

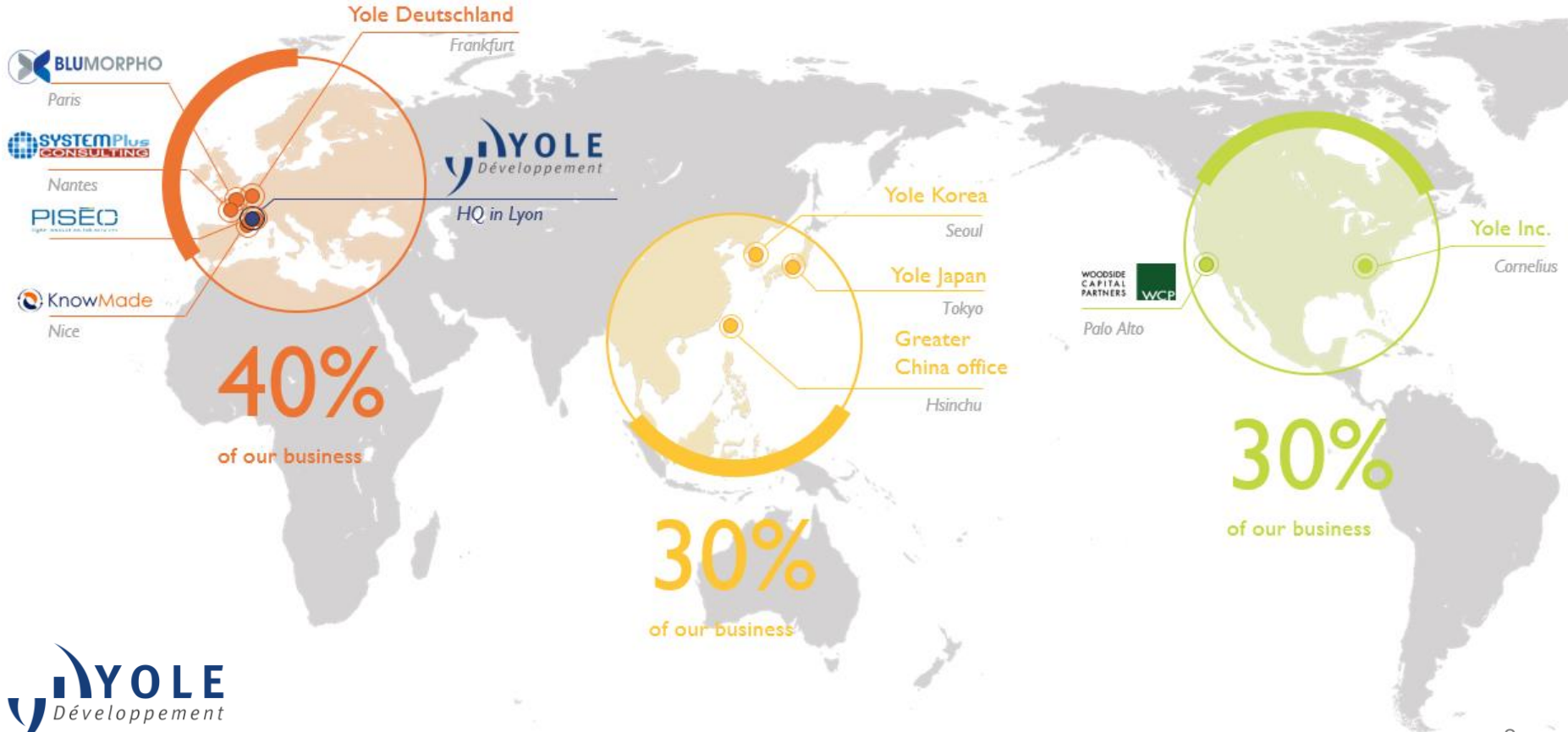


# MRAM Technology and Market Trends

Simone Bertolazzi, Ph.D.

Technology and Market Analyst, Yole Développement

# Yole's Global Activity



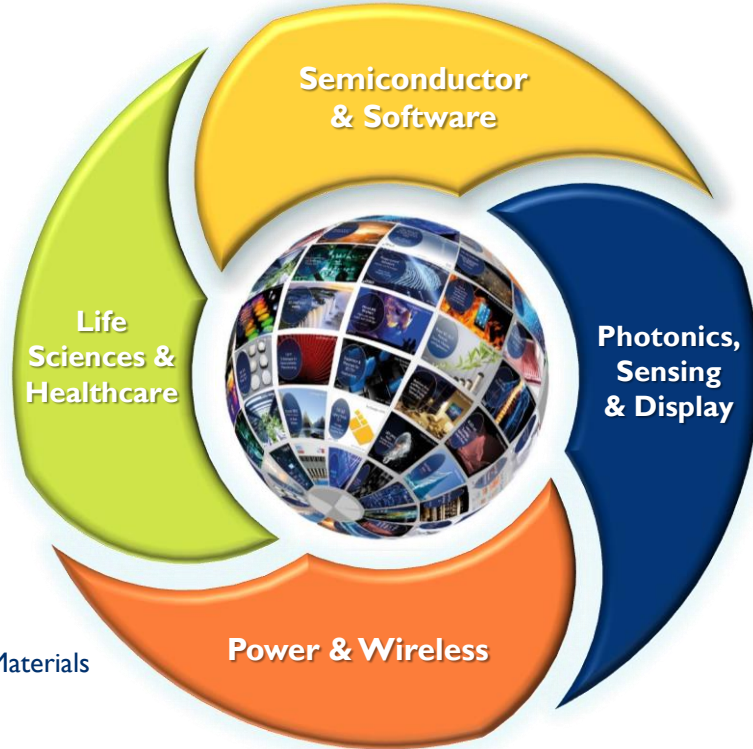
# Yole Développement - Fields of Expertise

## Life Sciences & Healthcare

- Microfluidics
- BioMEMS & Medical Microsystems
- Inkjet and accurate dispensing
- Solid-State Medical Imaging & BioPhotonics
- BioTechnologies

## Power & Wireless

- RF Devices & Technologies
- Compound Semiconductors & Emerging Materials
- Power Electronics
- Batteries & Energy Management



