

STATUS OF THE MEMORY INDUSTRY 2020 - FOCUS ON KIOXIA

Market & Technology Report - October 2020 Update

A 360° analysis of the memory industry and its competitive landscape with a deep dive into Kioxia's NAND business.

WHAT'S NEW

- Analysis of COVID-19's impact on the stand-alone memory market: effect on demand, bit shipments, and CAPEX
- Updated market forecast (2019 - 2025) for NAND and DRAM markets, considering COVID-19's effect and the entrance of new players from China
- Overview of the NOR memory business: players, growth drivers, density-dependent applications, market share, ASP, revenue, and more
- Updated financial analysis of leading IDM companies – including Samsung, SK hynix, Kioxia, Western Digital, Micron, and Intel
- Updated list of Chinese memory players and detailed presentation of their activities in the different businesses
- Deep dive into Kioxia's NAND business in view of the IPO

KEY FEATURES

- Summary of the stand-alone memory market and related technologies, including NAND, DRAM, persistent memory, NOR, (NV)SRAM, emerging NVM, and more
- Description of technical trends and challenges, scaling roadmaps, and overview of main players for stand-alone memory technologies
- Breakdown of the memory market from a system point of view, detailing present and future memory needs for servers, smartphones, personal computers, enterprise/client SSDs, and vehicles
- Profile of the most important end-markets for stand-alone memory, i.e. datacenters, mobile, automotive, PC, and consumer electronics
- Presentation of packaging solutions for memory devices, and description of emerging packaging technologies and market trends
- Overview of embedded memory technology and progress towards in-memory computing applications
- Mapping of the stand-alone memory supply chain, analysis of recent M&A and joint ventures, list of noteworthy news, and company announcements in 2019 - 2020

IN 2020 NAND AND DRAM WILL DRIVE NEW GROWTH IN THE STAND-ALONE MEMORY MARKET, DESPITE THE COVID-19 PANDEMIC

Driven by important megatrends such as mobility, cloud computing, artificial intelligence (AI), and the Internet of Things (IoT), the stand-alone memory market has experienced extraordinary growth over the past decade. However, this exciting growth period ended in Q4-2018 when both the NAND and DRAM markets started experiencing oversupply caused by weak demand. This included lower-than-expected smartphone sales and a slowdown in datacenter demand. Inventory levels increased for memory suppliers and their OEM customers, with average selling prices (\$/Gb) declining by more than 40% in 2019. Meanwhile, combined DRAM and NAND revenue reached ~\$106B, down 34% from 2018. In 2019, significant DRAM and NAND capex cuts initiated a market recovery that began in late-2019, and which has continued in 2020. Despite the COVID-19 outbreak – which negatively impacted the smartphone and automotive markets, but spurred demand for server and PC memory for stay-at-home activities – 2020 is expected to be a year of recovery and the beginning of a new era of prosperity for the memory industry.

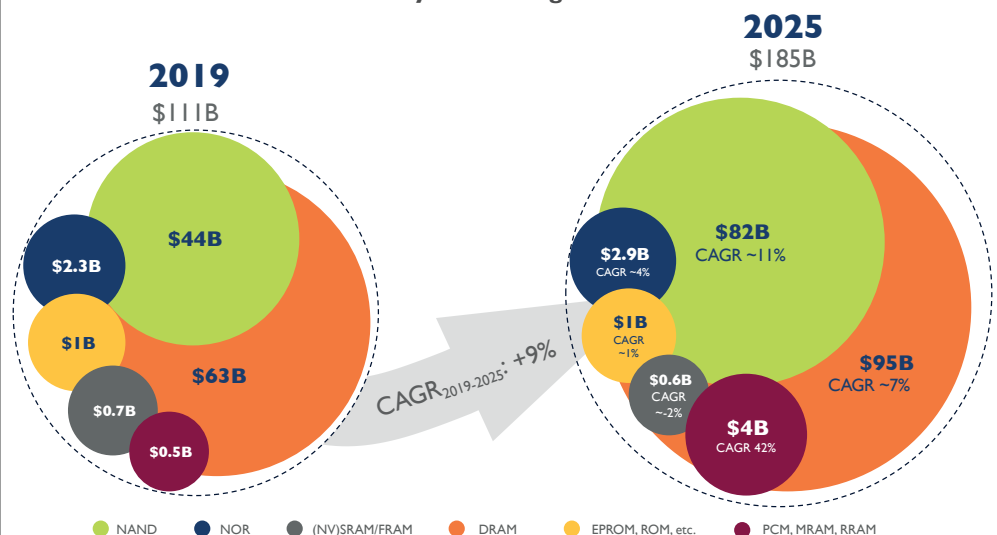
NAND and DRAM are ubiquitous technologies, together accounting for 96% of the overall stand-alone memory market. Thus, they have considerable influence over the memory

