - When will it sell in volume
- Detailed Forecasts

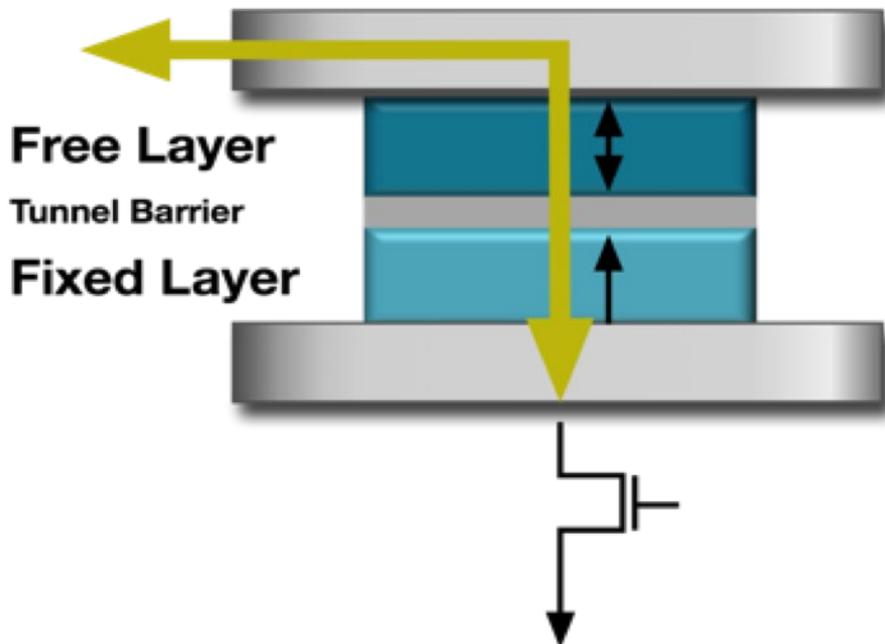
**Now Available!**



<https://Objective-Analysis.com/reports/#XPoint>

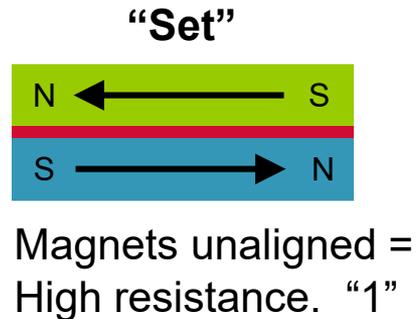
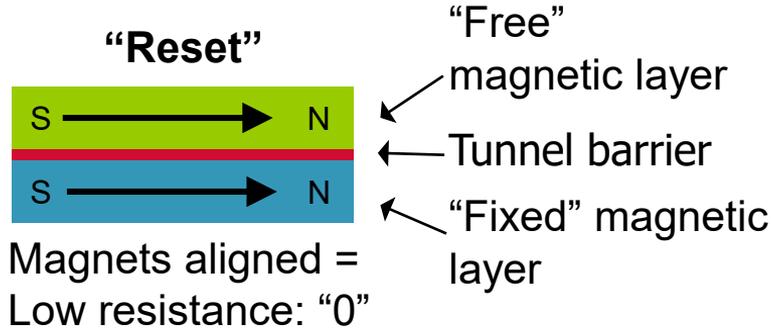
# Magnetic RAM: MRAM

San Jose, CA  
Santa Clara, CA

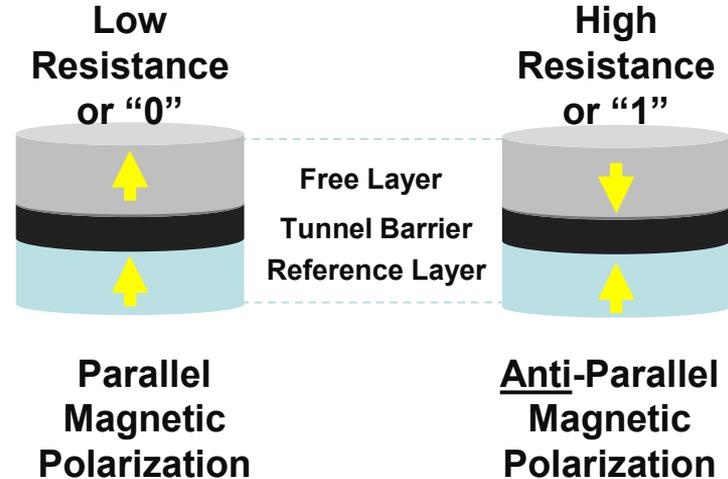


# Three MRAM Types: Toggle, STT, & SOT

## Toggle Mode (legacy)

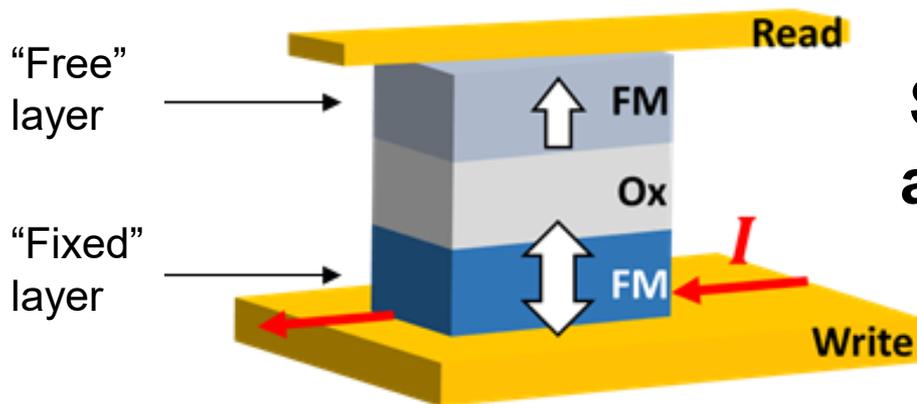


## Spin Transfer Torque (STT, ramping)



# Spin-Orbit Torque MRAM (future)

## Spin-Orbit Torque (SOT)



**SOT MRAM could achieve full SRAM speeds**

- Higher reliability in-plane current
- SOT switching faster than STT

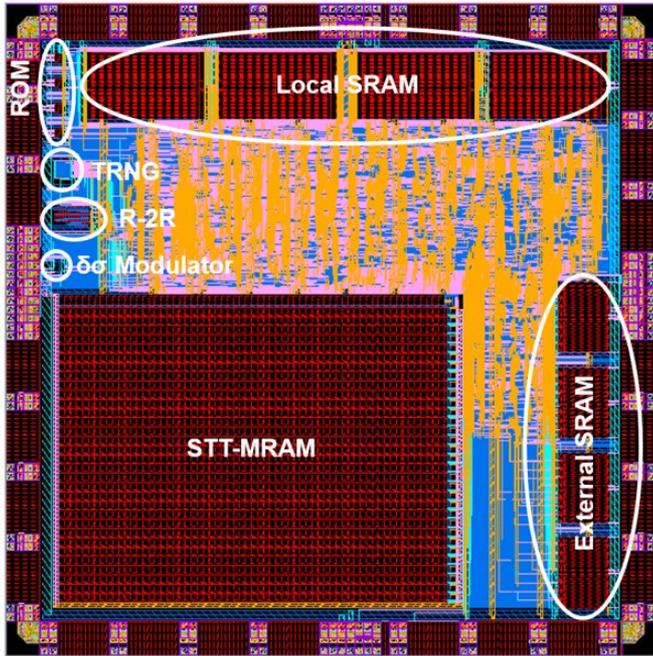
# MRAM Status

Storage Developer Conference 2019  
Santa Clara, CA

- MRAM cache in IBM SSDs
- Spin Memory (Spin Torque Technologies) launches:
  - Precessional Spin Current
  - Endurance Engine Technologies
- All major foundries sampling MRAM, two shipping
- Everspin still sole supplier of stand-alone MRAMs
  - Over 123 million units shipped
  - Avalanche is sampling
- Today's markets: Space, high-uptime systems, caches and buffers

