Future Scenarios for Emerging Memory Markets

Rev 1

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New Memories

- In previous presentations (FMS) we have shown WHY Emerging memories do not ever really emerge
- They need to be **Niche**, **Embedded**, or **no cost adder** to DRAM/NAND
  - Last year we also showed how Chiplets allow integration at low cost
- Optane showed that even with billions in spending and support for ecosystem, mass acceptance is too slow to build a fab around
  - We have spreadsheets to explain why finances don't make sense.
- Hence most end up as niche or abandoned

Memory Technologies Reviewed

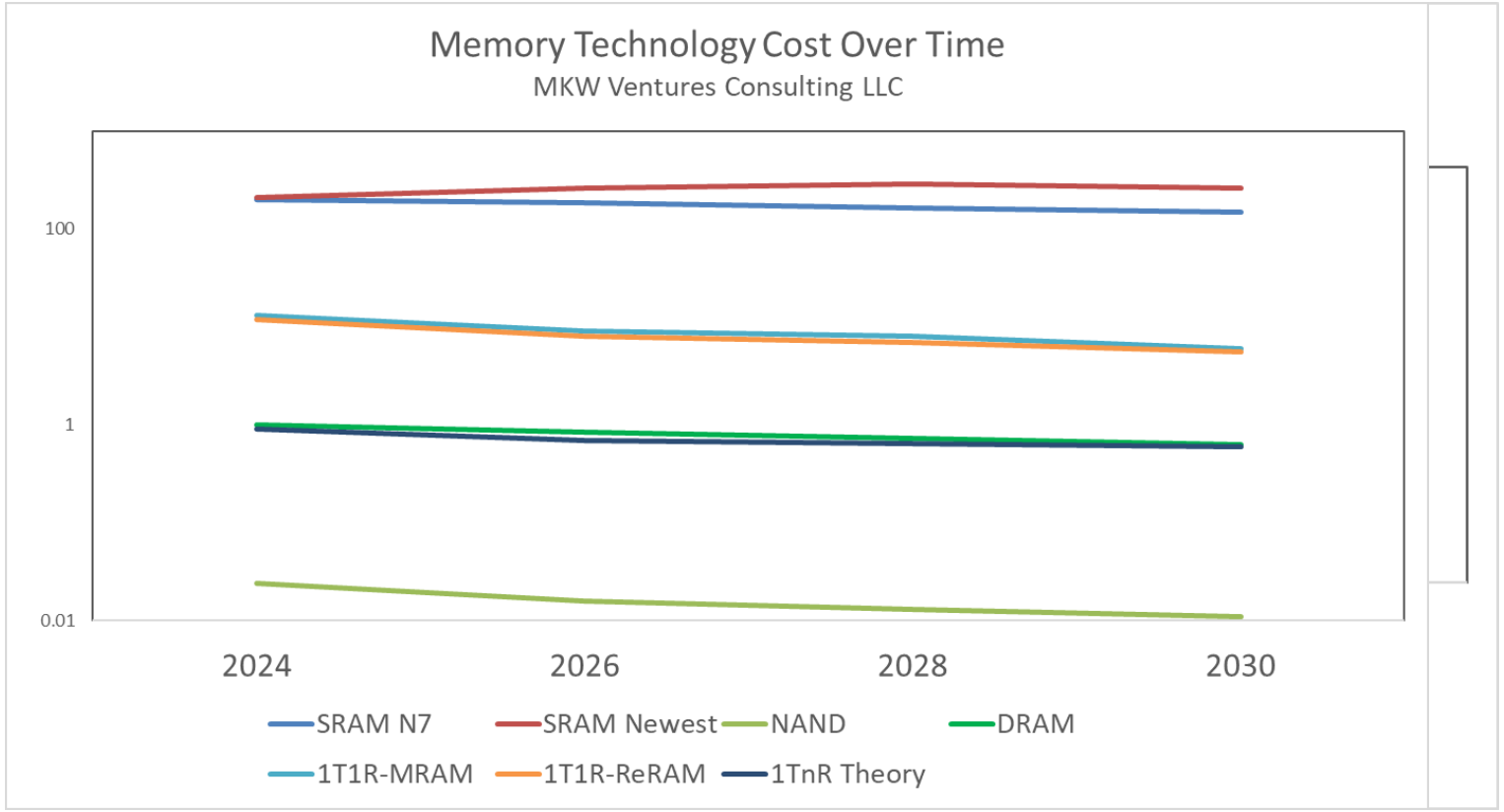
UPDATED Scorecard: We don't need Universal … Lots of Yellow!