industry's overall status and dynamics. However, besides NAND and DRAM, there exists a broad spectrum of technologies that fit the requirements of different end-systems and markets. NOR flash is the third-largest market (~\$2.3B in 2019), fueled by numerous applications including industry and security (e.g. surveillance cameras), consumer and automotive electronics, as well as telecom infrastructure (e.g. 5G base stations). Despite some seasonality and cyclicity, NOR revenue is expected to grow at a CAGR₂₀₁₉₋₂₀₂₅ of 4%.

Other technologies, such as volatile and non-volatile (NV) SRAM, ferroelectric RAM (FRAM), and EEPROM represent “niche” markets that are rather static and collectively account for just ~1.5% of the stand-alone memory market.

On the other hand, emerging non-volatile memory (NVM) technologies – e.g. MRAM, PCM, and RRAM – are taking off in the storage-class memory (SCM) market. Their combined revenue is expected to reach around ~\$4B by 2025, with a CAGR₂₀₁₉₋₂₀₂₅ of over 40%. In this area, PCM (3D XPoint) will maintain its leadership until 2025 thanks to the involvement of Intel, which leads the persistent memory business with its Optane™ non-volatile memory modules.

2019 – 2025 stand-alone memory market revenue forecast with breakdown by technologies



THE ENTRANCE OF NEW PLAYERS FROM CHINA IS POISED TO CHANGE THE MEMORY MARKET LANDSCAPE

Market concentration has accelerated dramatically in the last decade and is now remarkably high. Three dominant NAND and DRAM players – namely Samsung, Micron, and SK hynix – and two pure NAND players, Kioxia and Western Digital, together hold ~90% of the stand-alone memory market. Toshiba Corporation was expected to offload its subsidiary Kioxia Holdings Corporation by selling the 40.2% stake that it holds in the company in the form of an initial public offering (IPO) to be held in October 2020. However, recent reinforcement of US restrictions (September 15th, 2020) on Huawei - one of Kioxia’s major customers - and concerns for a second wave of COVID-19 pandemic have likely pushed Kioxia’s executives to postpone the date of the IPO. Kioxia has the 2nd highest market share in the NAND market, and has had a consistent

presence in the industry since inventing the technology in the late 1980’s. Kioxia and Western Digital’s joint venture holds the highest NAND wafer capacity in the industry but their operating margins remain behind those of the industry leader Samsung. The two companies have chosen to pursue 112-layer (below industry “standard” 128-layer) and 160-layer (vs. “standard” of 176-layer), presumably to increase tool reuse and save capital.

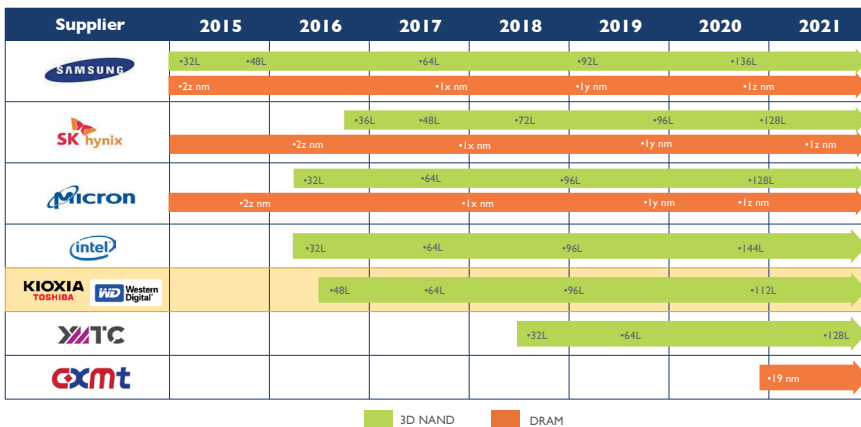
In the DRAM business, market equilibrium was sought via significant capital expenditure cuts in 2019 (25% - 30%) – and as late as Q3-19, plans existed at suppliers to reduce capital expenditure by as much again in 2020. Both Micron and Samsung are expected to introduce products based on 1z technology by 2020; SK hynix will follow.