## Semiconductor & Software

- Package, Assembly & Substrates
- Semiconductor Manufacturing
- Memory
- Software & Computing






## Photonics, Sensing & Display

- Solid-State Lighting
- Display
- MEMS, Sensors & Actuators
- Imaging
- Photonics & Optoelectronics

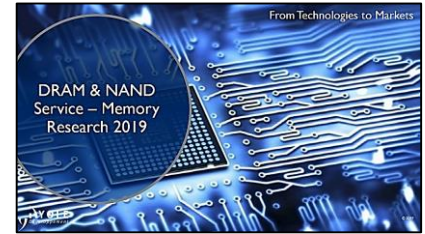
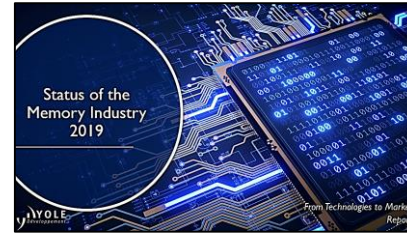
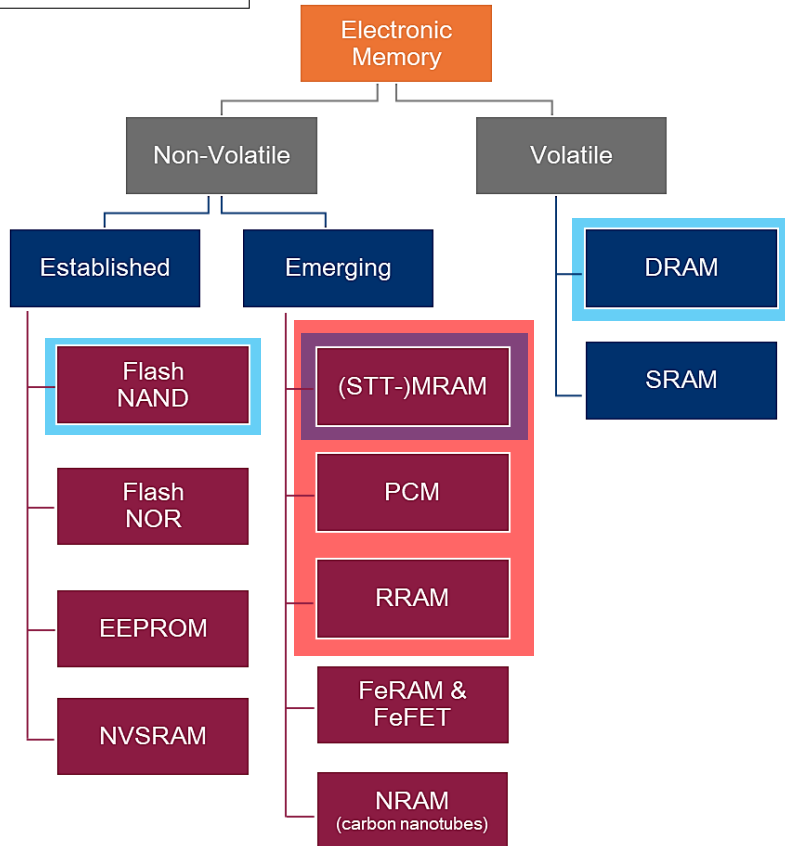


# About Yole's Memory Team



<p><b>Walt Coon</b> VP of NAND and Memory Research</p> 	<p><b>Mike Howard</b> VP of DRAM and Memory Research</p> 	<p><b>Simone Bertolazzi, PhD</b> Technology &amp; Market Analyst Memory</p> 	<p><b>Ivan Donaldson</b> VP of Yole Finance</p> 	<p><b>Emilie Jolivet</b> Division Director Semiconductor &amp; Software</p> 
<p><b>Experience:</b> 20 years in Memory</p>	<p><b>Experience:</b> 15 years in Memory</p>	<p><b>Experience:</b> 8 years in Emerging Semiconductors and Devices</p>	<p><b>Experience:</b> 14 years in Semiconductor Industry Strategy, Business Development, and IR</p>	<p><b>Experience:</b> 9 years in Equipment, Manufacturing, Processing</p>
<p><b>At Yole:</b> NAND</p>	<p><b>At Yole:</b> DRAM</p>	<p><b>At Yole:</b> Emerging Memory</p>	<p><b>At Yole:</b> Manages all services and relationships for global financial clients</p>	<p><b>At Yole:</b> Embedded Technologies, 3DIC &amp; Manufacturing</p>

# Memory Technologies



- Focus of Yole's NAND and DRAM Market Monitors (published every quarter)
- Focus of MRAM Technology and Business 2019
- and Emerging Non-Volatile Memory Report (updated every year)



# Outline



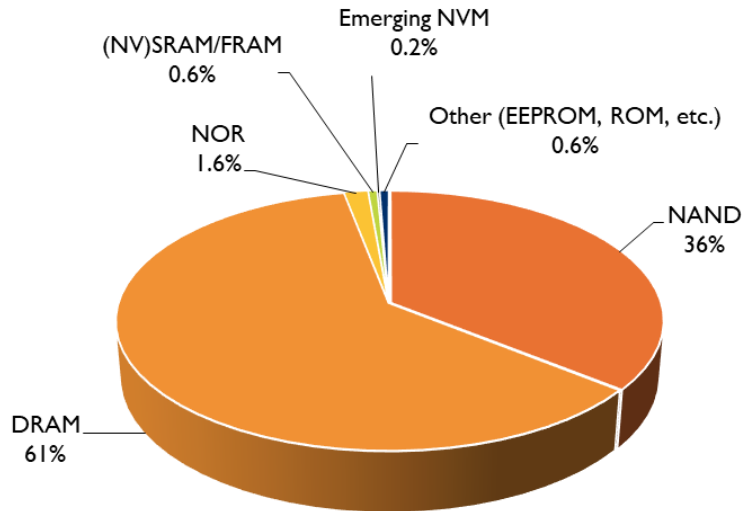
- **Overview of the Memory Market**
  - Established and Emerging Memory
- **(STT-)MRAM Technology - Overview**
  - Comparison with Other Memory Technologies
- **(STT-)MRAM Market and Ecosystem**
  - Applications & Players' Dynamics
  - Market Projections and Outlook



