JAPANESE SEMICONDUCTOR RENAISSANCE

October 2024

ACCELERATING THE “NEW DIRECTION” WITH TECHNOLOGY LEADERSHIP

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EXECUTIVE SUMMARY

Over the past five years, BCG has published a series of in-depth reports on the semiconductor supply chain[1] that "look around the corner" at key issues and future developments in the sector. Continuing on this path, we are starting a series of reports on parts of the supply chain, geographies and topic areas which we have not previously focused on.

In this report, we explore the Japanese semiconductor industry as well as recent shifts in the memory market.

The key points we highlight are:

- **Semiconductors are critical to today's economy.** Semiconductors represent a $600B market undergirding both everyday technologies as well as industries critical to national and economic security.

- **Japan has a unique position in the semiconductor industry.** Japan is a global leader in NAND and discrete, analog, and other (DAO) wafer fabrication. Japan is also a leader in semiconductor equipment & tools and materials, with a high share in sub-segments such as photoresist processing equipment. These supply chain activities are distributed in clusters spanning more than two dozen prefectures across Japan.

- **Japan is building on this starting point.** From this starting point, Japan is now making strategic bets to support the semiconductor industry, leveraging its original equipment manufacturers (OEMs), foreign investment, and close ties with the United States, including investments in both leading-edge and mature logic.

- **Investments in next-generation DRAM will accelerate Japan's New Direction policy.** AI/GenAI technologies are driving an explosive need for semiconductor memory. As a result, next-generation DRAM demand is growing rapidly and is expected to be supply-constrained through 2028. Building on existing strategic bets, including investments in EUV, as well as mature and leading-edge logic, scaled investments in next-generation DRAM would substantially accelerate progress towards the goals of the Japanese government's New Direction—by promoting energy efficiency, workforce productivity, and supply chain resilience and other priorities.

- **Such investments will benefit Japan's economy and society.** Memory fabs create significant economic benefits in terms of jobs and output; they represent a highly value-adding use of Japan's shrinking workforce; and steadily drive the country's semiconductor ecosystem due to continued capital and R&D requirements. Furthermore, advanced memory chips are also widely used in downstream industries that contribute a substantial share of Japan's current and future value-added output.

- **While still Capital-intensive, the memory industry is now a safer bet than it once was.** Thanks to reduced market fragmentation, the economic viability of memory investments is greater than at any other point in recent history. Peak-to-trough price variability over a memory cycle is now 20 percentage points less intense than it was pre-2010. Further, by virtue of deeper cooperation with logic foundries, customized memory will increase differentiation for memory makers, partially reducing the pressures of commoditization.

- **Regardless of where Japan decides to focus, there are a few critical factors for success.** To enhance its attractiveness for semiconductor investment, a goal which Japan has publicly committed to, Japan can crowd-in private investment, ensure local innovation, adopt a long-term policy focus, and develop local talent.

By focusing on these success factors and leveraging its unique position, Japan can accelerate into its New Direction, bolstering its economic and national security as well as its position as a global technology leader.

1. *See Government Incentives and US Competitiveness in Semiconductor Manufacturing* (BCG & SIA, September 2020)*; Strengthening the Global Semiconductor Supply Chain in an Uncertain Era* (BCG & SIA, April 2021)*; Establishing Leadership in Advanced Logic Technology* (BCG, November 2021)*; Emerging Resilience in the Semiconductor Supply Chain* (BCG & SIA, May 2024).

1. SEMICONDUCTORS ARE INCREASINGLY CRITICAL FOR THE 21ST CENTURY ECONOMY—ATTRACTING SUBSTANTIAL INVESTMENT IN THE NEXT DECADE

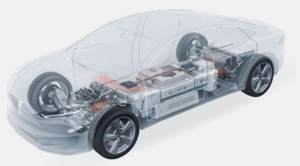
Semiconductors are an increasingly critical component in modern technology and global infrastructure. They feature in everyday products like mobile devices, computers, TVs, home appliances, and connected vehicles.

Semiconductors also form the backbone of the digital economy, in the compute and storage infrastructure that enables AI, self-driving cars, and Industry 4.0. They are equally critical for less commonplace applications like those in aerospace and defense systems (**Exhibit 1**).

A typical smartphone contains dozens of chips, and chips can account for over half of its total cost.[2] A battery-electric vehicle with advanced driver assistance systems (ADAS) contains up to $1,700 worth of semiconductor content—four times the amount in a non-ADAS, internal combustion vehicle.[3] An F-35 fighter jet contains over 3,500 semiconductors and over 200 field-programmable gate arrays used in 12 subsystems.[4]

Exhibit 1:
Semiconductors serve critical functions in everyday products, as well as industrial, infrastructure, and defense systems

Everyday products: *Ex. Connected cars*

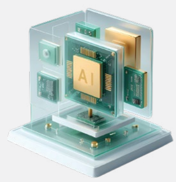


Traditional ADAS and automated driving including lane changes, traffic sign adherence and navigation

Infotainment systems, including AI enabled functions, on-demand entertainment, voice interaction, and connectedness

Centralized processing architecture for efficient operation and over-the-air updates

Emerging tech: *Ex. AI servers*



Data storage for storing training models and model parameters such as biases, as well as temporary storage of results

Instruction fetching for code execution and high-speed data access and parallel processing

Data movement among various components of the chip

Industrial tools: *Ex. Industrial robots*

Centralized control through powerful central processing systems, controlling multiple robots simultaneously across factory floor

Machine vision and advanced automation supported by AI

Digital twin for real time monitoring of factory machinery performance and production workflows

Defense: *Ex. Military planes*

Increased bandwidth supports better communication among this aircraft, other allied aircraft, and command centers

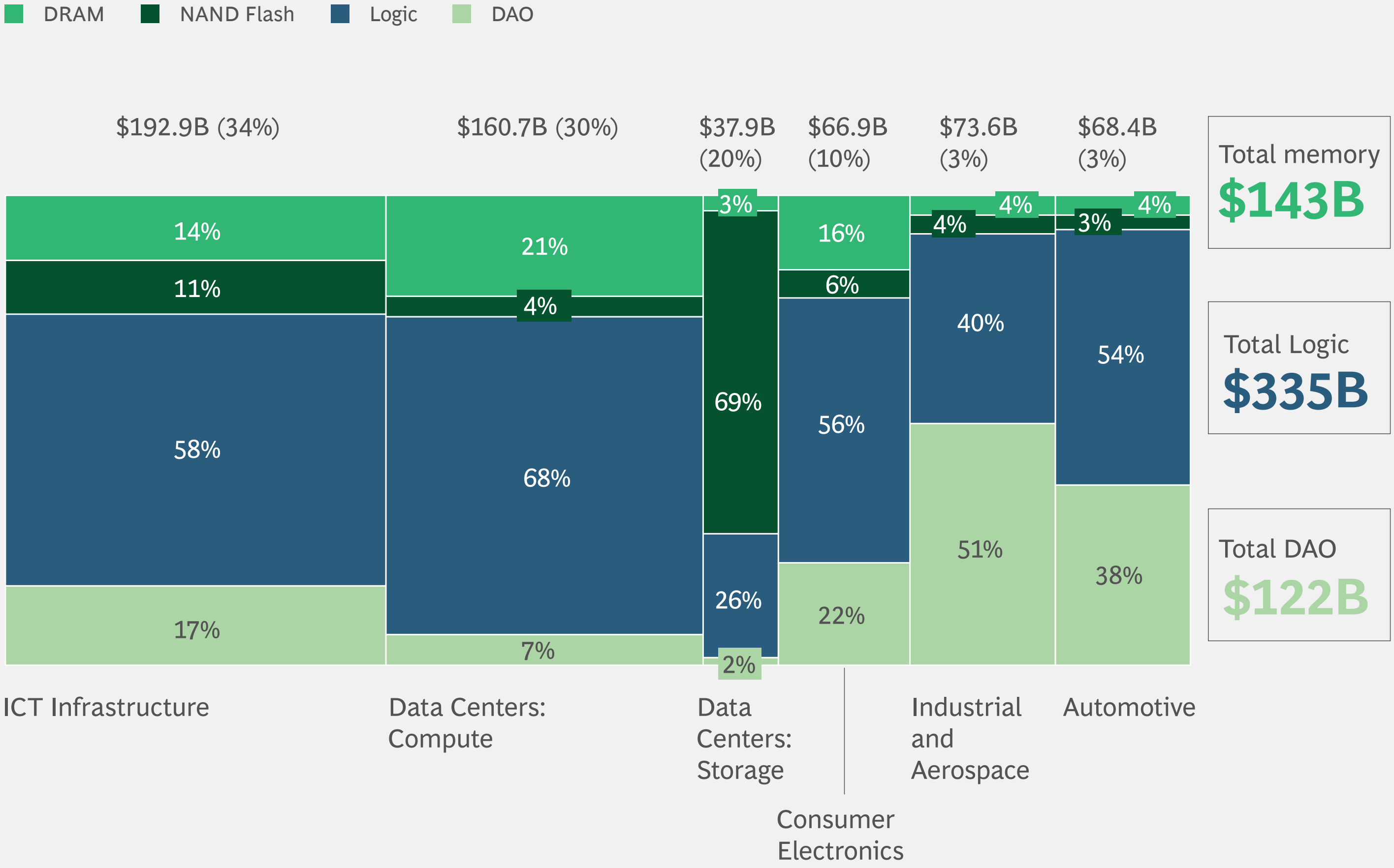
Collection, processing, and management of air and aircraft data, such as health, performance, and navigation

Advanced sensors and radar systems to detect threats to aircraft security and target tracking

2. Quartr, *The Suppliers Making the iPhone Possible* (10 May 2024). https://quartr.com/insights/company-research/the-suppliers-making-the-iphone-possible; CNBC, *How Manufacturing Chips in the US Could Make Smartphones More Expensive* (9 March 2023).
3. Gartner and Strategy Analytics; BCG semiconductor supply-demand forecast.
4. Potomac Institute for Policy Studies, 2019

Exhibit 2:
Semiconductor market is worth ~$600B, serving a variety of end-markets

Global semiconductor sales by application market, 2022 ($, %)



Source: Gartner, BCG analysis

As a result of all these wide uses, the global semiconductor market today is estimated at $600B, growing at 7-8%, across a variety of end-markets, led by information and communications technology (ICT) infrastructure and data center storage and compute. In terms of types of semiconductor devices, the market is segmented into logic ($335B), memory ($143B), and discrete, analog, and other (DAO) ($122B). Within memory, there are two broad types of devices—NAND, which is used primarily for storage of data and information, and DRAM, which is effectively the “working memory” for compute-intensive devices (**Exhibit 2**).