# Embedded MRAM (1)

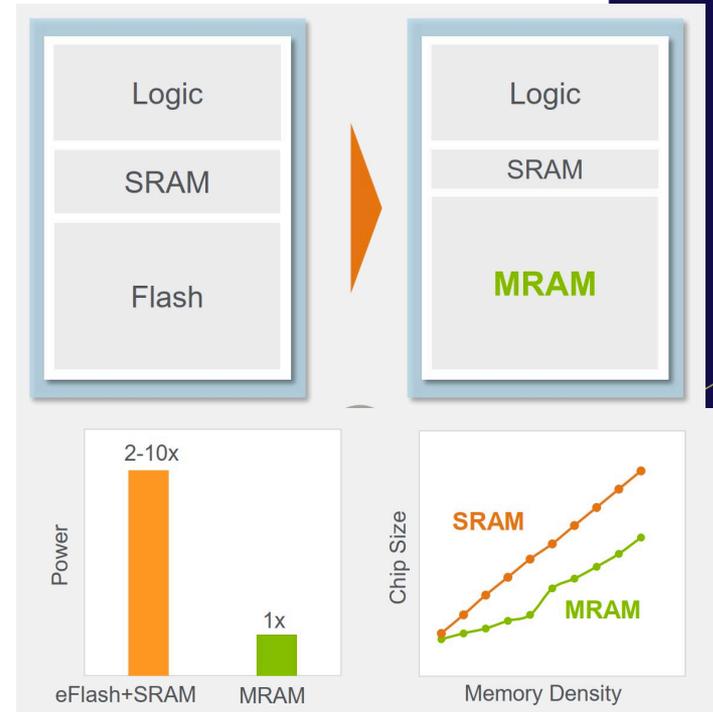
Santa Clara, CA



- MRAM will shrink past SRAM & flash
- Tuned to application
  - Retention
  - Endurance
  - Capacity

# Embedded MRAM (2)

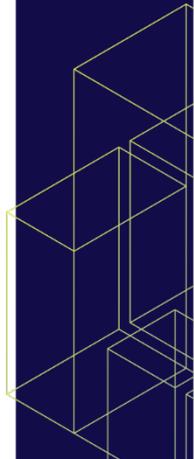
- 1T/2T MRAM smaller than 6T SRAM
- NOR flash scaling limit  $\leq 15\text{nm}$
- MRAM could replace embedded SRAM & NOR
  - Lower power
  - Lower cost
  - Higher density



Source: Kevin Moraes, AMAT, 2019

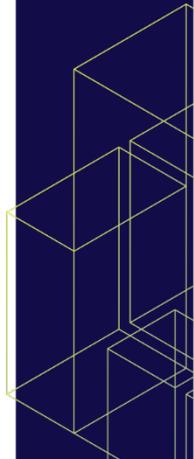
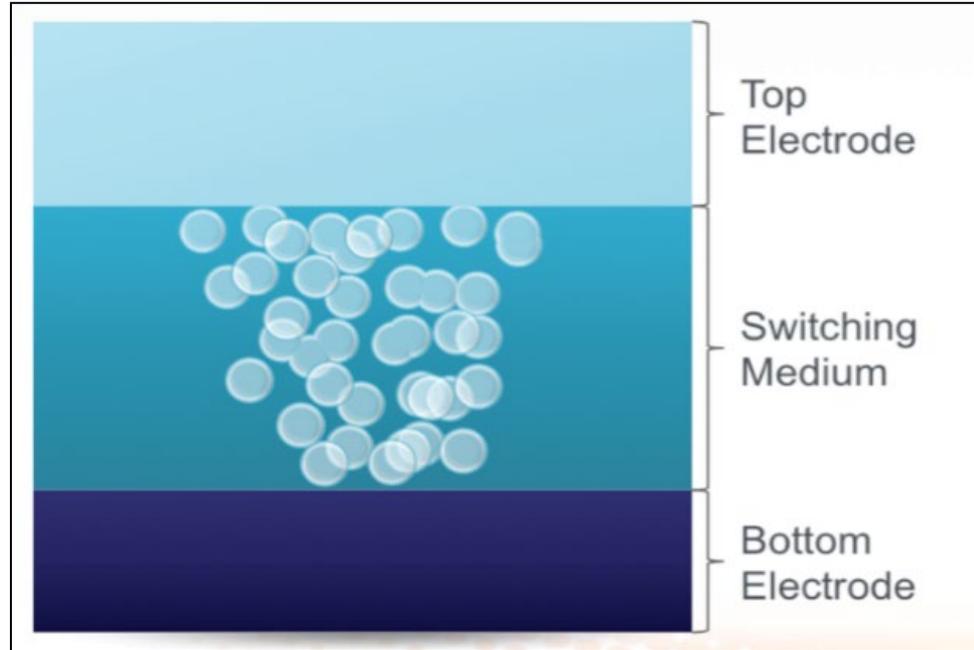
# MRAM Foundry Developments

- All major semiconductor foundries involved
  - Samsung, TSMC, Global Foundries, UMC...
- Many plan to cost reduce
  - Moving from BEOL to front end
- MRAM needs new tools
  - Drives more capital spending



# Resistive RAM: ReRAM

San Jose, CA  
Santa Clara, CA



# Many Flavors of ReRAM

September 23, 2019  
Santa Clara, CA

- CMOx
- CBRAM
- PCM
- Memristor
- Carbon nanotubes

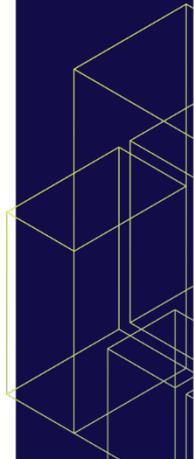
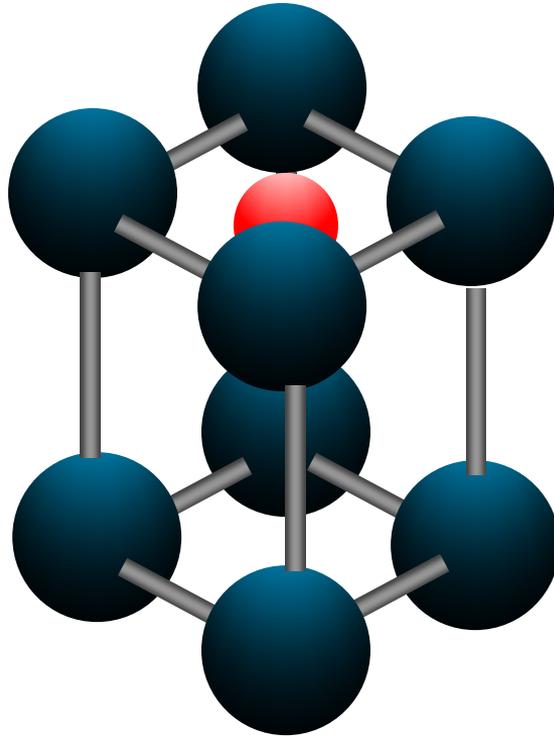
All use the value of a resistance to represent a “1” or “0”

# Two ReRAM Types in the Lead

- SiO<sub>2</sub>-based
  - Crossbar, Weebit Nano
    - Positioned as the memory for neural networks
    - Crossbar production at SMIC
  - Not yet in volume
- Metal filament
  - Adesto in volume production

# Ferroelectrics: FRAM

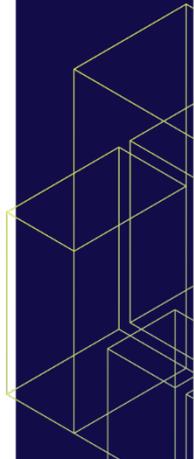
Santa Clara, CA



# FRAM Status

Santa Clara, CA 2019

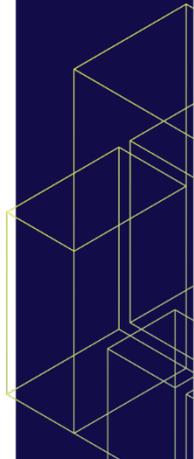
- Ramtron (Now Cypress)
  - Sole supplier of stand-alone FRAM
    - PZT – Lead Zirconium Titanate
- Other renditions:
  - Thinfilm, organic FRAMs
  - Symetrix IP provider
- New HfO<sub>2</sub> approach from NamLab, Dresden
  - Uses well-understood materials (Hafnium Oxide)
- Today's markets:
  - RFID, other low write current applications