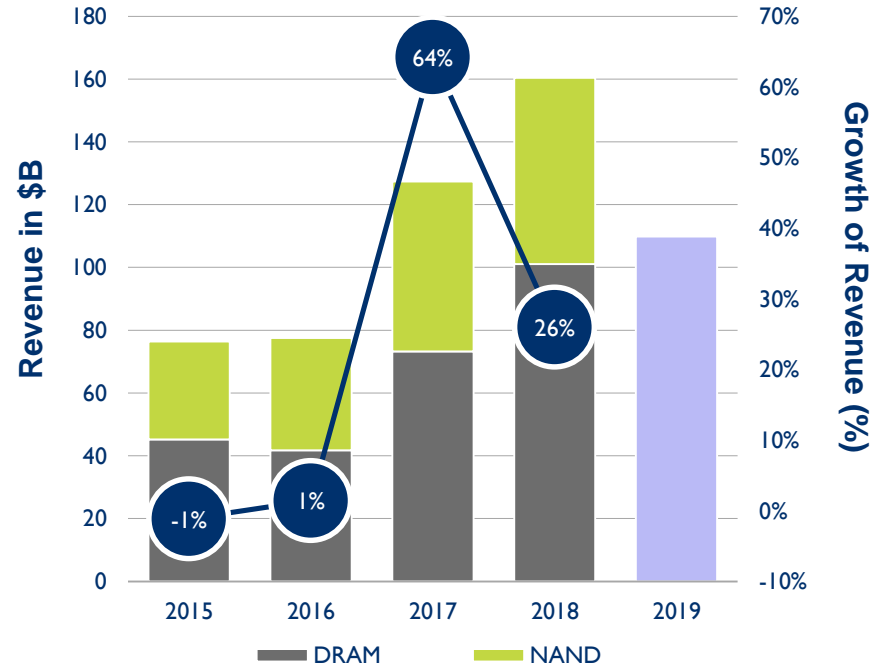
# Stand-Alone Memory Market - Overview

- NAND and DRAM account for ≈97% of the overall stand-alone memory market.
- Combined NAND and DRAM revenue was ≈ \$160 billion in 2018, up 26% from 2017.

2018 Memory Market - Breakdown by Technology

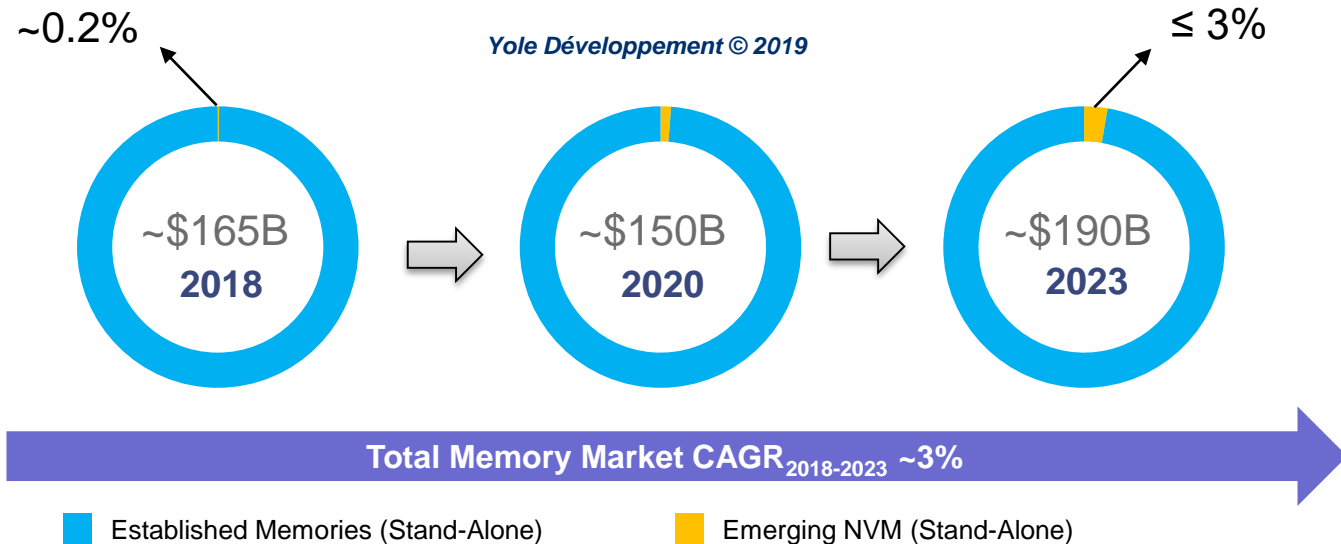


Total Stand-Alone Market in 2018 ≈ \$165 billions



# Emerging NVM Market - Overview

- Flash NAND and DRAM will maintain their leading position over the next five years thanks to new technical solutions enabling further scalability.
- Emerging NVM is gaining significant momentum, but will remain below 3% of the total stand-alone memory market.

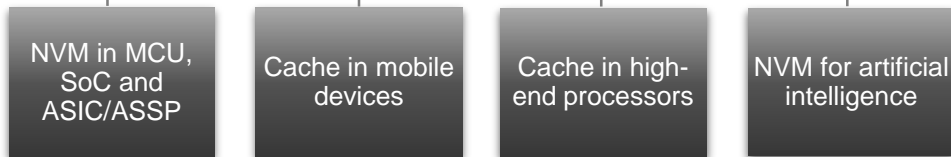


Source: “Emerging NVM” and “Status of the Memory Industry” Reports by Yole



## Stand-Alone

## Embedded



Industrial automation

Smart meters

Automotive

Journal

Databases

Persistent memory (NVDIMM)

Workstation

Notebook

NAND memory

IoT

Smart card

General purpose

Automotive

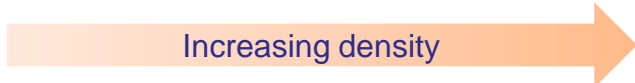
Smartphones & tablets

Last-Level Cache (SRAM and eDRAM)