Over the past four years, the semiconductor industry has witnessed significant new investment around the world, focused on innovation, technology development, and manufacturing capacity expansion.

In recent BCG reports, we have projected $2.3T of capital investment in the industry through 2032, much of which is being invested outside the HQ regions of semiconductor companies.[5] As discussed elsewhere, a range of industrial policy efforts are contributing to this shift in global investment patterns, including for example:

5. For detailed projections, see *Emerging Resilience in the Semiconductor Supply Chain* (BCG & SIA, May 2024).

- In the United States, the CHIPS Act, enacted in 2022, appropriated over $52 billion in funding to support the semiconductor industry, including $39 billion in grants for manufacturing and $13 billion in funding for R&D and workforce development, in addition to a 25% semiconductor manufacturing investment tax credit.[6]

- Mainland China has developed a comprehensive semiconductor industrial policy centered on the National Integrated Circuits Industry Development Investment Fund,[7] which has gone through three phases since being established in 2014. Phase I (2014) raised over $20 billion in state-backed financing in support of fabrication and design activities; Phase II (2019) raised an additional $32 billion, with a greater focus on supporting older node fabrication projects[8] and design activities; and Phase III (as of 2023) aims to raise a record $40 billion, with priority on manufacturing equipment.[9]

- In Europe, the EU Chips Act, enacted in September 2023, seeks to mobilize $47 billion in public and private funds via three funding mechanisms: Invest EU, the European Investment Bank Group, and the European Innovation Council.[10]

- Japan has conferred significant financial support to major wafer fab construction, including TSMC's joint venture with Sony, DENSO, and Toyota for a new logic fab in Kumamoto; Kioxia and Western Digital's joint venture to construct Yokkaichi Fab 7; and Micron's capacity expansion in Hiroshima.[11] Japan is also supporting leading-edge chip innovation through Rapidus, a consortium backed by Japanese companies and IBM.[12]

- South Korea in 2021 unveiled the K-Belt Semiconductor Strategy, aimed at attracting up to $450 billion of investment. Korea is offering a series of tax credits: for R&D, 50% for SMEs and 30% for large enterprises; for manufacturing, 25% for SMEs and 15% for large enterprises.[13]

- In Taiwan, the Chip-based Industrial Innovation Program allocates $9.2 billion in funding in 2024-2033 for innovation programs, and Taiwan is also offering tax incentives of up to 25% for R&D activities in logic chips and 5% for equipment used in advanced manufacturing processes.[14]

These and other programs, including semiconductor strategies, international partnerships, and incentive programs recently announced by Costa Rica, India, Indonesia, Malaysia, Panama, the Philippines, and Vietnam, will shape the industry over the coming decade.

6. John D. Sargent Jr., Manpreet Singh, Karen M. Sutter, "Frequently Asked Questions: CHIPS Act of 2022 Provisions and Implementation," Congressional Research Service, 25 April 2023.

7. Notice on Issuing Guidelines for the Development and Promotion of the Integrated Circuit Industry (State Council, issued 24 June 2024).

8. The focus on more mature node fabrication is reflected in China's production capacity build up primarily in semiconductors at or older than 28 nm.

9. SIA, "Taking Stock of China's Semiconductor Industry," July 2021; *Notice on Issuing Guidelines for the Development and Promotion of the Integrated Circuit Industry* (People's Republic of China State Council, issued 24 June 2024)

10. European Commission, *European Chips Act*. https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age/european-chips-act_en

11. Bloomberg, "In Boost for Chip Ambitions, Japan Inks $1.3 Billion in Subsidies for Micron Plant," 2 October 2023; Nikkei Asia, "Japan to Subsidize TSMC's Kumamoto Plant by Up to $3.5bn," 17 June 2022.

12. CSIS, "Japan Seeks to Revitalize Its Semiconductor Industry," 25 August 2023.

13. Korea Legislation Research Institute translation of "Act on Restriction on Special Cases Concerning Taxation."; Kim & Chang, "Enactment of the K-CHIPS Act - Government's Support and Regulatory Policies for the Semiconductor Industry," 22 May 2023.

14. Department Information Services, Executive Yuan, "Taiwan Chip-Based Industrial Innovation Program," 13 November 2023.

2. JAPAN HAS A UNIQUE POSITION IN THE INDUSTRY—AND IS BUILDING ON IT

2.1 Japan's Position Today

Japan has a rich history in the semiconductor industry. Japanese electronics companies began importing US semiconductor technology in the early 1970s, and Japan soon began producing semiconductors as well as developing a domestic supply chain. By the 1980s, Japanese companies had become major players in the global semiconductor industry.

While the industry has undergone significant change, including multiple waves of market consolidation—Japan and Japanese companies remain key players.

To make this concrete, Japanese companies are major suppliers of NAND and DAO devices, accounting for approximately 30% and 25% of global wafer production capacity respectively.[15] In addition, Japanese materials suppliers provide critical inputs for both front-end and back-end manufacturing flows. Japan also has depth in equipment and automation tools; for example, Japan-headquartered companies account for 92% of global revenue for photoresist processing equipment and 64% for manufacturing automation equipment (**Exhibit 3**).

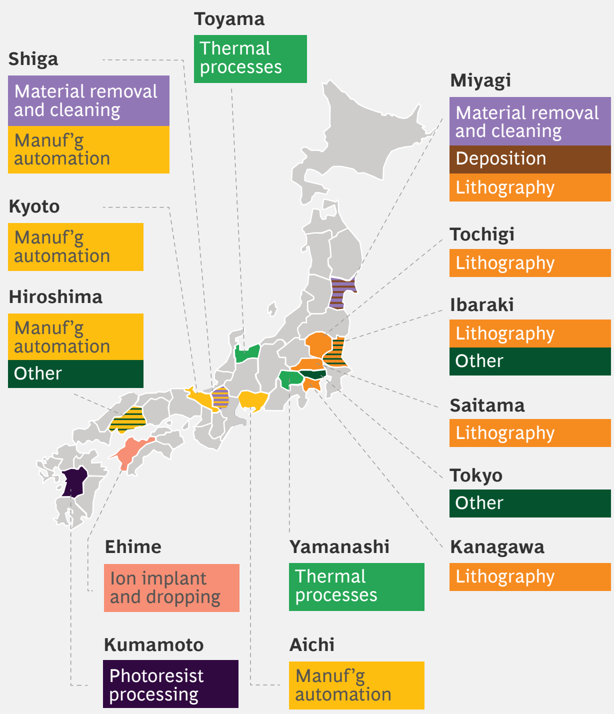
Exhibit 3:
Japan is a global leader in semiconductor equipment across many segments, with a broad site footprint across Japan

% Share of Global Market by Revenue (2022)

Wafer fabrication process	US	EU	CN	KR	JP	OTHERS
Lithography	1%	89%			10%	
Photoresist processing			3%	5%	92%	
Ion implant and doping eqpt	83%				17%	
Thermal processes	57%	4%	2%	1%	37%	
Deposition	67%	11%	2%	5%	15%	
Material removal and cleaning	56%	0%	5%	4%	35%	0%
Manuf'g automation	5%			11%	64%	21%
Process control	76%	7%	0%		11%	6%
Other	1%	8%		5%	43%	42%

1–5% 6–10% 11–25% 26–50% 51–75% 75–100%

Key Regions with Sites in Japan



Source: Gartner, company websites; BCG analysis

15. For detailed figures and charts on wafer fabrication capacity by process technology, see *Emerging Resilience in the Semiconductor Supply Chain* (BCG & SIA, May 2024).

Japan's deep semiconductor supply chain is distributed across multiple clusters—there are presently 25 prefectures in Japan with significant semiconductor wafer fabrication sites (**Exhibit 4**). As Japan's semiconductor industry continues to develop, these regional economies could serve as seeds for the development of major industrial ecosystems anchored, for example, on leading-edge manufacturing or design investments.