	Latency	Density	Cost	HVM ready
DRAM	*****	***	***	*****
NAND	*	*****	*****	*****
SRAM	*****	*	*	*****
NOR	***	**	**	*****
MRAM	****	**	**	****
RRAM	***	**	**	****
PCM (1T1R)	***	**	**	****
FE DRAM (Gb)	***+	***	***	*
Other	***	**	**	*

MKW Ventures Model

Costs for All Memory Technologies Over Time

- Memory costs differ by orders of magnitude. Huge tradeoffs.
- SRAM on leading edge cost increases. SRAM on N7 node cost decreases



MKW Ventures Cost Model

NOTE: SRAM is based on cost of 2MB L2 Cache macro based on bit cost

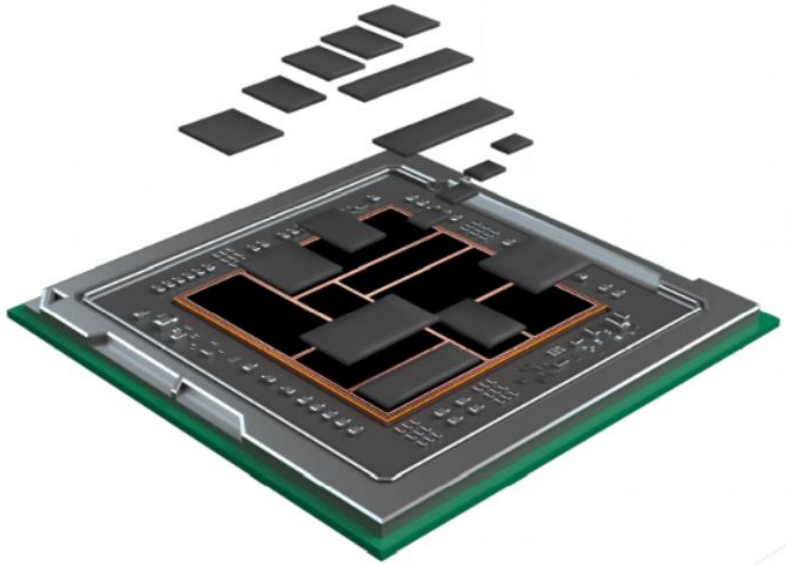
Status Updates In 2025

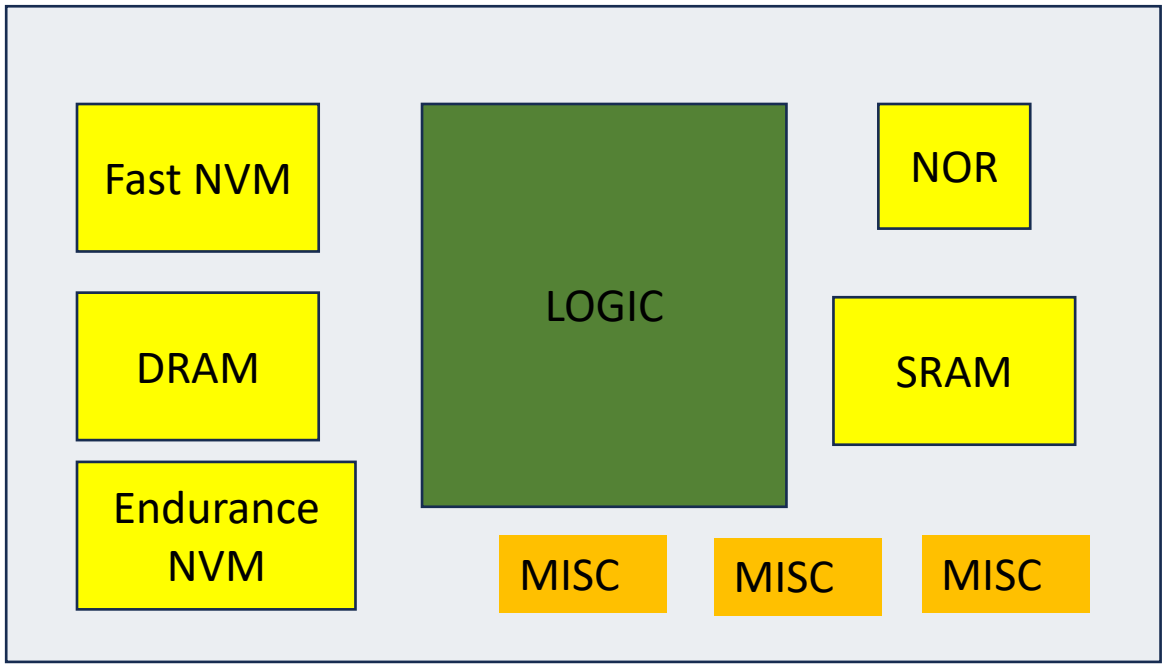
- MRAM and RRAM continue to have their place and are growing slowly
  - Embedded options with foundries large and small
  - MRAM has performance advantages, RRAM can be simpler
  - Both are more cost effective than eFLASH long term
- Phase Change is still publicized by those with PCM experience
- Historic FerroElectric (<Gbit) still used by companies who have used it
- None are close to SRAM/DRAM in performance or NAND in Cost.
  - No replacement, no universal memory ….. YET
- Newer technologies are in the early phases of development (Single cell/Small arrays). They are 8+ years from productization.
  - We have details on Product lifecycle with all the milestones

Changes in 2025

- Chiplets are becoming more widespread
  - This enables “special memory” to be used regardless of other processes. AI Applications
  - Used with N2, N7, TSMC, Intel on same base die …. Without need for true embedding.
- Only a “low Cost Adder” with >90% reuse from DRAM or NAND process can ramp as a high volume technology.
  - FE Capacitor DRAM is the ideal candidate due to tools and processes
  - Micron Presented NV DRAM with FE Storage node (NVM in DRAM process) at IEDM in 2023. No Product is being sampled at this time
  - FMC (FerroElectric Memory Corporation) Publicized FE based NV DRAM in 2025. Caching and DRAM replacement applications for multiple applications. Performance matching DRAM
  - Other memory companies are working on HF based DRAM replacement as the simplest, most cost effective NV DRAM implementation
- If the memory technology does NOT have 90% reuse, the development costs and market dynamics PREVENT growth above a niche market.
- HBM market growth has caused memory companies to change priorities and this makes support for new memories and markets difficult
  - This plus 4F/3D DRAM hurts new memory funding in major companies