CPU

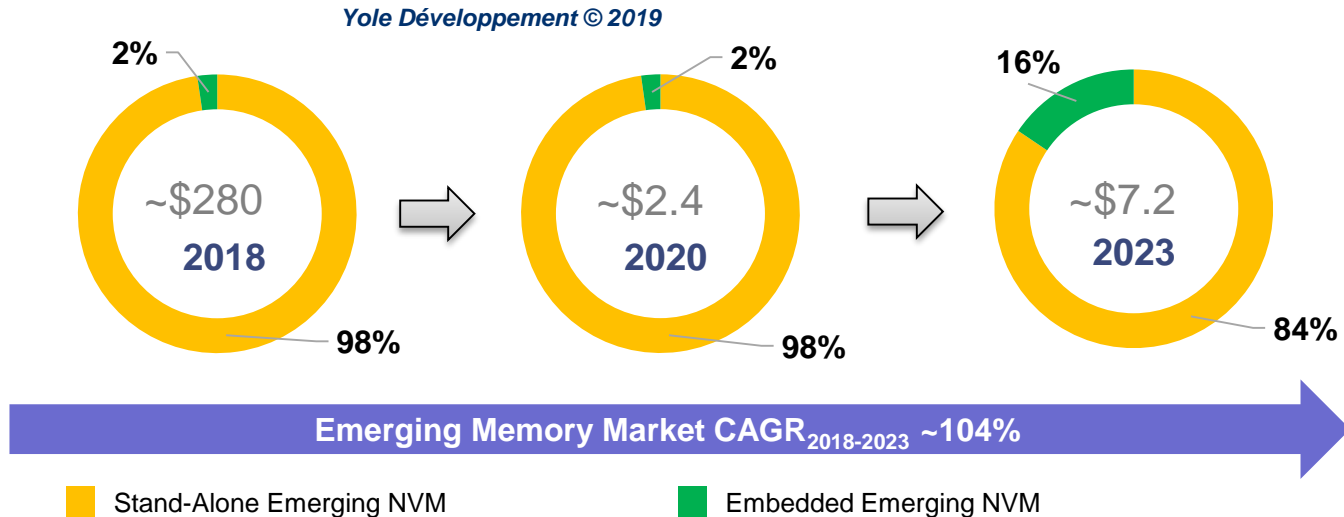
In-memory computing

Source: "Emerging NVM" Report by Yole



# Stand-Alone vs Embedded NVM

- Stand-alone memory will be the dominant market and is driven primarily by Storage Class Memory (SCM) enterprise and client applications (3D XPoint).
- Embedded applications are gaining momentum and will be reaching 16% of the emerging NVM market by 2023

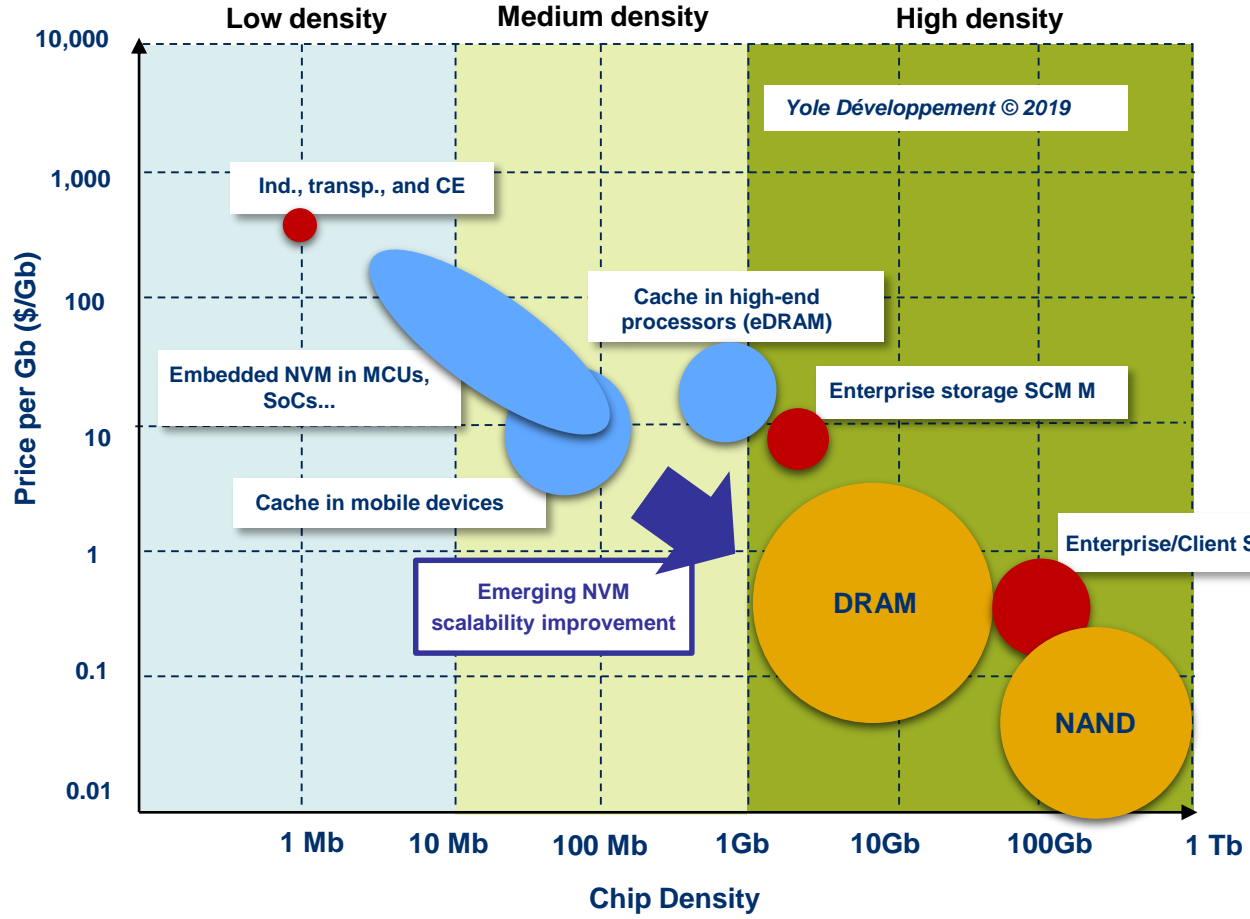


Source: "Status of the Memory Industry" and "Emerging NVM" Reports by Yole

# Opportunities for New Memories

- Embedded NVM
- Stand-alone NVM
- Mainstream memory

Bubble size corresponds to the total accessible market (TAM) size in 2018



Sources: "Emerging NVM" and "Status of the Memory Industry" (May 2019) Reports by Yole