# All New Memories Share Some Attributes

Santa Clara, CA

- Small single-element cell
  - Supports small/inexpensive die and 3D stacking
  - Promises to scale past DRAM & NAND flash
- Write in place
  - No “Block Erase”
  - More symmetrical read/write speeds
- Nonvolatile/Persistent
  - These can all be used as Persistent Memory: “PM”

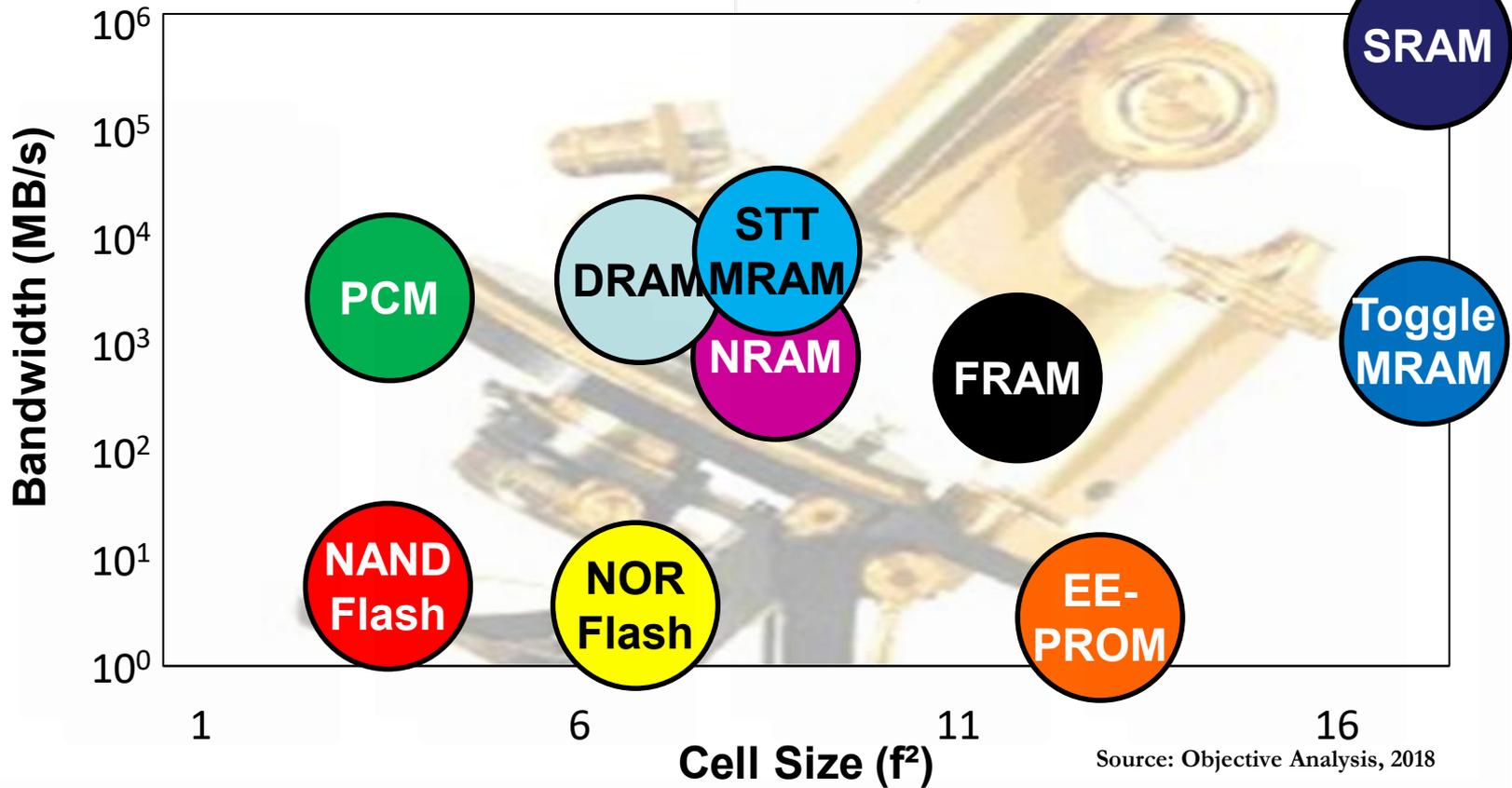


# Memory Attributes By Technology

September 3-26, 2019

	Units	SRAM	DRAM	NOR Flash	NAND Flash	Toggle MRAM	ST-MRAM	FRAM	PCM	RRAM
Byte Read Time	ns	2	10	25	10,000	35	<10	55	16	10
Byte Write Time	ns	2	10	5,000,000	200,000	35	<10	55	30	10
Standby Current	mA	<1	45	<1	<1	<1	<1	<1	<1	<1
Read Current	mA	20	220	20	25	30	15	<10	15	15
Write Current	mA	20	240	50	25	30	15	<10	20	20
Endurance	P/E Cycles	Infinite	Infinite	10 <sup>5</sup>	10 <sup>4</sup>	10 <sup>11</sup>	10 <sup>13</sup>	10 <sup>14</sup>	10 <sup>6</sup>	10 <sup>6</sup>
Retention	Yrs @ 55°C	0	10 <sup>-9</sup>	>10	>10	>20	>20	>10	>10	>10
Scaling Limit Cell Size	nm	5	10?	45?	14	65	5	5	5	5
	f <sup>2</sup>	50	6-8	6-8	4 effective with MLC	35-40	8-9	8-20	4	4
Select Device	N/A	Transistor	Transistor	Transistor	Transistor	Transistor	Transistor	Transistor	Diode	Diode
MLC Capability	Bits/ Cell	1	1	2	4	2	4	1	4	TBD
SEU Immune	N/A	No	No	No	No	Yes	Yes	No	Yes	Yes
SEL Immune	N/A	No	No	No	No	Yes	Yes	No	Yes	Yes
TID	krad (Si)	<100	<100	<100	<100	>1,000	>1,000	<100	>1,000	>1,000

# Comparing the Technologies

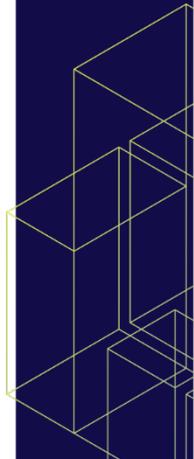


Source: Objective Analysis, 2018

# Outline

23-26, 2019  
Santa Clara, CA

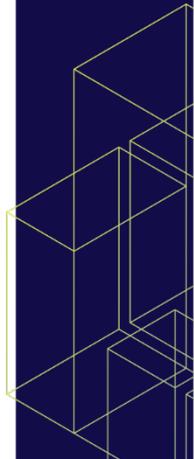
- Emerging Memory Update by Type
- Emerging Memory Support Update
- Hurdles & Outlook



# Support Requirements

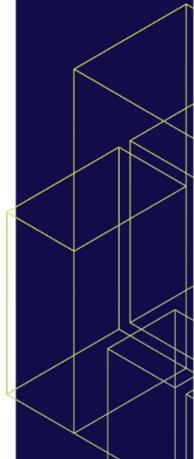
San Jose, CA

- Hardware advancements (JEDEC, Others)
  - Supporting early development
  - Ongoing requirements
- Software support (SNIA)
  - O/S support
  - Application program support
- EDA support