Japan continues to be a leading region in global semiconductor innovation. According to data from the World Intellectual Property Organization, Japanese entities have been among the leaders in semiconductor-related patent publications in the United States and Europe. Between 2004 and 2023, Japanese entities accounted for 29% of all such patents filed in the United States and Europe, only slightly behind the United States at 34% and ahead of all other major regions.[16]

Exhibit 4:
Prefectures ordered by number of semiconductor wafer fabrication sites

Prefecture ranking by the number of semiconductor factories by category

■ Prefectures with foreign-invested fabs

LOGIC

Prefecture	Total	Ownership: Japan	Ownership: Foreign	Capacity[2]
Kumamoto ■	7	4	3	270K
Nagasaki	6	6	0	101K
Oita	4	4	0	106K
Aichi	3	3	0	30K
Hokkaido	3	3	0	75K
Ibaraki	3	3	0	64K
Kagoshima	3	3	0	70K
Mie ■	3	0	3	83K
Shizuoka	3	3	0	38K
Yamagata	3	3	0	83K

MEMORY

Prefecture	Total	Ownership: Japan	Ownership: Foreign	Capacity[2]
Mie	9	9	0	785K
Hiroshima ■	3	0	3	130K
Iwate	2	2	0	200K
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-

ANALOG/POWER

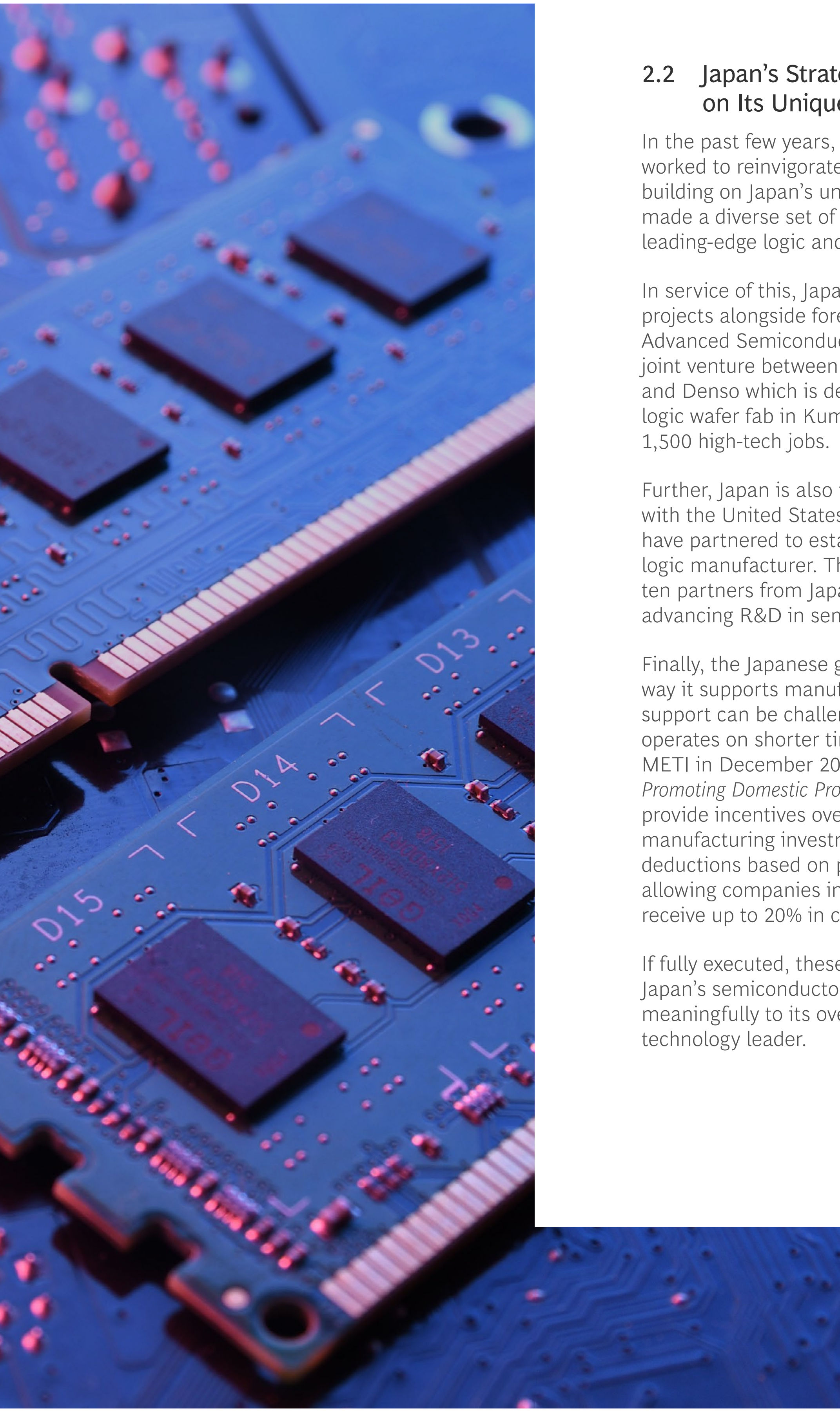
Prefecture	Total	Ownership: Japan	Ownership: Foreign	Capacity[2]
Yamagata	9	9	0	163K
Fukuoka	6	6	0	93K
Ishikawa	6	6	0	284K
Nagano	5	5	0	143K
Okayama	5	5	0	176K
Ibaraki	4	4	0	30K
Fukushima ■	4	2	2	166K
Yamanashi	4	4	0	87K
Kumamoto	3	3	0	210K
Aichi	3	3	0	23K

OTHERS[1]

Prefecture	Total	Ownership: Japan	Ownership: Foreign	Capacity[2]
Tokushima	9	9	0	320K
Kyoto ■	8	5	3	66K
Kanagawa ■	7	6	1	8K
Nagano	6	6	0	116K
Shizuoka	6	6	0	52K
Akita	5	5	0	91K
Ibaraki ■	4	2	2	52K
Saitama	4	4	0	68K
Miyagi	4	4	0	30K
Osaka ■	4	1	3	19K

Note: Jan 2023 to Dec 2025, 1Q24 (Mar 12, 2024)Edition
1. MEMS, LED, and etc.; **2.** Total wspm
Source: SEMI, BCG analysis

16. Based on an analysis of patent publications in the United States and Europe for semiconductor technology between 2003 and 2022. (At time of publication, data was not received for 2023.) Analysis included all patent publications for which region/country of origin was known, and excluded patent publications for which region/country of origin was not known.



2.2 Japan's Strategic Bets to Build on Its Unique Position

In the past few years, the Japanese government has worked to reinvigorate its semiconductor industry, building on Japan's unique position. To do this, it has made a diverse set of "strategic bets," largely in leading-edge logic and mature logic.

In service of this, Japanese OEMs have co-invested in projects alongside foreign companies. For example, Japan Advanced Semiconductor Manufacturing Inc. (JASM) is a joint venture between Taiwan's TSMC and Japan's Sony and Denso which is deploying $7B to construct a large logic wafer fab in Kumamoto prefecture, creating over 1,500 high-tech jobs.

Further, Japan is also taking advantage of its close ties with the United States. Rapidus and IBM, for example, have partnered to establish a new Japanese leading-edge logic manufacturer. The US-JOINT consortium, including ten partners from Japan and the United States, is now advancing R&D in semiconductor packaging technologies.

Finally, the Japanese government is also redefining the way it supports manufacturing investment. Long-term support can be challenging in Japan's fiscal system, which operates on shorter time horizons. To address this issue, METI in December 2023 announced *Tax Incentives for Promoting Domestic Production in Strategic Sectors*, which will provide incentives over the full operating lifecycle of a manufacturing investment. The new incentive offers tax deductions based on production and sales volume, allowing companies in the semiconductor sector to receive up to 20% in corporate tax deductions.[17]

If fully executed, these strategic bets will reinvigorate Japan's semiconductor industry and contribute meaningfully to its overall position as a global technology leader.

17. The incentive period lasts for 10 years after the business plan is approved by the government, with an additional tax carryforward period of up to three years for semiconductor companies. Currently, this incentive only covers MCU and analog semiconductors, not DRAM.

3. NEXT-GENERATION DRAM IS A VALUABLE OPPORTUNITY FOR JAPAN TO ENHANCE TECHNOLOGY LEADERSHIP

3.1 AI/GenAI Will Drive Explosive Growth in Next-Generation DRAM

AI and Generative AI are triggering levels of investment in both hardware and software that have not been seen since the dot com era. In the coming years, DRAM performance will need to evolve rapidly to keep pace with increasingly sophisticated AI systems. These could include, for example, new functions related to neuromorphic computing and new model frameworks for GenAI beyond the current transformer approach. As the very core and purpose of computing itself evolves because of AI—from search to synthesis, from serving up information to serving as agents, from computing using prior training to more extensive context, history, real time learning and autonomous agency—the memory sector, and DRAM in particular, will be called upon to add increasing value.

Shipments of AI-related servers are expected to grow six-fold between 2023 and 2027. During the same four-year period, on a per-server basis, high bandwidth memory (HBM)[18] content is expected to increase at a compound annual rate (CAGR) of 50%, and system DRAM at a CAGR of 30% **(Exhibit 5)**.[19]

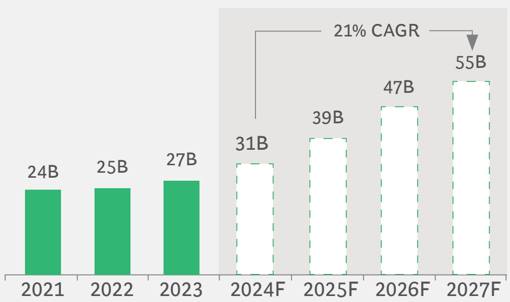
Exhibit 5:
GenAI driving demand for next-generation DRAM with shipments forecast to rise

Growth in AI will drive disproportionate growth, particularly in HBM and GDDR

MEMORY TYPE	BIT GROWTH (CAGR '24–27)	ASP[1] GROWTH	KEY DRIVER
HBM	30–40%		Growth in AI (esp. multi-modal models)
GDDR	15–20%		Increasing inferencing, especially cost-focused
DDR	10–15%		Increase in AI server shipments
LP-DDR	15–20%		Edge / smart devices inferencing (e.g. AI phones)
NAND	20–25%		Storage of training data, models, and outputs

Leading DRAM shipments overall to experience rapid growth over the next 3 years

DRAM shipments (GB)



1. Average selling price
Source: Gartner; Yole; Omdia; Analyst Reports, BCG analysis

18. High Bandwidth Memory (HBM) is a high-performance computer memory interface for 3D-stacked DRAM. It is designed to provide high bandwidth and low power consumption for applications that require fast data transfer rates, such as high-performance graphics, AI, networking, and high-performance computing.