# Memory Technology Comparison

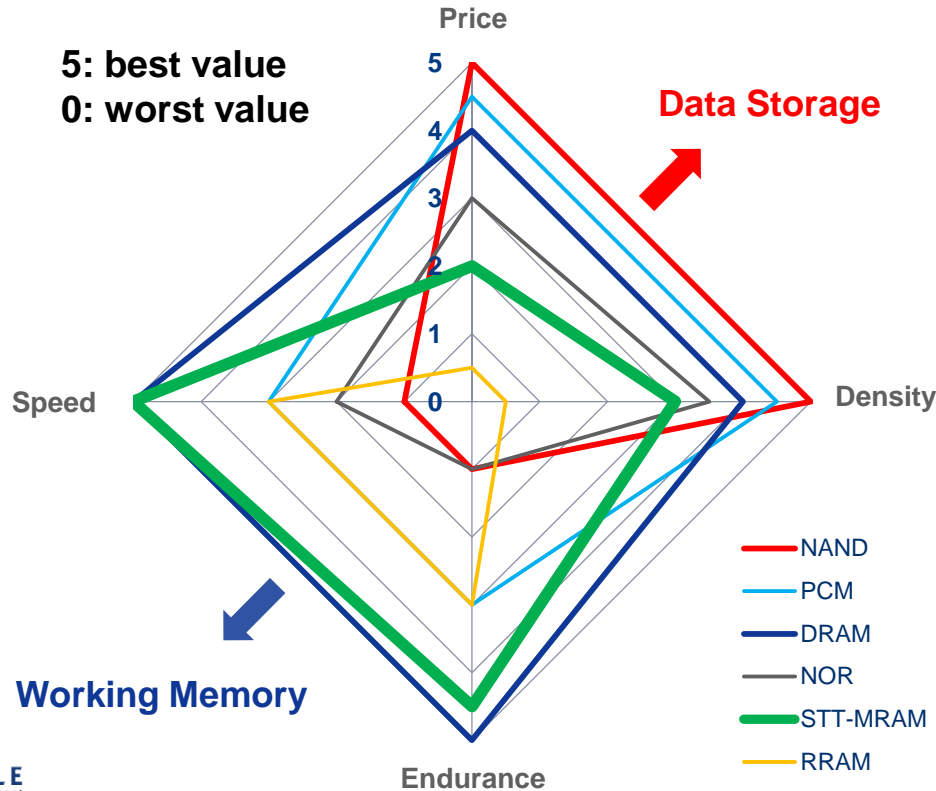
2018 stand-alone commercial products performance

	STT-MRAM	PCM 3D XPoint	RRAM	DRAM	Flash NAND	Flash NOR
<b>Non-volatile</b>	YES	YES	YES	NO	YES	YES
<b>Byte addressable</b>	YES	YES	YES	YES	YES	YES (but not for erase)
<b>Endurance (# cycles)</b>	High (>10 <sup>9</sup> )	Medium (10 <sup>7</sup> )	Low (10 <sup>6</sup> )	High (10 <sup>15</sup> )	Low (10 <sup>5</sup> )	Low (10 <sup>5</sup> )
<b>Maximum density for products in 2018</b>	256Mb (1Gb ready)	128Gb	4Mb	16Gb	1Tb	2Gb
<b>Cell size (cell size in F<sup>2</sup>)</b>	Medium (6-30)	Small (4/2L)	Medium (6-30)	Small (6-8)	Very small (4/96L)	Medium (6-30)
<b>Speed (Latency)</b>	Fast (~10 ns)	Fast (10-100ns)	Medium (~100 ns)	Fast (~10 ns)	Slow (100,000ns)	Slow write (100,000ns)
<b>Switching Power</b>	Medium/Low	Medium	Medium	Low	High	High
<b>2018 price (\$/Gb)</b>	High (\$10-100/Gb)	Low (≤ \$0.5/Gb)	High (\$100 - 1000/Gb)	Low (\$0.97 Gb)	Very low (\$0.03/Gb)	Medium (\$10/Gb)
<b>Key suppliers</b>	Everspin, Avalanche	Micron/Intel	Adesto, Fujitsu	Samsung, Micron, SK hynix, Nanya	Samsung, Micron, Toshiba, WDC, SK hynix, Intel	Micron, Winbond, Macronix, Cypress-Infinion, GigaDevice

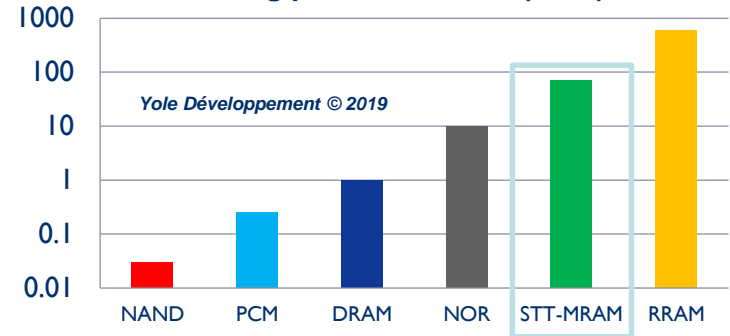


# Memory Technology Comparison

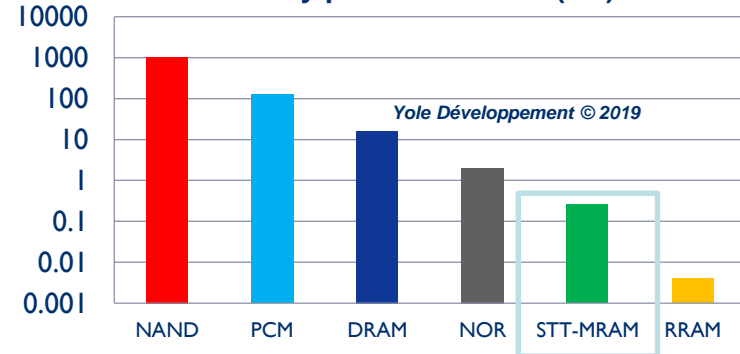
2018 stand-alone commercial products performance