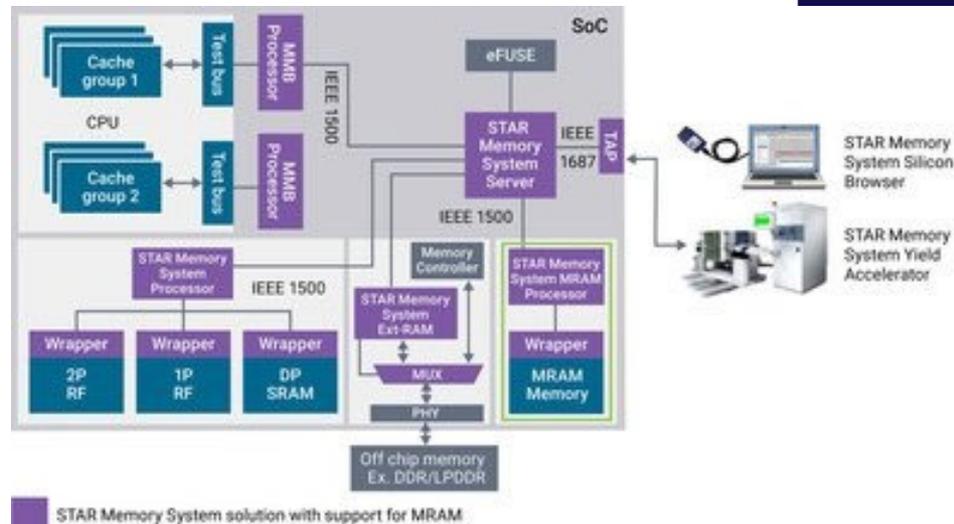
# Hardware: Early Development

- Early groundwork has been helpful
  - NVDIMM-N
    - DRAM with flash backup
  - BIOS changes
    - Boot without reloading memory
    - New power fail signal brought to DIMM
- 3D XPoint driving changes



# Design Tools MRAM Options

- Embedded MRAM needs EDA support
  - Synopsis support announced for 2Q19
  - Cadence to support MRAM in DDR4 controllers



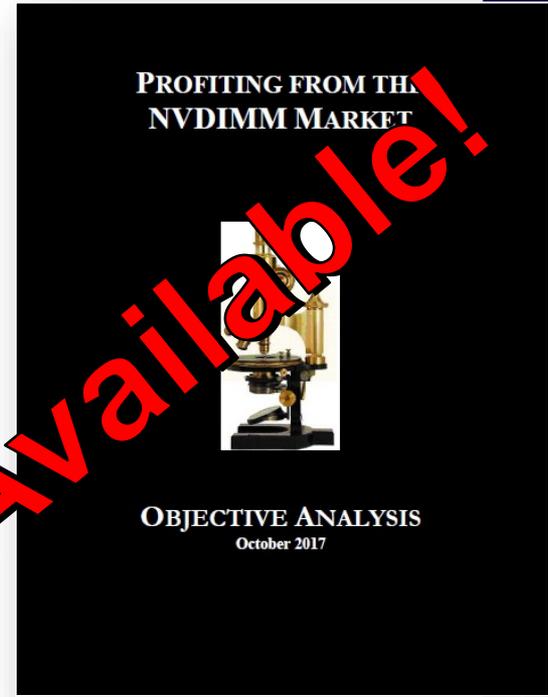
Source: Synopsis, October 2018

# NVDIMM Report

Objective Analysis  
Santa Clara, CA

- Objective Analysis
- Explains the NVDIMM markets
  - NVDIMM-N
  - NVDIMM-P
- Vendor profiles
- Support requirements
- Market forecast

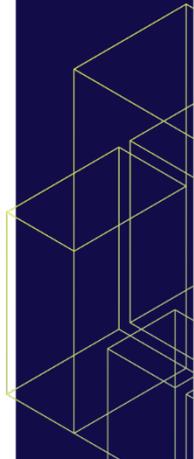
**Now Available!**



<https://Objective-Analysis.com/reports/#NVDIMM>

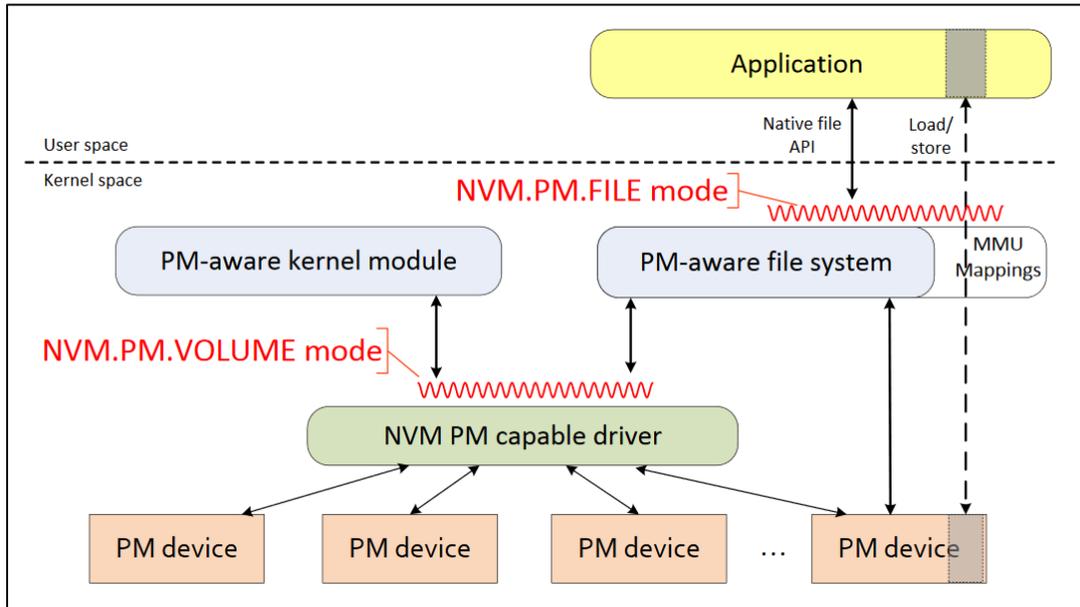
# Ongoing Hardware Requirements

- Nonuniform Memory Architecture: “NUMA”
- MMU Redesign
- Faster context switches needed
  - Use polling for now
- Updated DDR4 bus
  - Support for non-deterministic access times



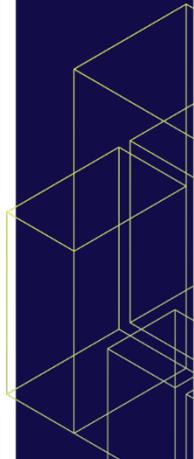
# Software: Operating System Support

- SNIA's Persistent Memory Programming Model
  - <https://www.SNIA.org/PM>



# Software: Application Program Support

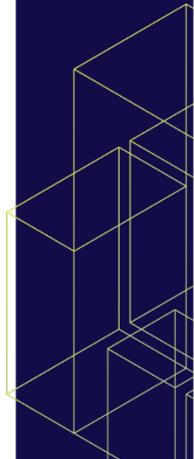
- PM is useless if its advantage is untapped
  - Persistence is unknown in most software
- This change will take some time
  - Closed systems can use it now
    - Hyperscale Data Centers, SANs
  - Open systems will evolve