Meanwhile, Chinese players are starting to threaten the market’s equilibrium and could trigger profound changes in the memory business. In the NAND business, Yangtze Memory Technologies Co. (YMTC) is the leading memory maker in China. The company is currently shipping 64L NAND domestically in low volumes (including SSDs), with 128L production in development and shipments expected in 2021.

In comparison, Chinese DRAM is still in the technology development phase. DRAM manufacturing is incredibly difficult, and it will likely take a while longer for China to achieve competitive parity with the industry at-large. Changxin Memory Technologies (CXMT), China’s most advanced DRAM maker, is expected to ramp up production on the 1xnm node in 2020.

For NAND, we expect that significant output (~4%) from YMTC could reach the market in 2021, while it will take longer for DRAM.

3D NAND & DRAM: timeline and time-to-market of technology generation by key players

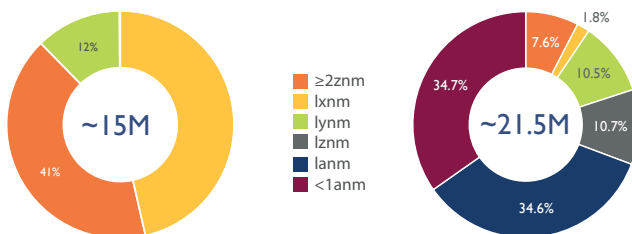


(Yole Développement, October 2020)

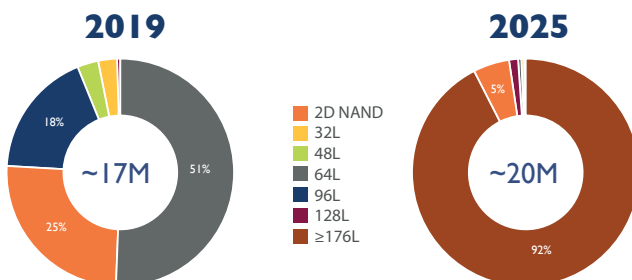
TECHNOLOGY-NODE MIGRATION IS BECOMING INCREASINGLY DIFFICULT AND EXPENSIVE

DRAM & NAND process mix evolution in 300mm wafer units production

DRAM
% of 300mm wafer production



NAND
% of 300mm wafer production



(Yole Développement, October 2020)

NAND and DRAM scalability was supposed to peak in 2020, but memory manufacturers and equipment players have found new solutions to exceed this limit. New manufacturing techniques include self-aligned multiple patterning, extreme ultra-violet (EUV) lithography and metrology, as well as high aspect ratio (HAR) etching to produce contact holes in 3D NAND devices. Novel advanced packaging methods for heterogeneous integration, i.e. 3D stacking and 2.5D silicon interposer, enable high-bandwidth memory (HBM) for fast data transfer between computing units (CPU/GPU) and DRAM.

All these singular technical solutions create new opportunities for the semiconductor industry to increase bit density in next-generation memory devices, improve their bandwidth, and reduce their power consumption and cost-per-bit. However, with each technology generation, bit growth is becoming significantly more expensive. For instance, multi-patterning requirements in DRAM are

increasing with each node migration, resulting in additional processing steps and therefore more cleanroom space per wafer produced. As DRAM shrinks and defect probability augments, DRAM manufacturers are evaluating the idea of switching from self-aligned multiple patterning to EUV lithography. Noteworthy, Samsung recently announced the shipment of one million DDR4 DRAM modules that were manufactured using the EUV technology at the 1x node.