Pricing position in 2018 (\$/Gb)



Density position in 2018 (Gb)



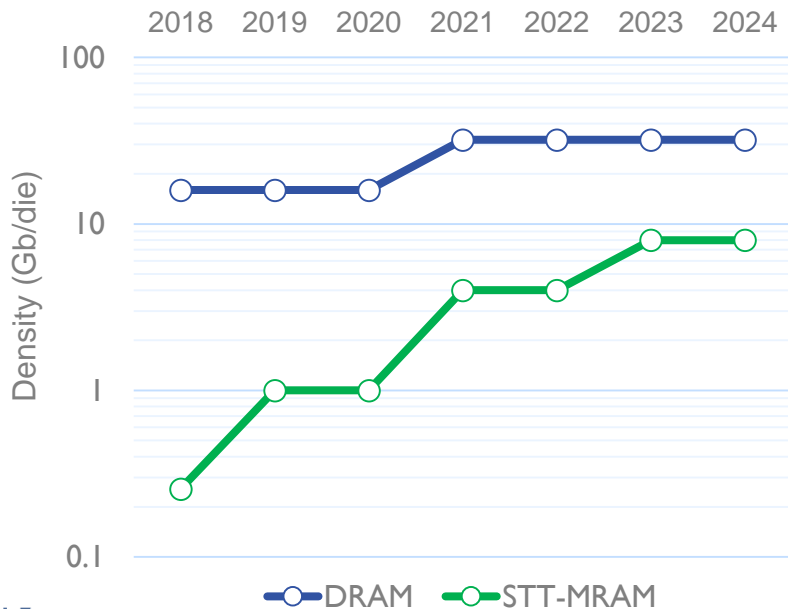


# Stand-Alone STT-MRAM Roadmap

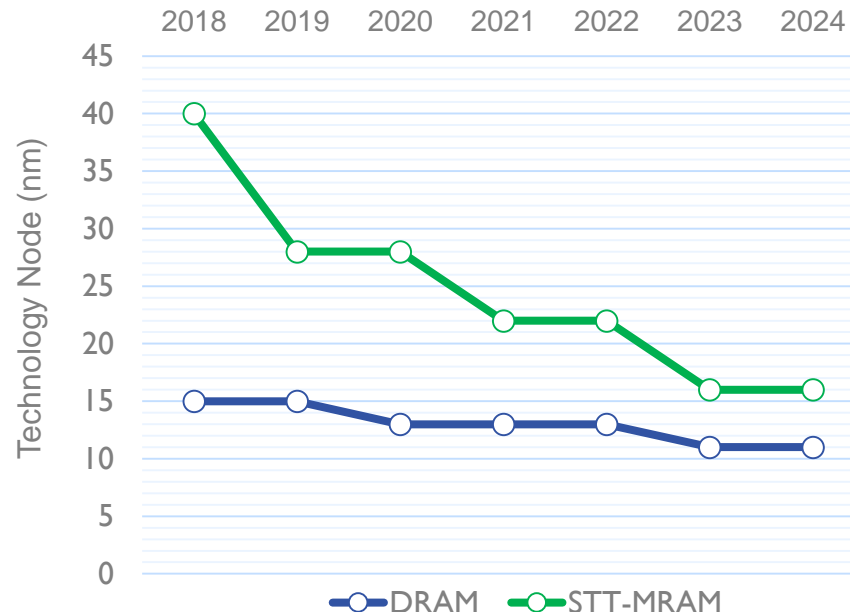
Chip density and technology node scaling - Comparison with DRAM

- STT-MRAM will target enterprise storage (SCM) applications for a long time before trying to substitute DRAM.