# Outline

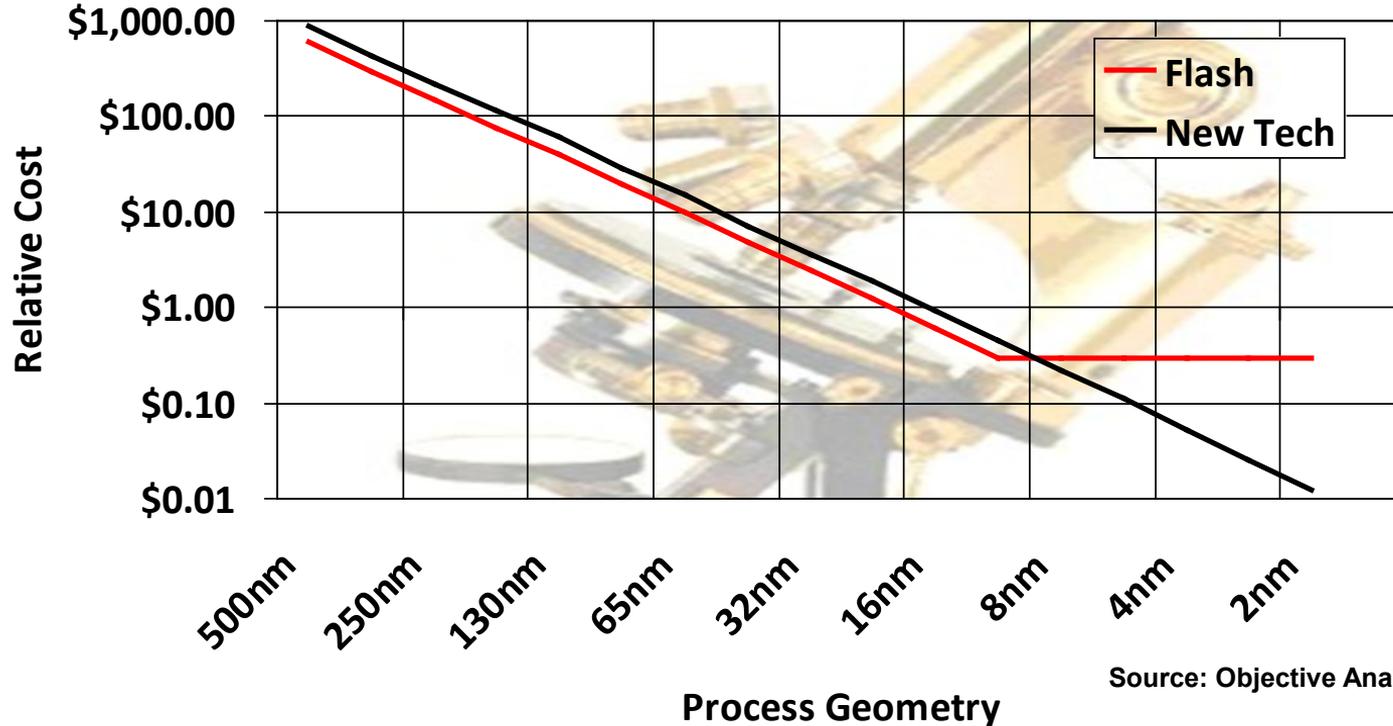
23-26, 2019  
Santa Clara, CA

- Emerging Memory Update by Type
- Emerging Memory Support Update
- **Hurdles & Outlook**



# The Vision: Replace Existing Technologies

September 23-26, 2019  
San Jose, CA

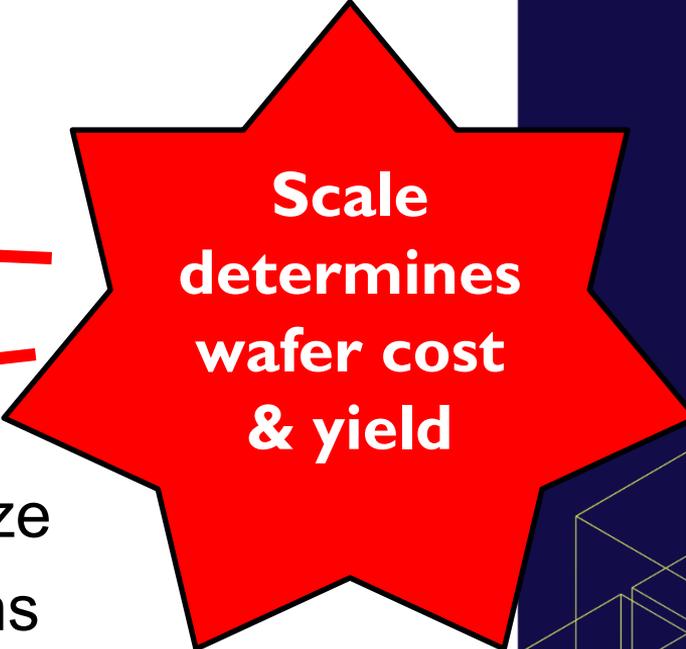


Source: Objective Analysis

# What Dictates Memory Cost?

Santa Clara, CA

- Cost per megabyte depends on:
  - Wafer cost
  - Megabytes per wafer
  - Yield
- Megabytes per wafer driven by bit size
  - Shrinking bits allow cost reductions
  - Manufacturers shrink processes to drive this