Chiplet Hypothetical





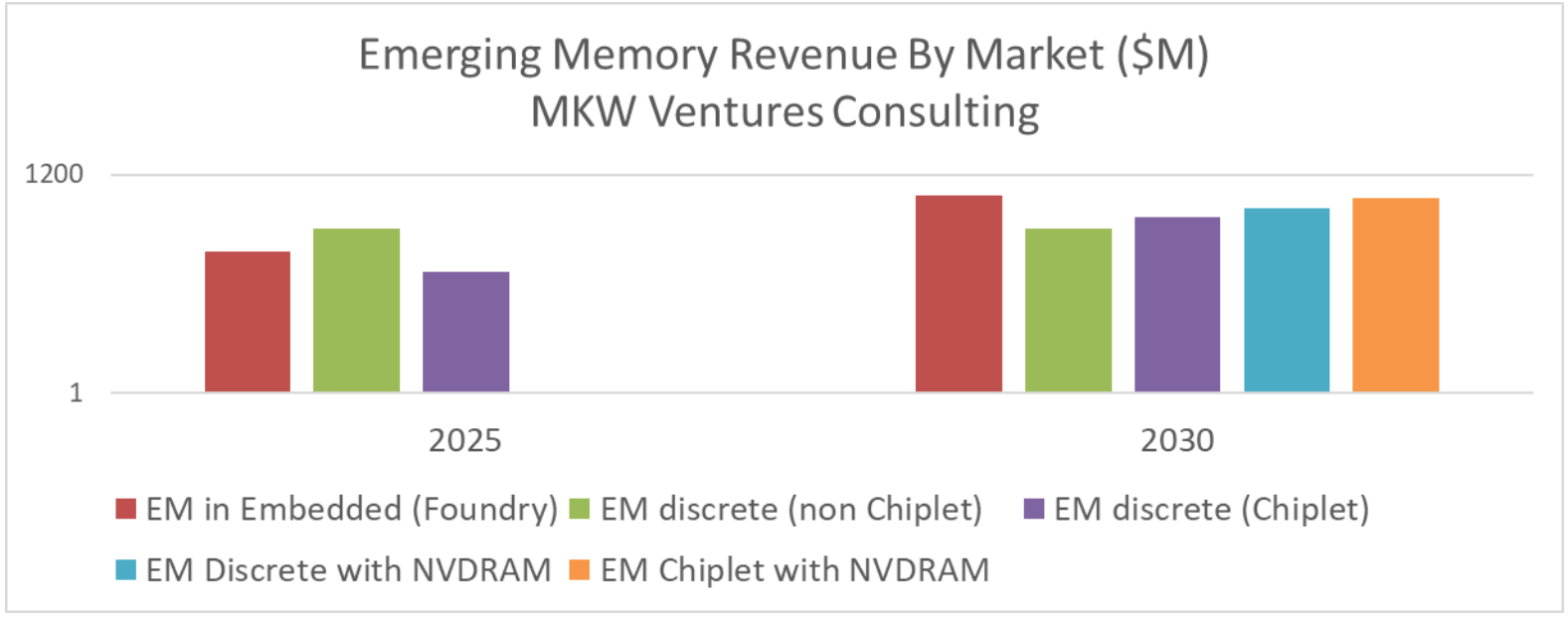
NAND/CXL DRAM off Chip

Emerging Memory Market Revenue
A new partitioning

- Existing technologies (MRAM, RRAM, PCM, FERAM) will be 99% of the revenue through 2030. Other Technologies may ramp after that
- Embedded is modelled based on amount of die area used
- Discrete is broken out by chiplet and non-chiplet (this can blur)
- IF a memory company releases a FE DRAM (Like Micron or FMC), that market has significant discrete and chiplet applications. Performance close to DRAM

CAGR through 2030

40% Embedded
20% Discrete Non-Chiplet
50% Discrete Chiplet
50%+ NV DRAM



Summary

- RRAM, MRAM, PCM, FE “mature memories” are out and growing modestly
- Newer technologies have not emerged and are 8+ years from HVM or measurable revenue
- FE based NV DRAM is the likely “no cost adder” capable of high volume (Others are Niche/embedded/Chiplet)
- We break out market revenue possibilities to allow the very different implementations to be tracked
- Total Revenue for all Emerging Memory technologies and segments is $1B in 2030. $2B if we add FE NVDRAM to the market.

Follow up

- Lots of details available on website and in follow up discussions
- Spreadsheets to discuss trade off numbers available for discussion

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