19. *Memory and the AI Cycle: And What If It Were Only the Beginning: Increasing Micron's Price Target to $150* (New Street Research, 27 March 2024).

We estimate that even after adjusting for the fact that DRAM makers have and will likely continue to find ways to increase memory density—i.e., the number of GB of storage capacity per square millimeter of wafer—growth in memory storage demand will outpace supply based on currently announced plans by ~2-4 percentage points per year through the end of the decade.

This trend will likely contribute to a supply-constrained environment around 2027 or 2028 which could extend beyond that, given the three-to-five-year lead time to get a new fab investment off the ground.

3.2 Japan Has Strong Comparative Advantages in DRAM to Leverage

Japan has two crucial comparative advantages in DRAM to draw on should it aim to establish itself as a technology leader in next-generation DRAM. First, Japan is one of the only countries in the world where DRAM intellectual property is or has been generated at material levels.

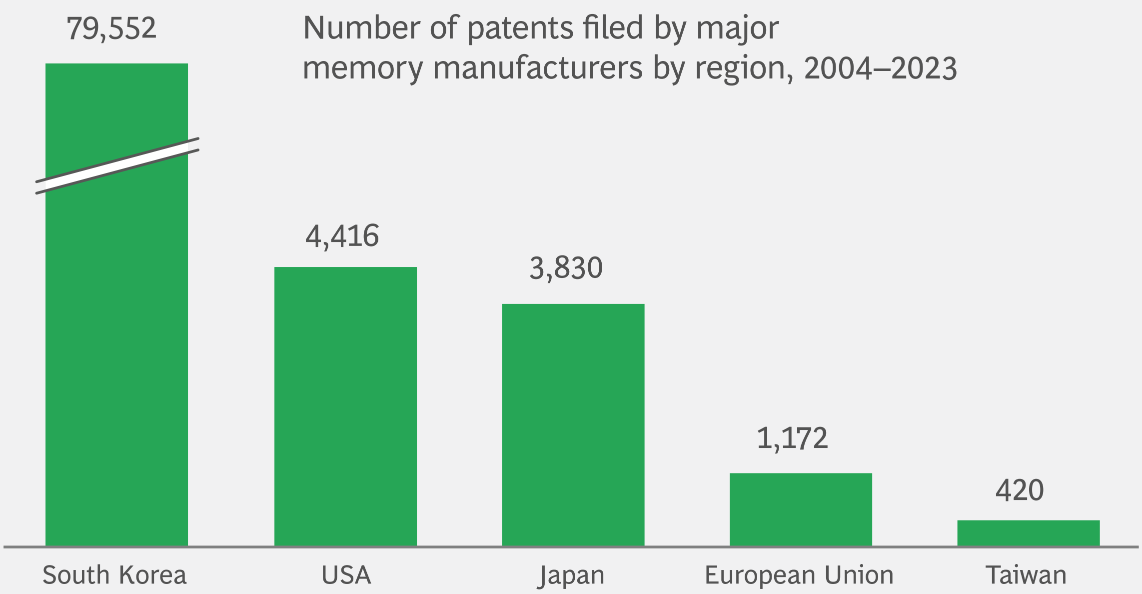
Analysis based on manufacturing-related patents filed over the last twenty years by the leading memory semiconductor companies shows Japan has contributed significantly to the advancement of the state of the art in this space (**Exhibit 6**).

Second, Japan is also one of the few countries where extreme ultraviolet (EUV) lithography is expected to be used to make advanced memory chips. Proactive moves by the Japanese government, as part of the previously mentioned "strategic bets," have fostered collaboration between universities and domestic and foreign companies and resulted in strong R&D partnerships as well as more integration of EUV into DRAM production processes.

Taken together, Japan's innovation and manufacturing assets set it up for a higher likelihood of success in developing next-generation DRAM than many other countries, especially in combination with its position in semiconductor materials, equipment and tools, and wafer fabrication.

Exhibit 6:
IP generation related to memory manufacturing is concentrated in a small number of countries

Memory IP generation by region



Note: Analysis based on manufacturing related patents filed by players of interest since 2003. Region of IP generation is sourced by using inventor address. Manufacturing-related patents are identified using patent technology codes and keywords. For readability, roughly 2% of patents from 12 other countries with smaller filing volume, including India, Singapore, and mainland China not shown. Major memory manufacturers considered are SK Hynix, Samsung, and Micron. Patents with multiple authors are counted separately in each region. Includes all patents including those acquired through acquisition.
Source: Patentsight, Center for Growth & innovation Analytics (GIA), BCG Analysis

4. INVESTING IN DRAM, AS PART OF ITS BROADER STRATEGY, BENEFITS JAPAN AND THE GLOBAL TECHNOLOGY SECTOR

Investing behind DRAM as part of Japan's broader semiconductor strategy would align with Japan's strategic focus and drive several benefits. For example, such a choice:

- **Supports Japan's New Direction policy in energy, supply chain resilience, and workforce**
- **Mutually reinforces competitive advantage in Japan's downstream industries**
- **Benefits Japan's semiconductor ecosystem**
- **Creates a positive economic impact for Japan**
- **Produces high economic output per unit of workforce input**

In addition, it would also benefit the global technology sector—and the downstream industries it supports—by enhancing global resilience in the memory sector.

4.1 Supports Japan's New Direction in Energy, Supply Chain Resilience, and Workforce

The Japanese government is embarking on a "New Direction" in its economic and industrial policy. The New Direction aims to address pressing social and economic challenges (including climate change, digitization, Japan's aging workforce, economic security, and supply chain resilience) through "mission-oriented projects" that are large-scale, long-term, and well-planned.[20]

As part of the New Direction, Japan's Ministry of Economy, Trade and Industry (METI) in 2023 updated the Semiconductor and Digital Industry Strategy. The Strategy seeks to accelerate digitization throughout the economy, using AI/GenAI, to address energy consumption, labor shortages, and other challenges. To power this, the Strategy promotes the use of semiconductors and software that enable large-scale & high-speed information processing, and enhanced adoption of HBM chips for more memory bandwidth and less power consumption.[21] By enabling widespread use of AI in an energy-efficient manner, the memory sector, especially next-generation DRAM, can support many strategic aims of the New Direction and address:

- **Energy efficiency:** Japan is targeting net-zero greenhouse gas emissions by 2050, with an ambitious interim target set for 2030. In support of this goal, Japan adopted a Green Growth Strategy in 2020. As Japan builds data centers to accommodate AI/Gen AI (for all industry), the evolution of advanced HBM chips—including a potential 11-fold improvement in energy consumption—can allow Japan to reconcile this technology with its sustainability goals.

- **Supply chain resilience:** Japan is working actively to "reshore" key manufacturing to remove supply chain bottlenecks and reduce reliance on raw materials imports. Next-generation DRAM chips can contribute to this objective. For one, they can enable efficiency gains in advanced manufacturing industries to offset capital and operational costs of bringing production back to Japan. They can also power data-driven solutions—such as in robotics and Industry 4.0—to economize on raw materials.

- **Aging population:** A key thrust of the New Direction's efforts is to mitigate the impact of Japan's aging population. By enabling improvements in ICT infrastructure and data center compute and storage, next-generation DRAM chips can accelerate Japan's digital transformation in service industries that drive the bulk of employment in Japan today and are contending with labor shortages. Moreover, as further discussed at Section 4.5 below, a memory fab generates significant value per worker and is therefore a smart choice for deploying Japan's shrinking industrial labor force.

20. METI press release, 2021. Available at: https://www.meti.go.jp/english/press/2021/pdf/1116_Current_Situation.pdf.

21. METI policy document. Available at: https://www.meti.go.jp/policy/mono_info_service/joho/conference/semicon_digital/kaitei_senryaku.pdf

4.2 Drives Competitive Advantage in Japan's Downstream Industries

Japan excels in developing ecosystems that feed into its key downstream industries—including automotive, robotics and machinery, telco equipment, consumer electronics, and gaming. These highly competitive industries will increasingly rely on AI/GenAI—and therefore advanced memory semiconductors.

The value-added output of manufacturing industries that use memory chips[22] in Japan is estimated at $483B today and is forecast by Oxford Economics to grow to $557B by 2032.

These industries will benefit tremendously from having a local supply of leading-edge memory chips, and similarly will form a natural source of demand for domestically produced chips.