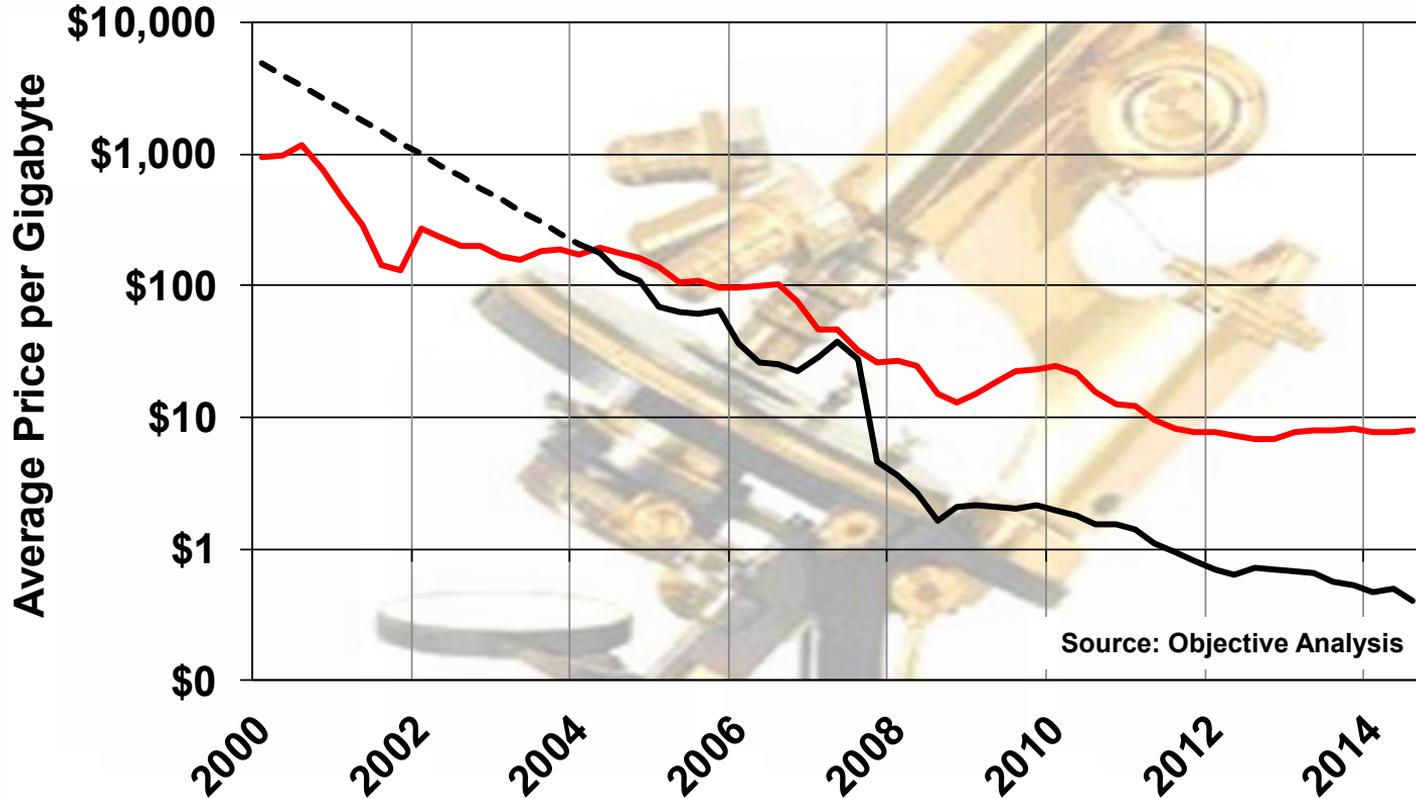


**Scale  
determines  
wafer cost  
& yield**

**This is Moore's Law in Action!**

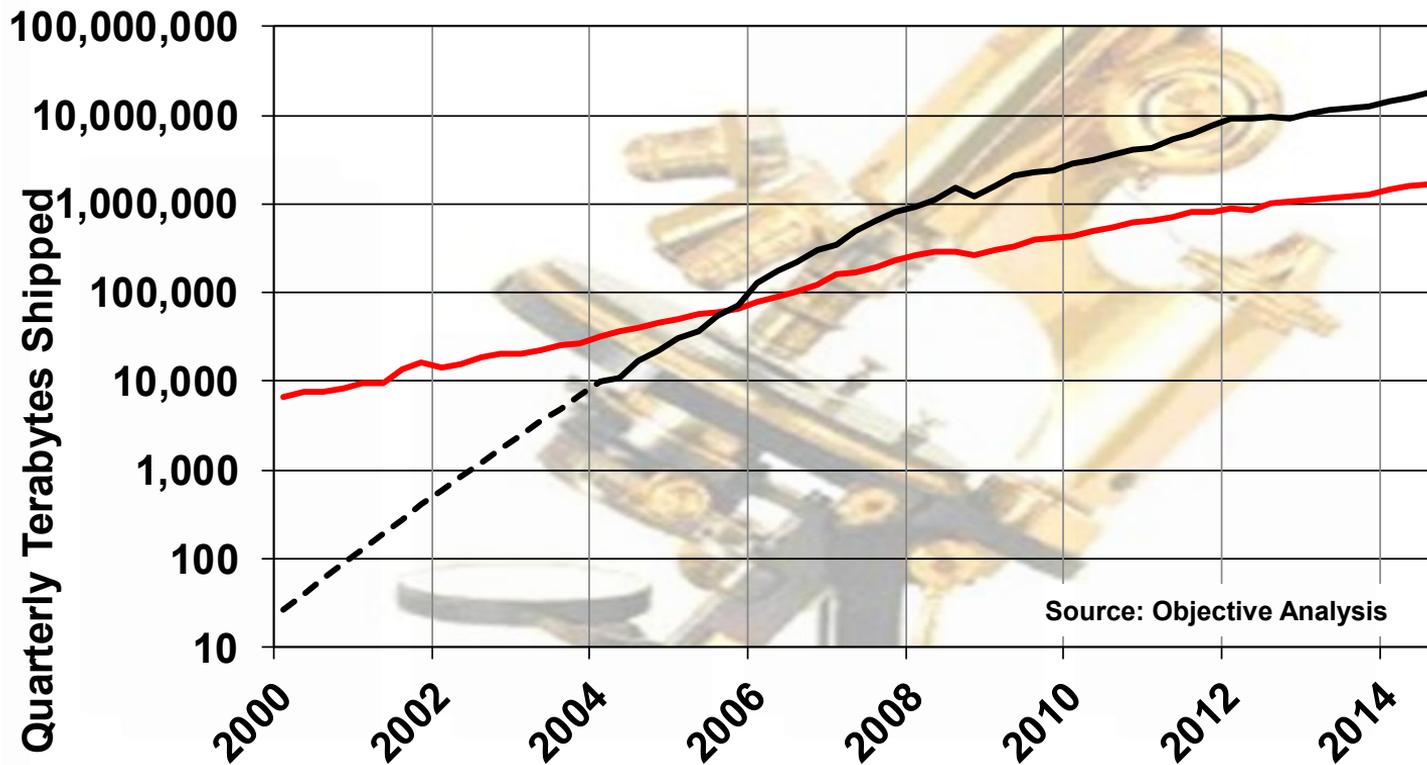
# NAND \$/GB > DRAM's Until 2004

Santa Clara, CA



# In 2004 NAND GB $\frac{1}{3}$ of DRAM's

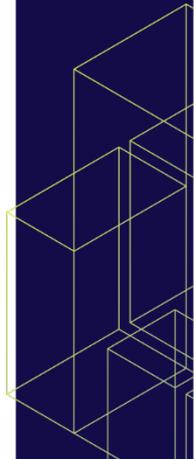
Objective Analysis  
Santa Clara, CA



Source: Objective Analysis

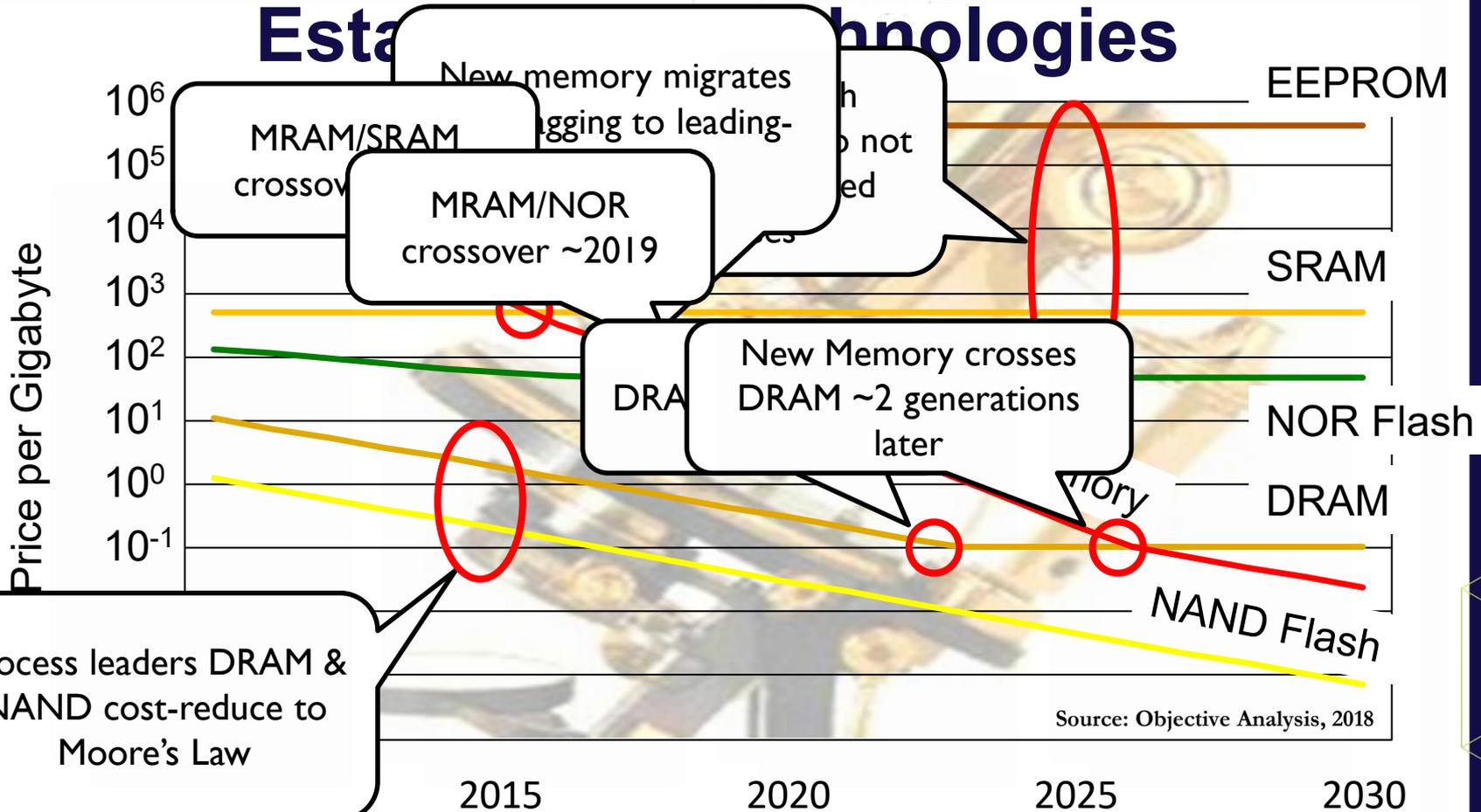
# The Same is True of All Memory Technologies