Leveraging our comprehensive expertise in memory technologies and related markets, Yole introduces the second edition of its Status of the Memory Industry report. This report seeks to provide the broadest overview of the stand-alone memory market and its competitive landscape, detailing technical challenges, opportunities, and trends in the field of stand-alone memory, including NAND, DRAM, NOR, (NV)SRAM, emerging NVM, and much more.

COMPANIES CITED IN THE REPORT (non exhaustive list)

4DS, Adata, Adesto, Advantest, Alliance Memory, AP Memory, Apacer, Apple, Applied Materials, ASE Tech. Hold., ASML, Avalanche, Buffalo, Canon, Centon, CXMT, Cisco, CNE, Crocus, Crossbar, Cypress, Dell, Dossilicon, Etron, ESMT, Everspin, Facebook, Ferroelectric Memory Company, Fidelix, Freescale, Fudan Microelectronics, Fujitsu, Fusion IO, GigaDevice, GlobalFoundries, Google, GSI Technology, H-Grace, Hikstor, Hitachi, HLMC, Honeywell, HP, Huawei, IBM, IDT, Imec, Infineon, Intel, ISSI, JHICC, Kingston, Kioxia, KLA Tencor, Lam Research, Lapis, Lenovo, Longsys, Liteon, Lyontek, Macronix, Marvell, Maxio, Maxim, Materion, Mediatek, Microchip, Micron, Montage Technology, Nantero, Nanya, Naura, Nikon, NEC, NetApp, NetList, Numonyx, NXP, ON Semiconductors, Panasonic, Phison, Powerchip, Powertech, ProMOS Technologies, Qualcomm, Rambus, Reliance, Realtek, Renesas, Rohm, Samsung, Sandisk, Seagate, Semtech, Silicon Motion, SK hynix, SK Materials, Smart Modular Technologies, SMIC, Sony, SPIL, SST, Spin Memory, STMicroelectronics, STEC, Swissbit, TDK, Texas Instruments, Tezzaron, TEL, Teledyne e2v, Toshiba, TowerJazz, TPSCo, Transcend, Tsinghua Unigroup, TSMC, UMC, UnilC Semiconductors, Unimos Microelectronics, Viking, Violin Memory, Weebit, Western Digital, Winbond, X-Fab, XMC, YMTC, new Chinese emerging NVM players, and many more.

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> NAND market and technology		Plus a 70-slide Kioxia analysis	
> DRAM market and technology			

RELATED REPORTS, MONITORS & TRACKS



- NAND and DRAM Quarterly Market Monitors
- MRAM Technology and Business 2019
- YMTC’s 3D-NAND Flash Memory – by System Plus Consulting
- LPDDR4 Memory Comparison 2019 – by System Plus Consulting
- Samsung 3D V-NAND 92-Layer Memory – by System Plus Consulting

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REPORT OBJECTIVES

Provide an understanding of stand-alone memory technologies and applications:

- Roadmaps with technology nodes, product development status, chip density, scaling challenges, and potential solutions
- Memory content evolution in key systems: servers, smartphones, personal computers, vehicles, enterprise, and client SSDs
- Main memory end-markets: datacenter, mobile, automotive, PC, and consumer electronics

Offer market forecasts for the stand-alone memory business:

- Market forecast (2019 - 2025) for NOR, (NV)SRAM, and other technologies including PCM, MRAM, and RRAM
- Market forecast (2019 - 2025) for NAND and DRAM, with details on capex by players, price per bit, market share, bit demand, bit shipments, wafer production, and more.

Detail and analyze the competitive landscape:

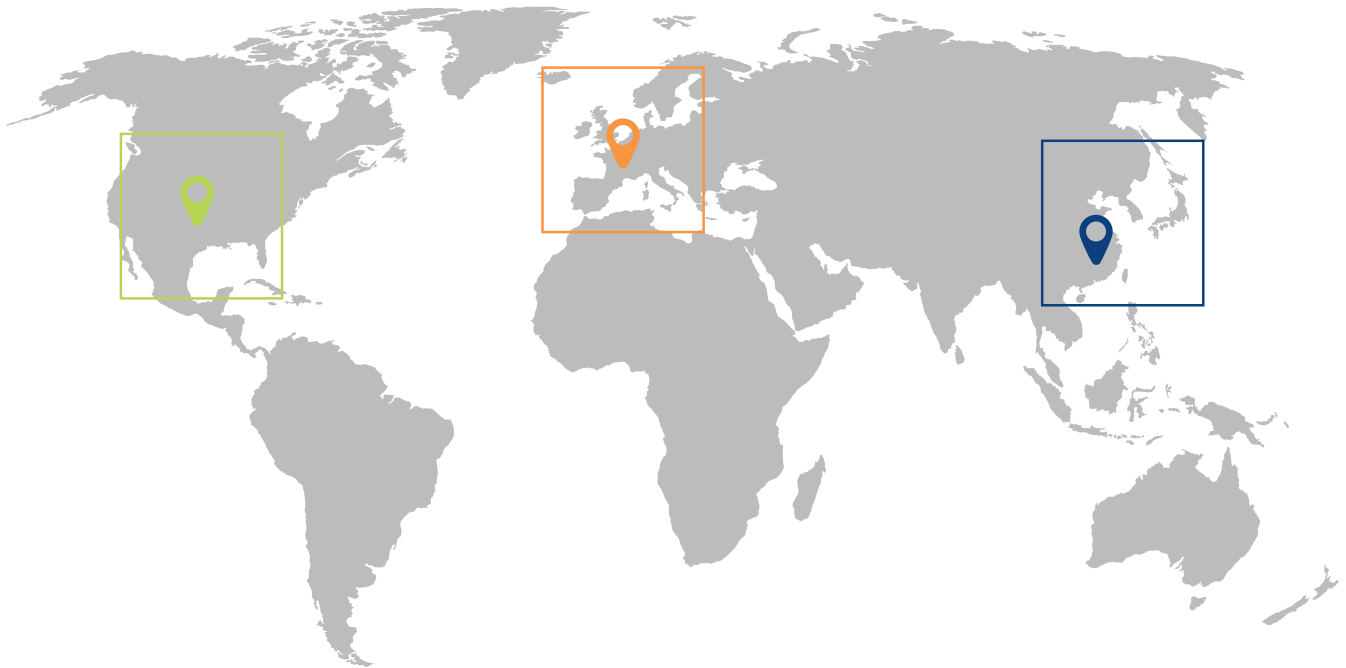
- Financial analysis: key memory companies’ revenue, capex, R&D, operating costs, and margins
- Recent mergers and acquisitions, start-up funding, and latest company news



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ABOUT YOLE DEVELOPPEMENT

Founded in 1998, Yole Développement (Yole) has grown to become a group of companies providing marketing, technology and strategy consulting, media and corporate finance services, reverse engineering and reverse costing services. With a strong focus on emerging applications using silicon and/or micro manufacturing, the Yole group of companies has expanded to include more than 120 collaborators worldwide covering MEMS and Image Sensors, Compound Semiconductors, RF Electronics, Solid-state Lighting, Displays, Software, Optoelectronics, Microfluidics & Medical, Advanced Packaging, Manufacturing, Power Electronics, Batteries & Energy Management and Memory.

The “More than Moore” market research, technology and strategy consulting company Yole Développement, along with its partners System Plus Consulting, PISEO and Blumorpho, supports industrial companies, investors and R&D organizations worldwide to help them understand markets and follow technology trends to grow their business.

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 - Within a reasonable time for Products ordered prior to their effective release. In this case, the Seller shall use its best endeavours to inform the Buyer of an indicative release date and the evolution of the work in progress.
- 2.2 The Seller shall by no means be responsible for any delay pursuant to Article 2.1 above, in particular in cases where a new event or access to new contradictory information would require the Seller analyst to dedicate extra time to compute or compare the data in order to enable the Seller to deliver a high quality Product.
- 2.3 The mailing of the Product will occur only upon payment by the Buyer, in accordance with the conditions contained in Article 3 above.

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Bank code: 30056
Branch code: 00170
Account n°: 0170 200 1565 87
BIC or SWIFT code: CCFRFRPP
IBAN: FR76 3005 6001 7001 7020 0156 587

To secure the payments due to the Seller, the Seller reserves the right to request down payments from the Buyer. In such case, the need for a down payment will be mentioned on the corresponding order.