### Stand-alone memory density roadmap (Gb)



### Technology-node scaling (nm)



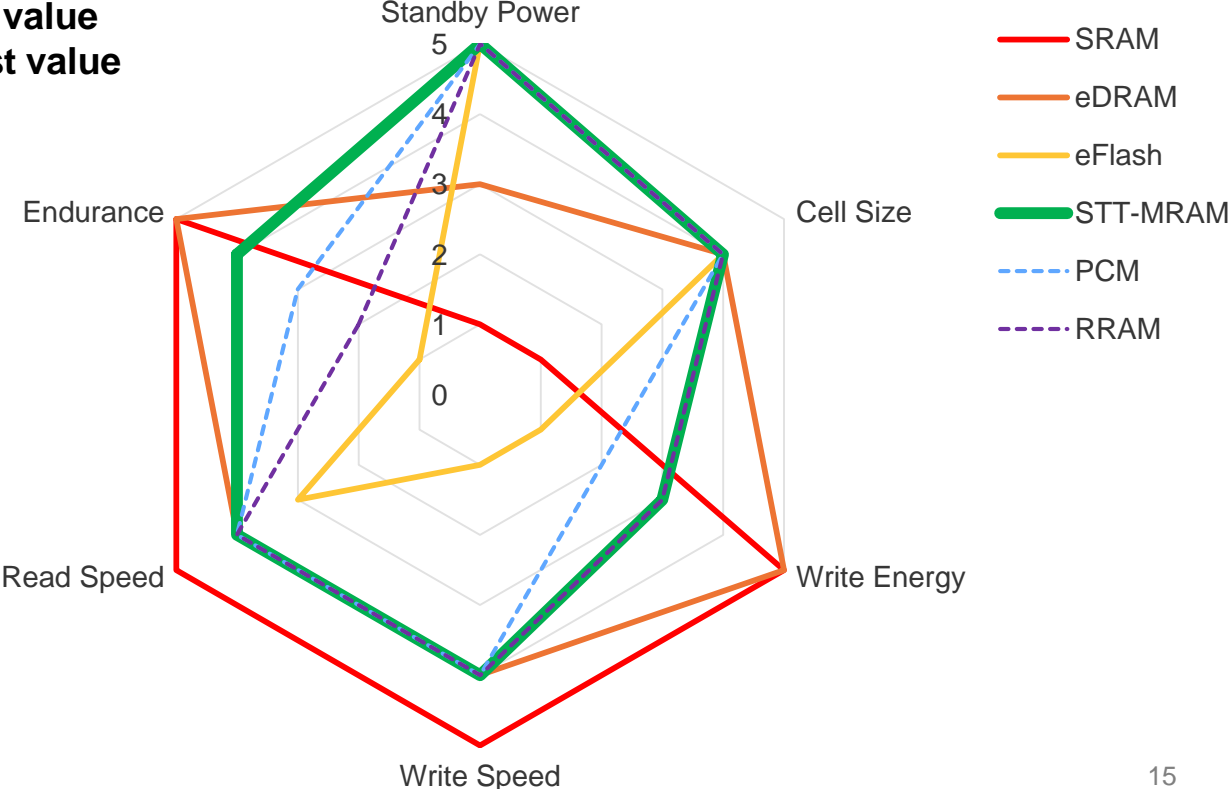


# Embedded Memory Technologies

Comparison of embedded technologies (based on technical literature data)

**5: best value**  
**0: worst value**

Among established and emerging embedded memory technologies, STT-MRAM is promising as it offers a combination of persistence, low-power consumption, high speed and high endurance



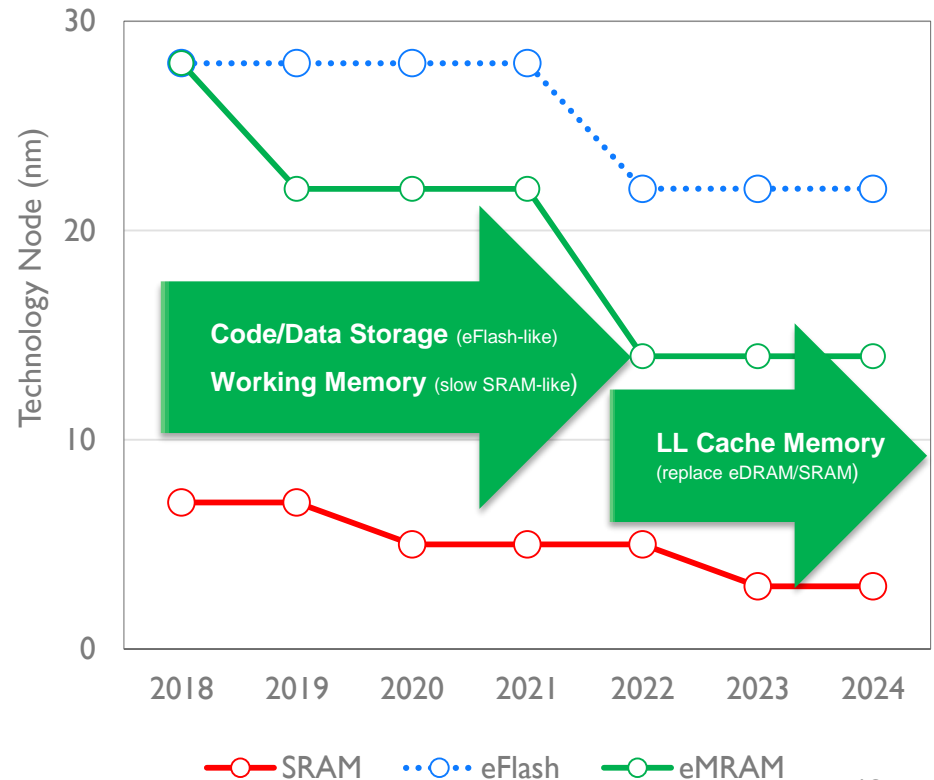


# Embedded MRAM is Taking Off!

## Embedded Memory Technology Highlights

- **eFlash scaling is reaching its end:** 28nm/22nm will be likely the last technology nodes.
- **SRAM scaling is also slowing down.** The cell footprint (# of  $F^2$ ) degrades at advanced FinFET nodes
- STT-MRAM offers non-volatility together with **low power consumption**, which is ideal for low-power MCUs, wearables and IoTs.
- STT-MRAM offer a significant **density gain over SRAM**. At advanced nodes ( $\leq 1\text{nm}$ ) more than  $\times 3$  gain.

→ Thanks to strong support of top foundry/IDM players and equipment suppliers, embedded STT-MRAM is poised to become the next embedded NVM solution for nodes  $\leq 28\text{nm}$ .





# (STT-)MRAM Applications

## Stand-alone

## Embedded

Industry,  
transportation,  
and other

Enterprise Storage

Persistent Memory

Code/Data Storage  
(eFlash)

“Working” Memory  
(Slow SRAM)

Cache Memory  
(SRAM, eDRAM)



**NVS RAM**

- Industrial automation
- Transport
- Aerospace
- Medical
- Gaming
- Network & Infrastructure



**Storage Accelerators**  
**Network Interface Cards**



**Solid State Drives**  
Write caching, journaling,  
logs, data buffering and  
streams



**NVDIMM**  
Persistent Memory for Servers

**2023+**



**MCU, ASSP, ASIC, SoC**



**IoT / Wearables**



**General Purpose**



**Automotive**



**CMOS Image Sensors**  
Image memory buffer



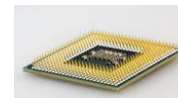
**Display Driver ICs**  
Tcon, memory buffers



**Edge AI accelerator chips**  
In memory computing

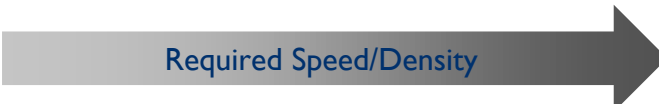
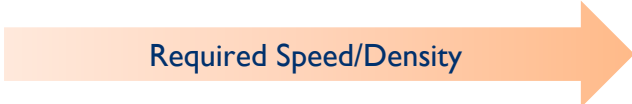


**CPU**



**Mobile AP**














**2023+**





# The MRAM Ecosystem is Growing













An increasing number of players are involved in the MRAM arena

<b>MRAM IP and Design</b>					
<b>Embedded MRAM manufacturers</b>	<p>Players in mass production or close to mass production</p> 				
<b>Stand-alone MRAM manufacturers</b>	<table border="1"><tbody><tr><td><b>40nm, up to 128Mb</b> </td><td><b>40nm, 28nm (256M, 1Gb)</b> </td><td><b>Toggle Manufacturing</b> </td><td><b>Expected: 28nm, 22nm</b> </td></tr></tbody></table>	<b>40nm, up to 128Mb</b> 	<b>40nm, 28nm (256M, 1Gb)</b> 	<b>Toggle Manufacturing</b> 	<b>Expected: 28nm, 22nm</b> 
<b>40nm, up to 128Mb</b> 	<b>40nm, 28nm (256M, 1Gb)</b> 	<b>Toggle Manufacturing</b> 	<b>Expected: 28nm, 22nm</b> 		

# Embedded MRAM Business

Key partnerships and developments for leading players.