There can be no price advantage  
without comparable scale



# New Memory Prices Will Move Past Established Technologies

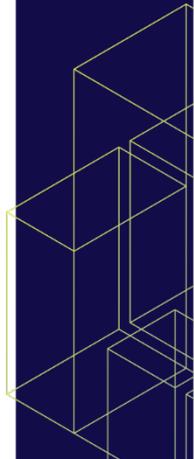
September 23-26, 2019



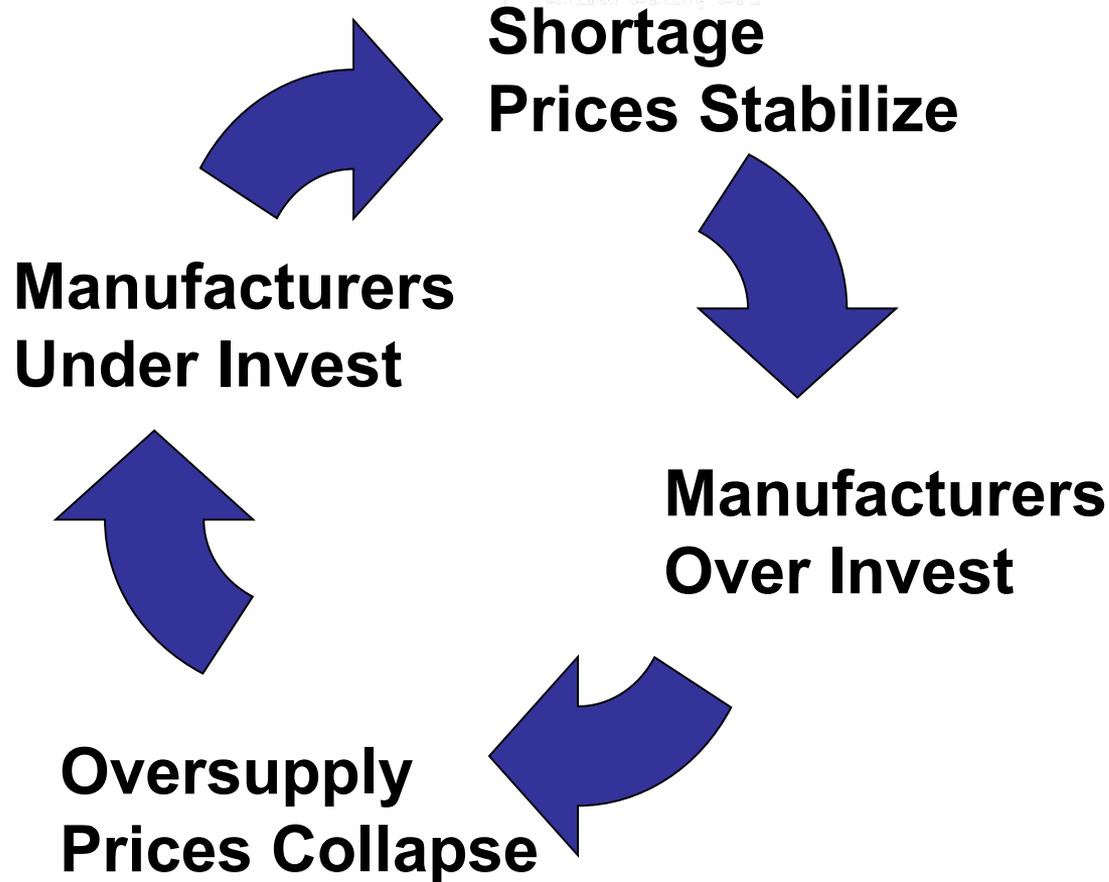
Source: Objective Analysis, 2018

Process leaders DRAM & NAND cost-reduce to Moore's Law

- Nothing works in a vacuum
  - PM is a part of the greater memory ecosystem
  - The memory market swings wildly
- Foundry processes will have a huge impact



# Commodity Price Cycle



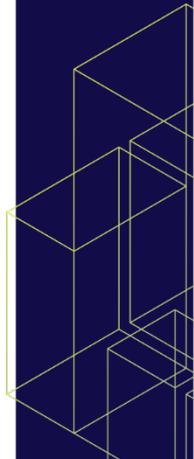
# Status of Today's Memory Cycle

- Predicted collapse is well underway
  - Supply-driven overcapacity
  - 3D NAND selling close to cost
  - DRAM still has room to fall
- Won't end until demand catches up with supply
  - Typically this takes 2 years
  - China likely to enter market in 2021

# Impact to PM?

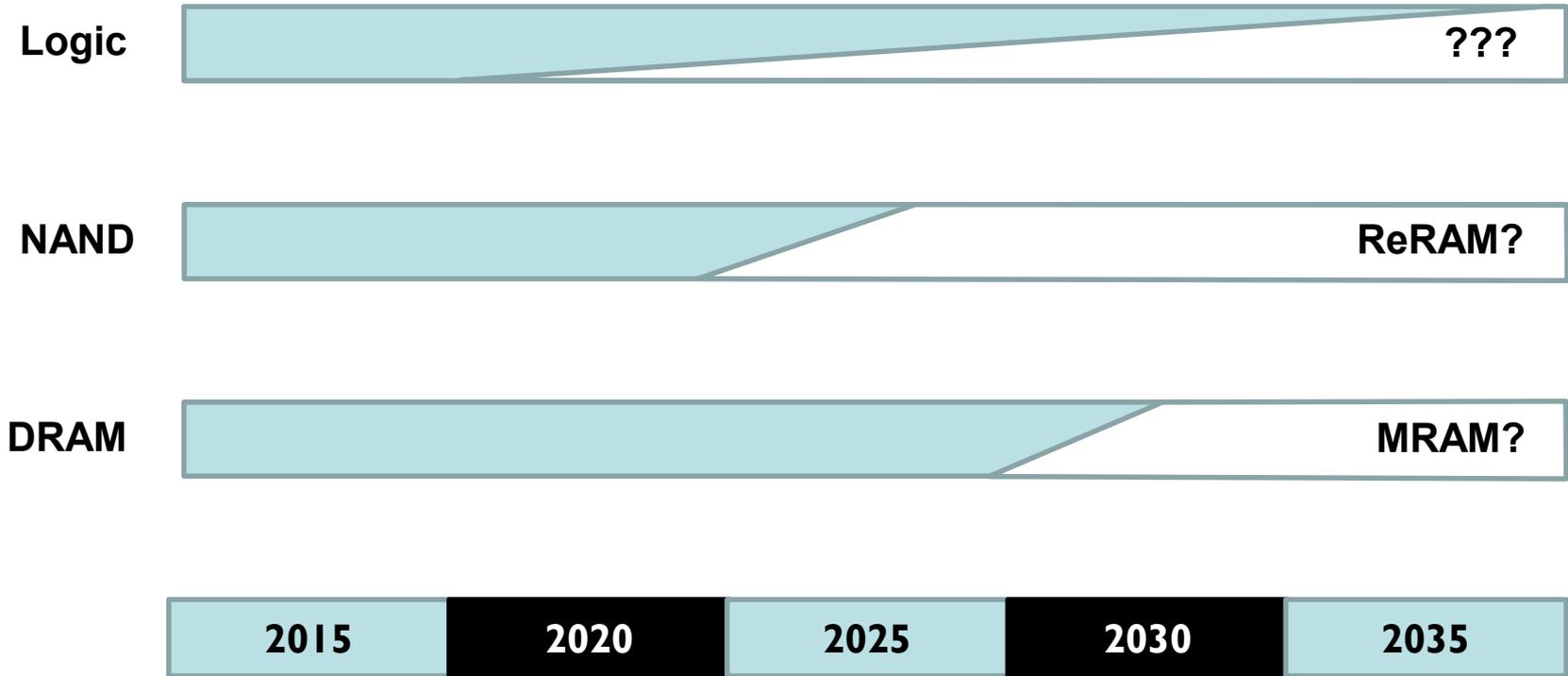
Storage Developer Conference 2019  
Santa Clara, CA

- Persistent memory competes against established technologies
  - Example: 3D XPoint must be cheaper than DRAM
- A DRAM collapse will create an XPoint collapse
  - Even though XPoint is sole-sourced!