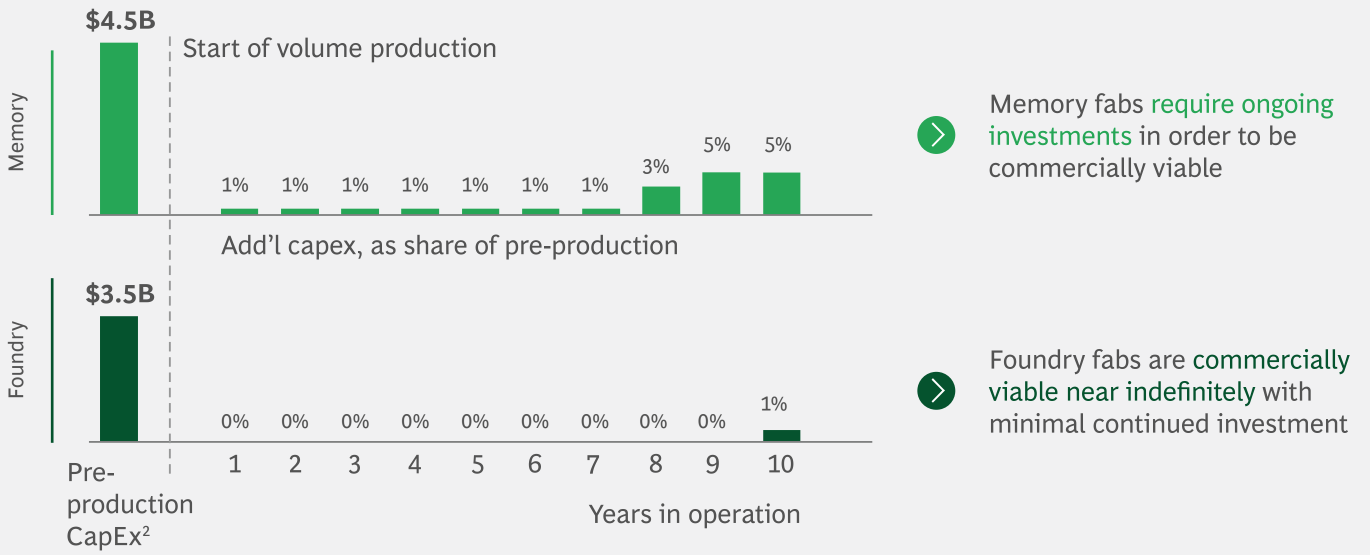
4.3 Benefits Japan's Semiconductor Ecosystem

While all semiconductor manufacturing is capital-intensive, memory fabs require not only greater upfront capital expenditures but also higher levels of ongoing capital expenditures. An illustrative survey of five major memory fab investments in the 2010-2015 period showed average pre-production capital expenditures of $4.5B, compared to $3.8B for an average foundry, and a greater capital requirement over the following 10 years to meet retooling needs (**Exhibit 7**).

The need for sustained investment means that memory can serve as a revenue source and a customer for the local semiconductor ecosystem at high levels over a longer span. This ongoing support is very much in line with the "large-scale, long-term, well-planned" mandate of Japan's New Direction.[23]

Exhibit 7:
Memory fabs require larger capital expenditures than a typical foundry at both pre-production and production stages

Capital expenditures, before and after start of commercial production[1]



1. For Micron, Samsung, SK Hynix, TSMC, GF fabs starting volume production between 2010–2015.; **2.** Average of total capital expenditures prior to initiation of commercial production of fabs defined in (1).
Source: SEMI WFF, BCG analysis

22. Represents the following manufacturing industries: Transport equipment (NACE rv2 29,30), Electrical, optical & high-tech (NACE rv2 26,27), Air transport (NACE rv2 51), Mechanical engineering (NACE rv2 28), Electronic components & boards (NACE rv2 26.1). Catalogued under the NACE taxonomy, using Japan Ministry of Economic, Trade, and Industry data for 2023 (via Oxford Economics) and Oxford Economics forecasts.

23. METI press release, 2021. Available at: https://www.meti.go.jp/english/press/2021/pdf/1116_Current_Situation.pdf

4.4 Creates Positive Impact for Japan

If Japan can attract new investment in leading-edge memory R&D, design, and fabrication, the benefits to Japan's economy would be considerable. BCG estimates that an at-scale memory fab in Japan[24] could create 10,300 total jobs, leading to average annual output from the fab itself exceeding $5B, with additional local materials spend of $2B per year, as well as $330M a year in consumption expenditure and corporate tax revenues of up to ~$220M a year (**Exhibit 8**).

Over a 10-year period, the total economic impact of an at-scale memory fab to jobs/wages, taxes, and materials suppliers could be up to $86B. An R&D fab, though smaller and primarily focused on R&D, would still generate ~1,500 jobs and ~$5B of economic impact.

Moreover, while some of the economic impact will be concentrated near the manufacturing site in question, there are also likely to be spillover benefits for other prefectures with existing semiconductor activity, supporting the revitalization of regional economies in line with the vision of successive Japanese governments.

Exhibit 8:
A typical at-scale memory fab or R&D facility in Japan could accrue substantial employment, fiscal, and economic output and spillover benefits

		AT-SCALE MEMORY FAB	MEMORY R&D FACILITY
Fab profile	**Total CapEx ($M)**	**$25,000M**	**$4,000M**
	Capacity (wspm)	135,000	20,000
	Cleanroom size (sqft)	600,000	90,000
Employment	**# Total jobs**	**10.3k at $36k/yr[1]**	**1.5k at $36k/yr[1]**
	Direct jobs	1.7k at $49k/yr	0.3k at $49k/yr
	Indirect jobs	2.1k at $37k/yr	0.3k at $37k/yr
	Induced jobs	6.5k at $32k/yr	1.0k at $32k/yr
Fiscal revenue	**Total tax benefits** ($M, 10 years)	**$2,500M**	**$120M**
	Corporate tax from fab operations ($M/year)[2]	$165M	$0M
	Corporate tax from materials purchases ($M/year)[3]	$55M	$8M
	Individual tax ($M/year)[4]	$28M	$4M
Economy	**Total economic output and spillover benefits** ($M, 10 years)	**$86,000M**	**$5,000M**
	Direct output from fab operations ($M/year)	$5,200M	$0M
	Materials and related supplier spend in Japan ($M/year)[5]	$2,000M	$300M
	Annual fab CapEx spend in Japan ($M/year)[6]	$1,000M	$150M
	Consumption expenditure from wages ($M/year)[7]	$330M	$50M

Note: Calculations for ten years of fab operation, assuming operation at full capacity.
1. Weighted average of direct, indirect, and induced jobs.; **2.** Effective corporate tax rate based on average of four major Japanese semiconductor companies in '22–'23.; **3.** Assuming 80% of materials and consumables are sourced from local vendors, vendor margin based on average of five major Japanese semiconductor materials vendors between '22–'23.; **4.** Sum of estimated personal income and resident taxes in Japan, based personal income tax rates by respective income bracket.; **5.** Assuming local input-output multiplier of 1.7.; **6.** 40% of total capital expenditures amortized over 10 years.; **7.** Assuming consumption based on wages, net of savings rate (2.8%) and personal taxes.
Source: REMI; OECD; METI Japan; Muchdie Muchdie & Sumarso Sumarso "Sector-specific and spatial-specific multipliers in Japanese economy: World input-output analysis, International Society for Development & Sustainability"; BCG analysis

24. $25B capital expenditures, 135K wafer starts per month, 600,000 square foot clean room.

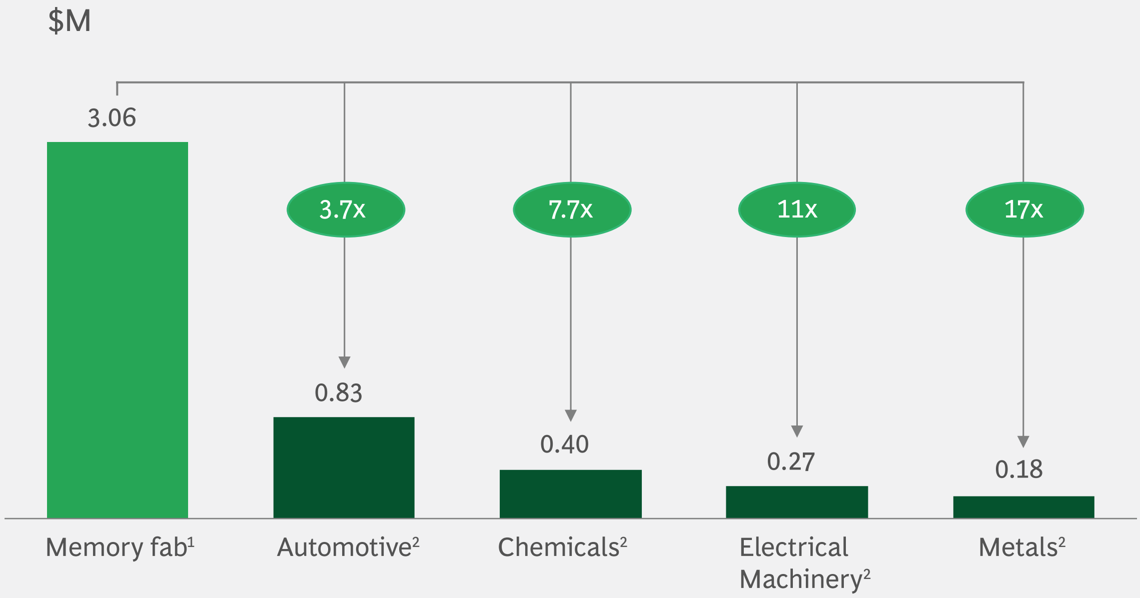
4.5 Produces High Economic Output Per Unit of Workforce Input

Japan today has a workforce of approximately 69 million people. It is expected to decrease by roughly 20% by 2040—meaning a potential loss of around 12 million workers over the next 10 years—due to a rapidly aging population and declining birth rates.[25] To maintain—or ideally, expand—its GDP, Japan must add high productivity jobs to effectively deploy its shrinking workforce.

Within this broader context, memory fabs (and semiconductors more broadly) are a smart choice for Japan. They are highly labor-efficient, generating ~$3M of economic activity per full-time employee (FTE) of direct labor consumed. That is significantly higher than output per worker in other manufacturing industries in Japan, including automotive (3.7x), chemicals (7.7x), electrical machinery (11x), and metals (17x) (**Exhibit 9**).