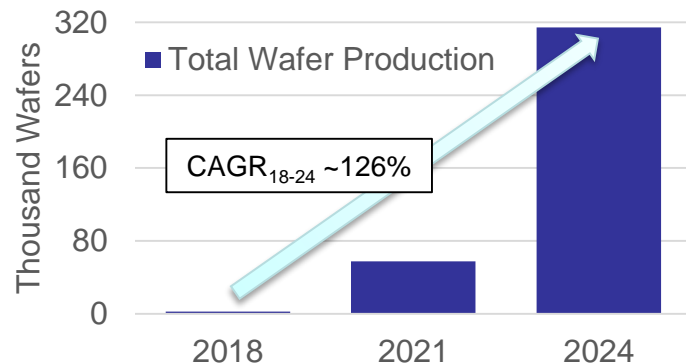
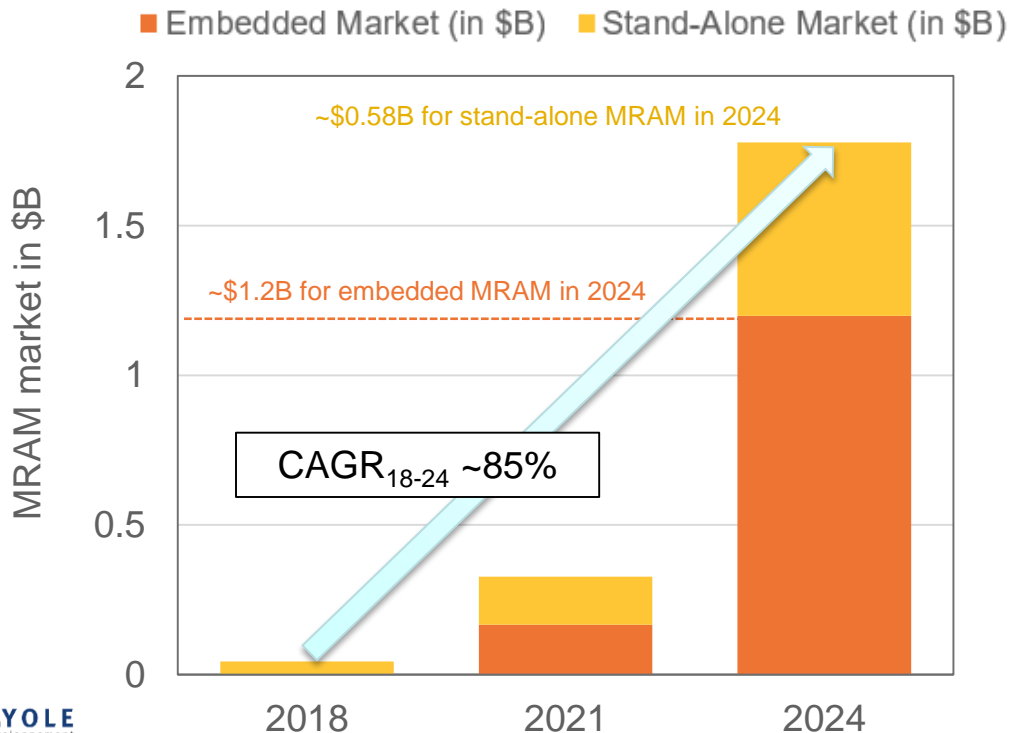
Foundry / IDM						<i>To be announced</i>
<b>(STT-)MRAM Players - Partners</b>						 
<b>Technology Process</b>	CMOS bulk 22nm planar (sampling)	FD-SOI 22nm planar (sampling)	FD-SOI 28nm planar (in mass production)	CMOS bulk 28/22nm planar (in development)	CMOS 22nm FinFET (sampling)	28/22nm
<b>Expected Short- Term Application</b>	"Slow" SRAM	eFlash	"Slow" SRAM	eFlash "Slow" SRAM	eFlash "Slow" SRAM	"Slow" SRAM

Critical Challenges	Key Equipment Suppliers (Example of Tools)				
<ul style="list-style-type: none"> <li><b>Deposition of MTJ stack</b> <i>Goal: high-quality stacks via real-time property monitoring</i></li> </ul>	 (System Endura Clover)	 (NC7900 )	 (EXIM)		
<ul style="list-style-type: none"> <li><b>Etching of MTJ cells</b> <i>Goal: high-density, narrow pitch</i></li> </ul>	 (System Centura)	 (NC8000)	 (Tactras)	 (Kyio)	 (E-9000)
<ul style="list-style-type: none"> <li><b>Testing and Metrology</b> <i>Goal: high-speed measurement of electrical and magnetics properties</i></li> </ul>	 (IBEX 300/FD)	 (T5385ES )	 (Polar Kerr System)	 (CIPTech)	



# (STT-)MRAM Market Projections

Market Forecast for Embedded and Stand-Alone (STT-)MRAM



New Report by Yole (August 2019)



# Summary and Outlook



- Thanks to strong support of top foundry/IDM players and equipment suppliers, embedded STT-MRAM is poised to become the next embedded NVM solution for technology nodes  $\leq 28\text{nm}$ .
- The **embedded STT-MRAM market** has the potential to grow up to **~\$1.2B by 2024**, driven by code/data storage and “slow” working memory applications.
- The **stand-alone (STT-)MRAM market** is expected to grow less vigorously than its embedded counterpart, with revenues up to **~\$580M in 2024**.
- In the coming years, enterprise storage (SSD caching, storage and network accelerators) will be the leading stand-alone STT-MRAM applications.



Thank you for your attention  
Questions?

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