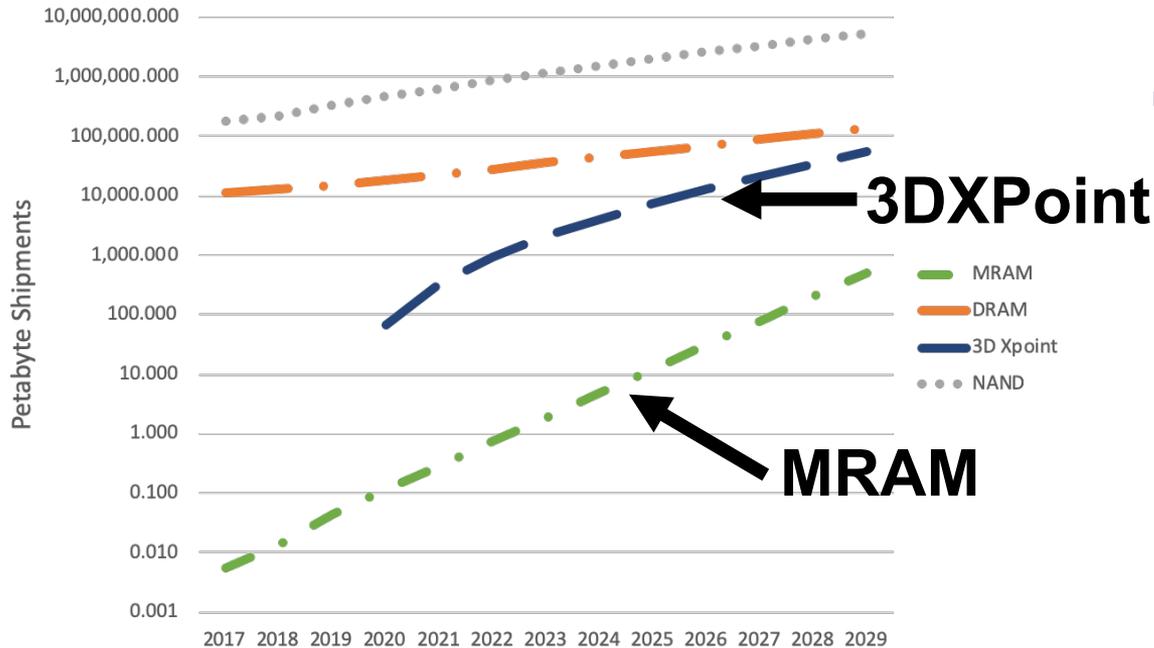
# Timeline for Change

Objective Analysis  
Santa Clara, CA



Source: Objective Analysis, 2018

# Growth in New Memory Shipments

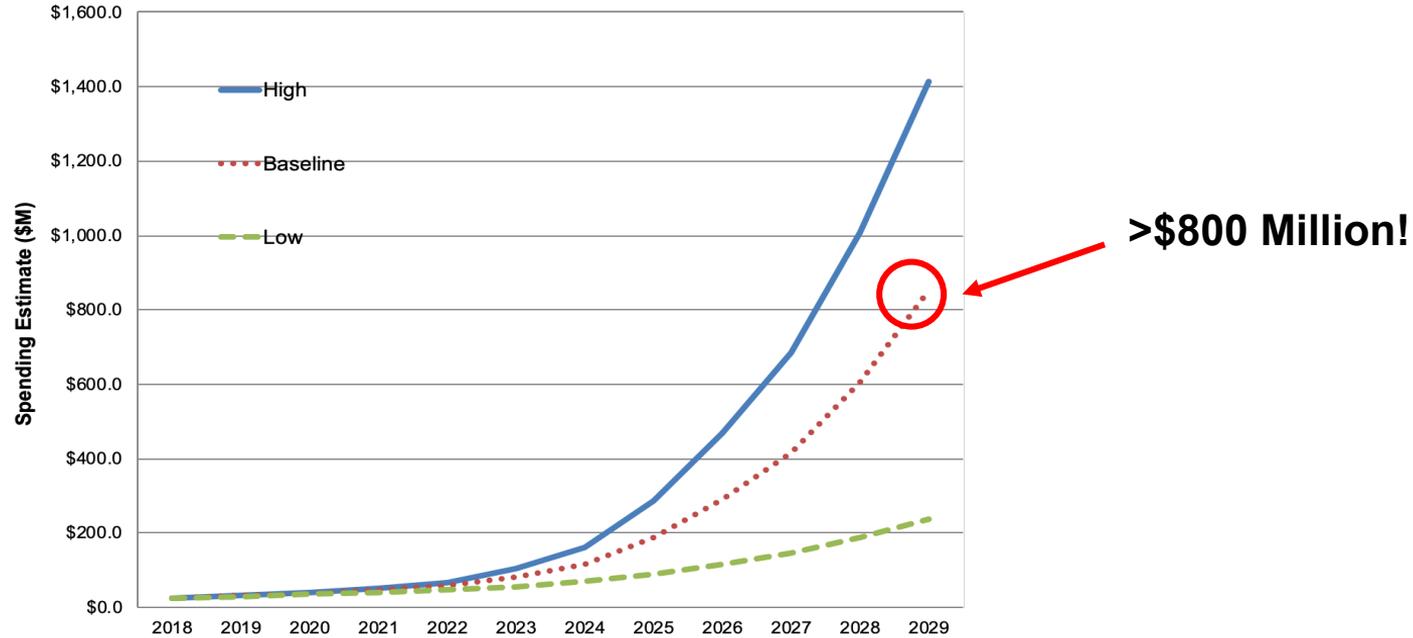


**Could exceed \$37B by 2029!**

- Embedded MRAM replaces most SoC NOR and SRAM
- Strong appeal in AI apps

# New Memory Capital Spending Increases

Santa Clara, CA



# New Emerging Memory Report

Santa Clara, CA

SDC<sup>19</sup>

- Coughlin Associates/Objective Analysis
- Examines Emerging Memory Ecosystem
  - Technologies (PCM, ReRAM, MRAM, FRAM...)
  - Companies
  - Markets
  - Support requirements
- Forecasts Emerging Memory consumption
  - Embedded Emerging Memories
  - Discrete Emerging Memories
- 172 pages, 30 tables, 125 figures

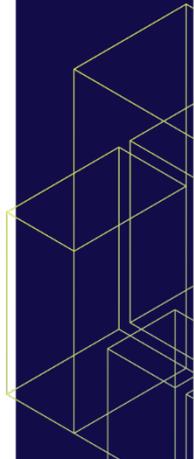


<http://www.tomcoughlin.com/techpapers.htm>  
<https://Objective-Analysis.com/reports/#Emerging>

# Summary

20, 2019  
Santa Clara, CA

- Emerging Memories Making Good Progress
  - Major commitments for server and embedded applications
  - Still hard to determine the frontrunner
- Support requirements being well addressed
- New memories will drive capital spending
- Many issues confront the market





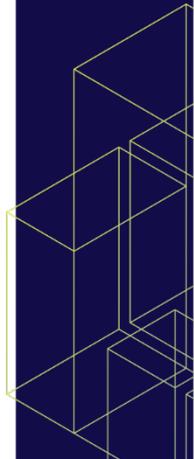
**Questions?**

# *Coughlin Associates*

September 23-26, 2019  
Santa Clara, CA

SDC<sup>19</sup>

- Technical and Market Analysis
- Consulting
- Reports and Newsletter
  - Emerging Memories Poised to Explode: Emerging Memory Report
  - Digital Storage in Media and Entertainment
  - Digital Storage Technology Newsletter
- Events
  - Emerging Memory and Artificial Intelligence Workshop, Stanford, 8/29/19
  - Storage Valley Supper Club



# OBJECTIVE ANALYSIS

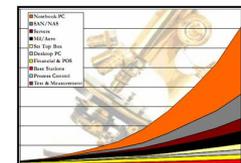
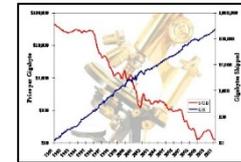
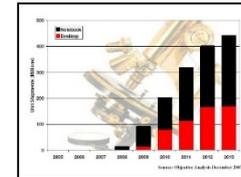


**Profound  
Analysts**



**Reports &  
Services**

**Custom  
Consulting**



# OBJECTIVE ANALYSIS

September 23-26, 2019

San Jose, CA

## Semiconductor Forecast Accuracy

Year	Forecast	Actual
<a href="#">2008</a>	Zero growth at best.	-3%
<a href="#">2009</a>	Growth in the mid teens	-9%
<a href="#">2010</a>	Should approach 30%	32%
<a href="#">2011</a>	Muted revenue growth: 5%	0%
<a href="#">2012</a>	Revenues drop as much as -5%	-2.7%
<a href="#">2013</a>	Revenues increase nearly 10%	4.9%
<a href="#">2014</a>	Revenues up 20%+	9.9%
<a href="#">2015</a>	Revenues up ~10%	-0.2%
<a href="#">2016</a>	Revenues up ~10%	1.1%
<a href="#">2017</a>	Revenues up ~20%	22%
<a href="#">2018</a>	Strong start supports 10+% growth	14%
<a href="#">2019</a>	Semiconductors down -5%	TBD