Exhibit 9:
A memory fab generates more output per worker than other sectors

Output per full-time employee, memory fab vs. other industries in Japan



1. Direct output per employee for a memory fab as estimated from bottoms-up model of fab economics.; **2.** Direct output per employee for sector based on Oxford Economics estimates of direct output, referred to by Oxford Economics as gross output, and Japan Statistics Bureau estimates of sector employment
Source: Oxford Economics; Japan Statistics Bureau; BCG analysis

25. World Economic Forum, *Japan's Workforce Will Be 20% Smaller by 2040* (12 February 2019).

5. ALTHOUGH STILL CAPITAL INTENSIVE, THE MEMORY SECTOR IS LESS RISKY THAN IT ONCE WAS

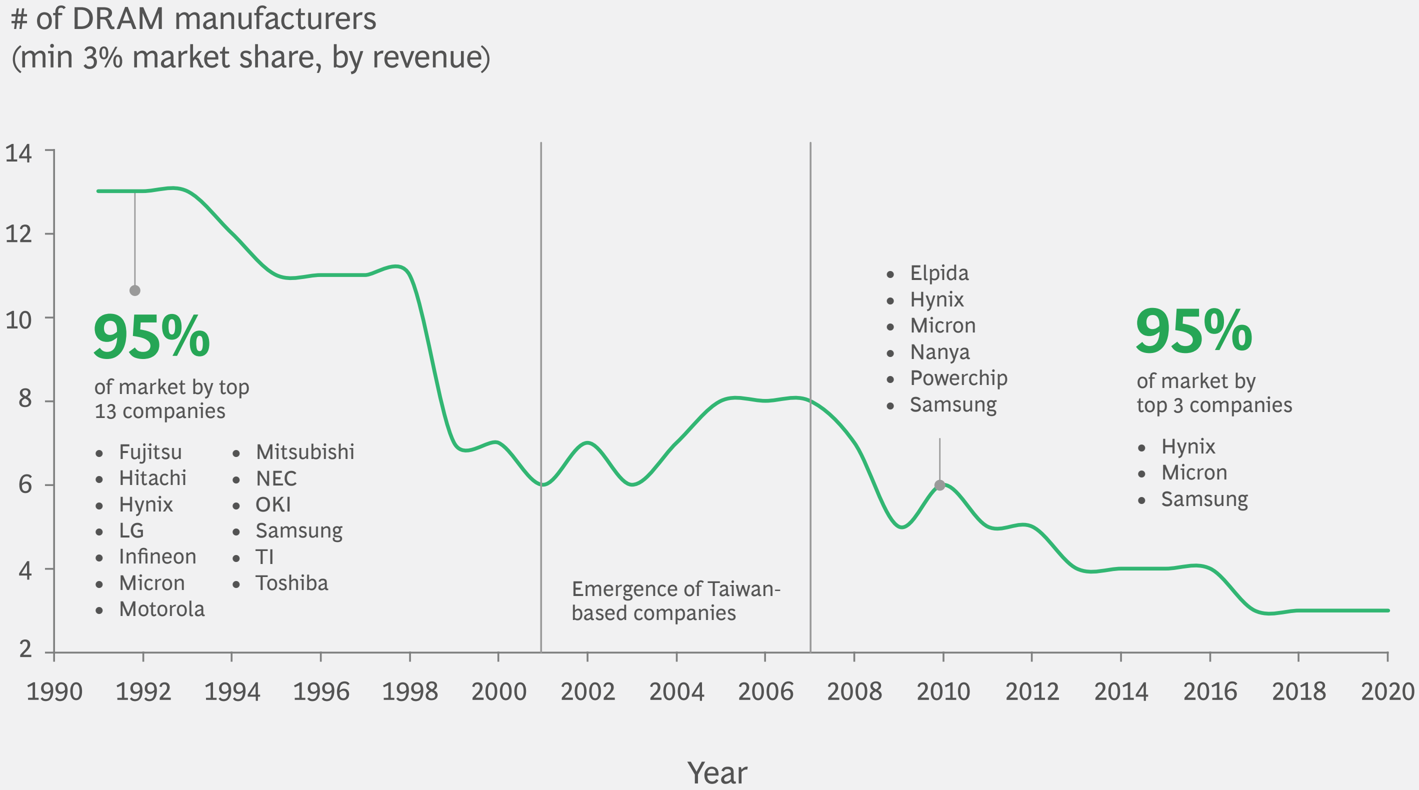
Key changes in the structure of the memory semiconductor industry over the past two decades, coupled with changes in memory chip technology during the current decade, have made the industry more stable, thereby reducing the risks for private and public investment.

5.1 The Sector Has Seen Reduced Fragmentation and Increased Stability

The memory industry has evolved from fragmentation and volatility toward comparative stability. In the 1980s, 13 major manufacturers competed with one another. This fragmented market structure was in many ways unsustainable as companies faced price volatility, intermittent overcapacity, and rising financial pressures from commoditization.

Starting in the late 1990s, the sector underwent rapid consolidation, with half of the major players exiting the market. A second round of consolidation followed in the early 2000s and by the 2010s, the industry had reduced to a host of small players and three major players (**Exhibit 10**).

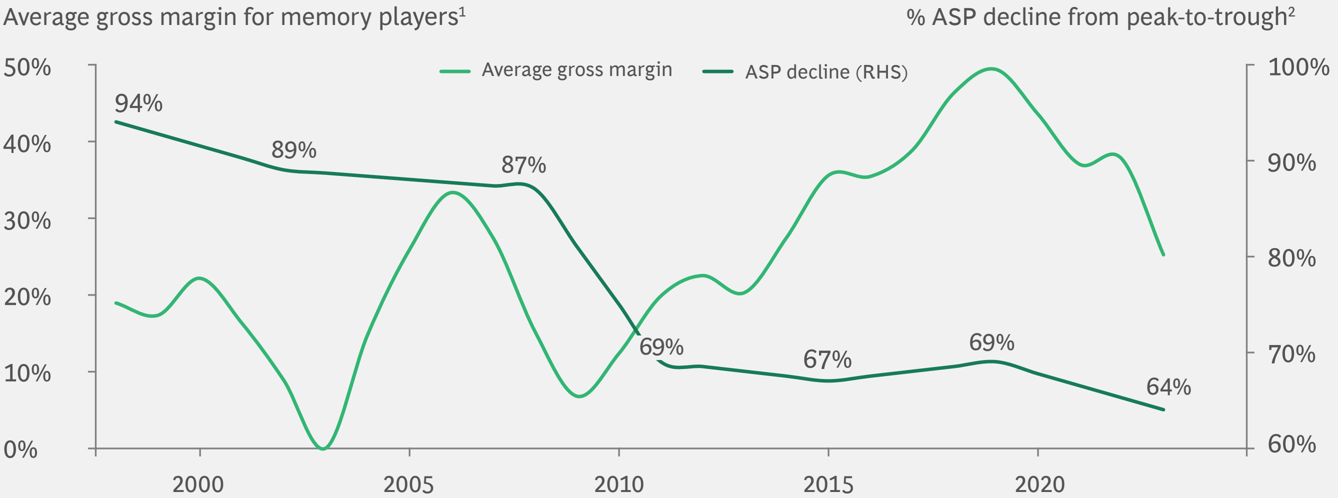
Exhibit 10:
DRAM market has become less fragmented with time



Note: Suppliers are listed in alphabetical order
Source: Objective Analysis; Yole Group; BCG analysis

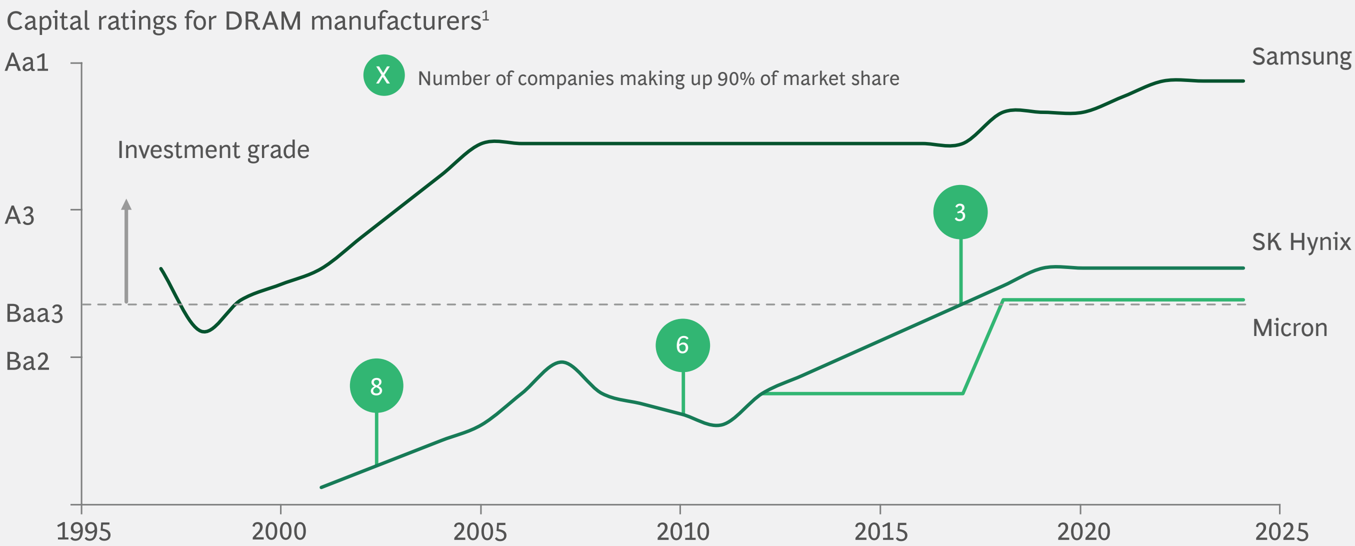
An upshot of this consolidation process, for those companies that remain, has been a decrease in price volatility compared to the 1980s-1990s. Prices for DRAM today—as measured by spot market indices—still exhibit a peak-and-trough behavior over the course of the "memory cycle," but fluctuations are more bounded (**Exhibit 11**). This change has coincided with, and likely contributed to, better financial performance among major memory players, as measured in revenue growth and investment-grade credit ratings[26] (**Exhibits 11 & 12**).