3.3 Payment is due by the Buyer to the Seller within 30 days from invoice date, except as otherwise specifically agreed in writing by the Buyer and the Seller. If the Buyer fails to pay at the due date and fails to request and obtain from the Seller a payment extension, the latter shall be entitled to invoice interest in arrears based on the annual rate Refi of the “BCE” + 7 points, in accordance with article L.441-6 of the French Commercial Code.

3.4 The Seller publications (reports, monitors, tracks...) are due for delivery only after receipt by the Seller of any payment due by the Buyer prior to delivery.

3.5 In the event of termination of the contract by the Seller attributable to Buyer misconduct during the contract, the Seller will have the right to invoice all work performed at the time of termination, and to take legal action for damages.

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- Recordings and re-transmittals over any network (including any local area network);
- Use in any timesharing, service bureau, bulletin board or similar arrangement or public display;
- Posting any Product to any other online service (including bulletin boards or the Internet);
- Licensing, leasing, selling, offering for sale or assigning a Product or any derivative thereof.

6.3 If the Buyer would like to use data coming from a Product for presentations, press announcements and any other projects, the Buyer needs to contact Yole Développement’s Public Relations Director (info@yole.fr) to get an official authorization and confirm that the data are up to date. In return the Seller will make sure to provide up-to-date data under a suitable public format.

6.4 The Buyer shall be solely responsible towards the Seller for any infringement of the obligation described in Article 6.3 above, whether such infringement originates from the Buyer’s employees or any person to whom the Buyer has sent the Products. Furthermore, the Buyer shall initiate and personally take care of any related proceedings in coordination with the Seller, and the Buyer shall bear the related financial consequences in their entirety.

6.5 The Buyer shall define within its Company an identified user who shall serve as a contact person for the License purchased by the Buyer. This person will be the recipient of each new report. This person shall also be responsible on behalf of the Buyer, for compliance with all copyrights and other obligations relating to the protection of the Seller’s IP rights and general compliance with the terms of the License purchased by the Company. In the context of Bundle and Annual Subscriptions, the contact person shall decide within the Buyer which person(s) shall be entitled to receive the protected link that will allow the Buyer to access the Products.

6.6 It is acknowledged and accepted by the Buyer that whether purchased in the form of Bundles or Annual Subscription, all unselected reports will be deemed cancelled and lost after a period of 12 month following acceptance of the corresponding order by the Seller in accordance with provisions of Article 1.3 above .

6.7 It is further acknowledged and agreed by the Buyer that any investor in the Buyer Company, any external consultant of the Buyer Company or any joint venture done with a third party in which the Buyer Company is involved , is not entitled to use a Product, without paying to the Seller the full price for a license to the required Product..

7. TERMINATION

If the Buyer cancels the order in whole or in part or postpones the date of mailing, the Buyer shall indemnify the Seller for the entire costs that have been incurred as at the date of notification by the Buyer of such delay or cancellation. This may also apply for any other direct or indirect consequential loss that may be incurred by the Seller, pursuant to such cancellation or postponement.

8. MISCELLANEOUS

8.1 All the provisions of these General Terms and Conditions of Sale are for the benefit of the Seller, but also for that of its licensors, resellers and agents. Each of them is entitled to assert and enforce these provisions against the Buyer.

Any notices under these Terms and Conditions shall be given in writing and shall be effective upon receipt by the other Party.

8.2 The Seller may, from time to time, update these General Terms and Conditions of Sale, and the Buyer, shall be deemed to have accepted the latest version of such General Terms and Conditions of Sale, once they have been duly communicated to the Buyer by the Seller.

9. GOVERNING LAW AND JURISDICTION

- 9.1 Any dispute arising out or linked to these General Terms and Conditions of Sale or to any Licenses or Products purchased in application thereof shall be submitted to the French Commercial Court of Lyon, which shall have exclusive jurisdiction upon such issues.
- 9.2 French law (without reference to any applicable conflict of law provisions) shall apply to these General Terms and Conditions of sale and any agreement between the Buyer and the Seller made pursuant thereto.