Exhibit 11:
Price volatility of DRAM has decreased and memory profitability has improved



1. 3-year moving average of Micron and SK Hynix.; **2.** DRAM spot price and ASP decline from '96–'98; '00–'03; '07–'09; '10–'12; '14–'16; '18–'20; '22–'23
Source: DRAMExchange; SemiAnalysis; BCG analysis

Exhibit 12:
Memory company credit ratings have steadily improved over the past 30 years



1. Credit rating by Moody's, for Senior Unsecured
Source: Moody's; Objective Analysis; Yole Group; BCG analysis

26. The memory market has recovered quickly from a 2023 downturn, with SK Hynix recording its highest quarterly profits since 2018 and Micron exceeding guidance range to post gross margins of 26.9% for CY2Q24.

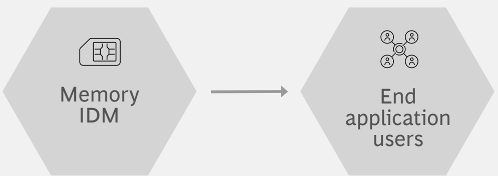
5.2 Next-Generation DRAM is Increasingly a Customized rather than Commodity Product

For decades, the DRAM sector struggled with commoditization due to a high level of standardization and an expectation of large volume and low cost. But as HBM technology advances to meet the surging demand for more powerful AI chips, and memory gets more integrated with GPU (and other types of inference approaches in future), the trend is towards *collaborative customization* across players in the value chain.

This collaborative customization requires close "trilateral" links between memory IDM, foundry, and design companies. The resultant outputs—integrated chips such as 3D stack of memory on logic—are also more complex than the modular, interchangeable chips in more standardized DRAM (**Exhibit 13**).

Exhibit 13:
Customized memory requires trilateral collaboration between design, foundry, IDM

Commoditized



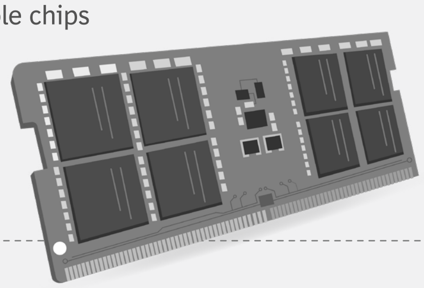
Memory IDM manufactures products compliant with JEDEC-defined standards:

- DRAM Components
- DRAM Modules
- HBM

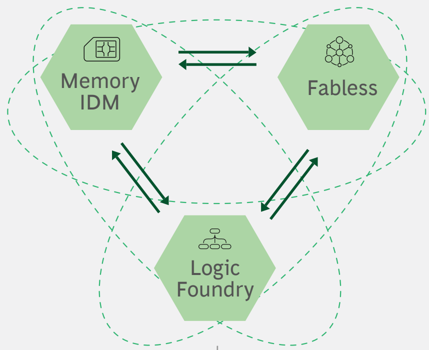
End applications use products that best fit their needs

Products are substitutable and commoditized, resulting in volatile market

Commoditized, modular, interchangeable chips



Customized

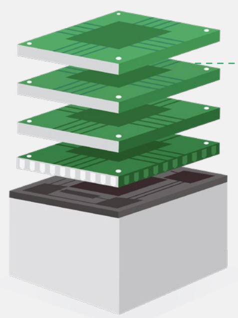


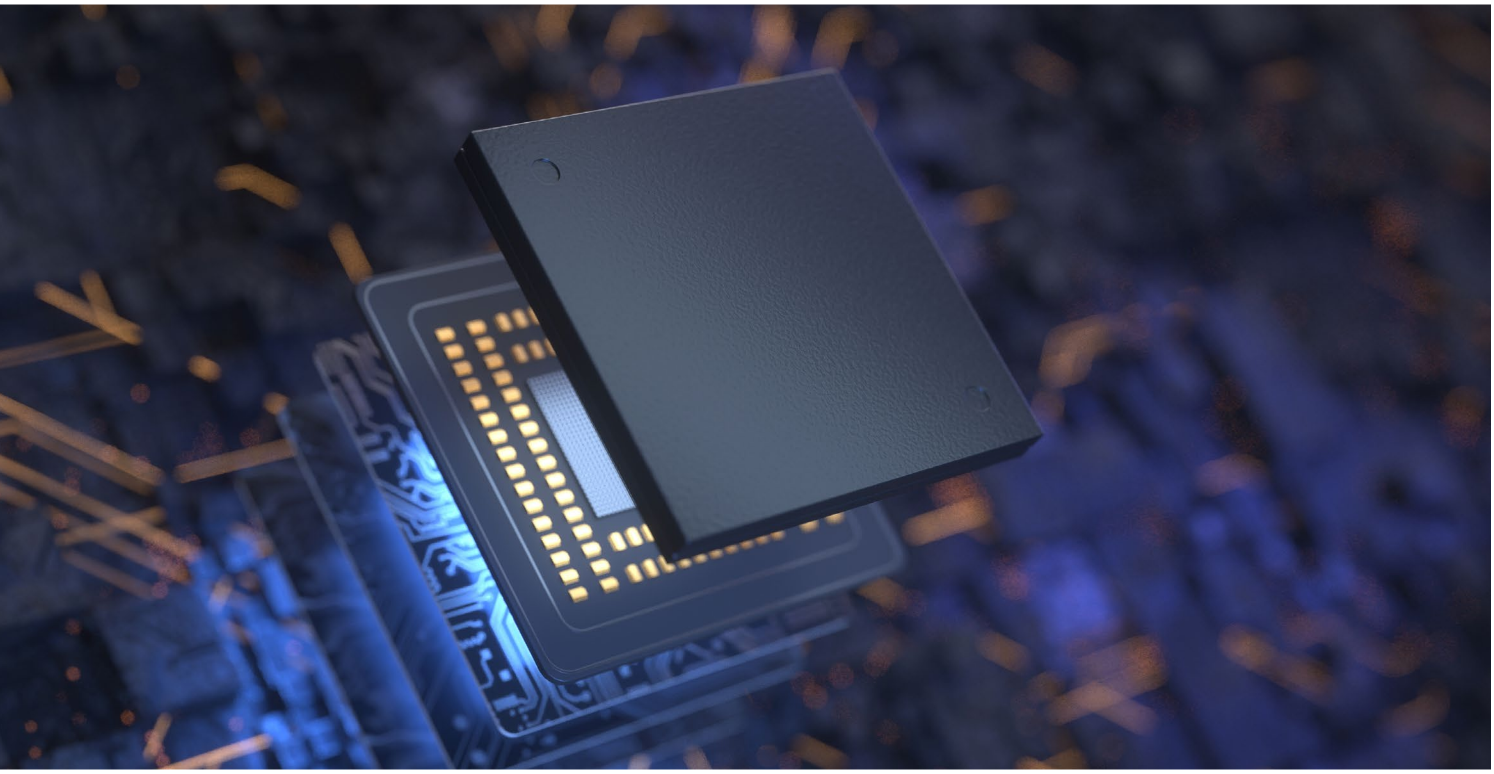
Trilateral collaboration across Pre-Si and Post-Si activities, including design and integration

Integrated memory chips optimized for end user's required specs

Chips are fully customized, leading to more predictable volumes and stable prices

Customized, optimized and integrated chips





Leading memory players are publicly discussing the impact customization is having on their business models. One leading company stated that collaborating with external foundries will "enable breakthroughs in memory performance through trilateral collaboration between product design, foundry, and memory provider."[27] Another noted that, "customers are thinking about HBM4E and beyond generations, that they need to find some way to create that differentiation and how HBM works with their processor … that then makes the HBM product more of a custom product to a customer."[28]

At the cutting edge of memory, the doubling of interface bits from 1,024 to 2,048 bits in HBM4 makes it increasingly difficult for pure memory players to fabricate HBM base dies[29] in-house, contributing to the need for deeper partnerships with third-party foundries.[30]

From an OEM's perspective, customization opens the door for optimizing base dies to specific needs, no longer bound by the constraints of mass production. As one concrete example, the number of HBM stacks is predicted to jump from five in H100 to eight in Blackwell, and twelve in Rubin Ultra—the next generations of Nvidia's graphics processing units (GPUs) by 2027.[31]

By virtue of deeper cooperation with logic foundries, customized memory constitutes a new form of value-adding activity and competitive differentiation for memory makers. Higher process complexity—even in more standardized next-generation DRAM—increases competitive differentiation in the power, cost, and performance envelope. Shorter product lifecycles will increase R&D intensity, and value-add per chip will necessarily rise to match. Customization will also make memory chip usage "stickier"—reducing the likelihood of an economically damaging "race-to-the-bottom" during downcycles.

Consequently, memory companies will be able to reinvest more in innovation, creating returns for shareholders, and spillover benefits for customers, suppliers, other partners, and the economic systems in which they operate.

27. SK Hynix press release, *SK Hynix Partners with TSMC to Strengthen HBM Technological Leadership* (19 April 2024).

28. Micron Technology Inc. at Goldman Sachs Global Semiconductor Conference (30 May 2024).

29. A base die refers to the foundational component of an integrated circuit (IC). A die is a small block of semiconducting material, typically silicon, that contains the functional circuit elements necessary for the operation of electronic devices.

30. *The Memory Wall: Past, Present, and Future of DRAM: Winners & Losers in the 3D DRAM Revolution* (SemiAnalysis, 3 September 2024).

31. *NVIDIA CEO Jensen Huang Announces the Latest Rubin Architecture – Rubin Ultra GPU to Feature 12 HBM4* (Trendforce, 3 June 2024).

6. CRITICAL SUCCESS FACTORS AS JAPAN GROWS SEMICONDUCTOR SECTOR

In sections 3, 4, and 5 of this report, we focused on memory, and more specifically next-generation DRAM, as a specific area that would add substantial value to Japan and support its position as a technology leader. Stepping back, however, regardless of the specific path chosen, a set of common, critical success factors should be sharply in focus as Japan grows its semiconductor sector consistent with its New Direction.

1

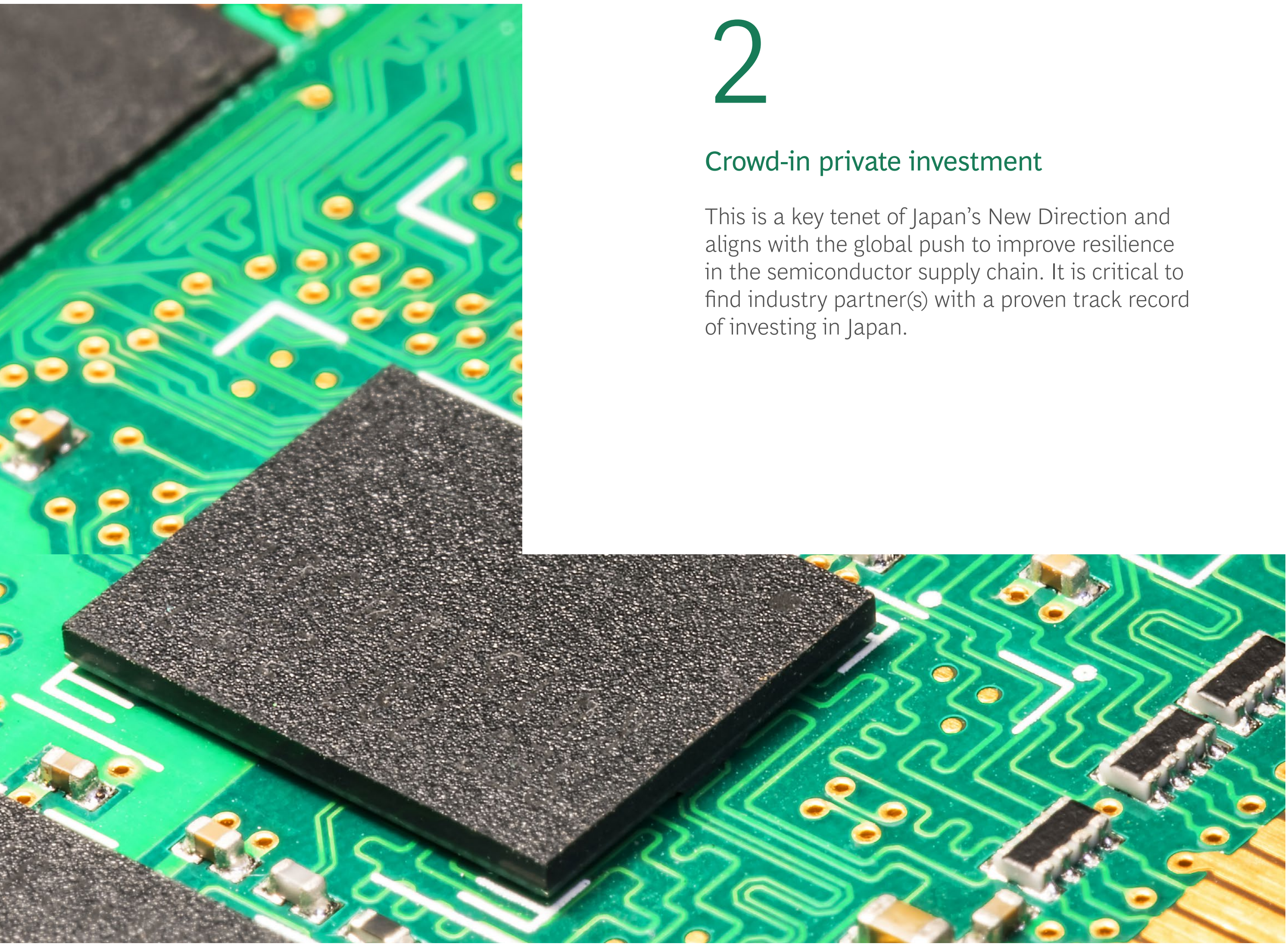
Aim for technology leadership, not just participation

Japan is a large market, likely in the top 5 for most categories. It is rational—and aligned with the "large-scale, long-term, well-planned" thrust of the New Direction—to craft an approach that ultimately drives Japan to be a leading player in the sector, not merely a participant.

2

Crowd-in private investment

This is a key tenet of Japan's New Direction and aligns with the global push to improve resilience in the semiconductor supply chain. It is critical to find industry partner(s) with a proven track record of investing in Japan.



3

Ensure local innovation

Innovation is a must-have in next-generation DRAM and today's highly competitive technology landscape. There are two key elements of innovation: localized IP generation and access to the latest process technologies.

- *IP generation* outside of the headquarters location is not common and will require targeted upfront dialogue as well as ongoing alignment to find win-wins with partners.
- *The latest process technologies* are not widely distributed. Here too, ensuring the transfer of critical technologies to sites in Japan is key.

4

Craft policy moves with a long-term focus

A healthy memory fab investment has a long timeline. As discussed above **(see Exhibit 7)**, memory fabs need substantial re-investment—especially in years 8, 9, 10 of a 10-year lifecycle—to stay competitive.

- *A long-term, targeted industrial policy* is key. Competition to attract memory chip investment will be intense in the coming years. Companies will make strategic decisions on where to upgrade to keep pace with next-generation DRAM. As they do so, they will evaluate the cost of capacity and operations in different regions. Policymakers have different tools at their disposal; selecting the right ones requires careful calibration against tools offered in other regions.
- *Incentives focused on equipment*—for acquisition, upgrading and retooling—can be particularly effective. For a typical leading-edge memory fab[32], the 10-year total cost of ownership (TCO) divides into land, construction & facilities, labor, materials, overhead, and equipment. Among these items, equipment is by far the largest, accounting for 50% of TCO.

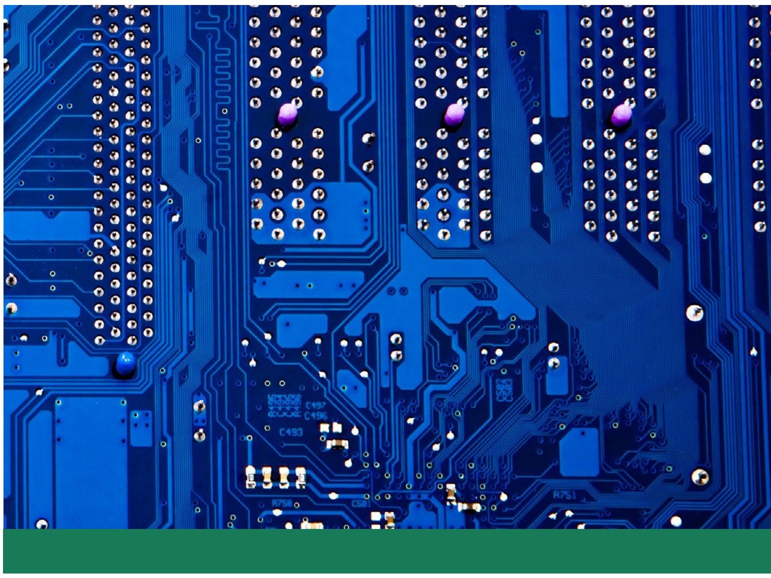
5

Prioritize development of local talent

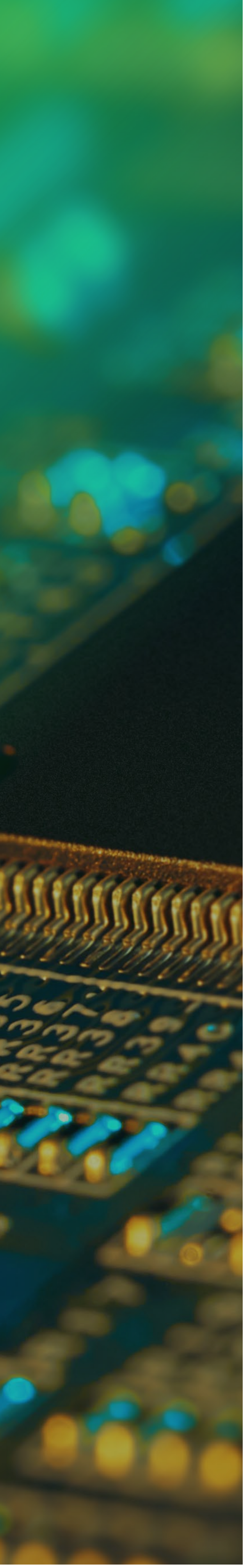
One of the critical tenets of Japan's New Direction is "fostering future talent." Ensuring that there is IP development and process technologies locally will go a long way to this goal—but it may not be sufficient. Picking partners that have a track record of ensuring Japan's substantial research capability is not just leveraged but multiplied, and crafting policy to support those partners, will go a long way toward meeting that goal.

There is a massive emerging demand for next-generation DRAM, fueled by a strong tailwind of AI and Generative AI use cases and investments, against the backdrop of a clear secular trend of global investments in semiconductors.

Japan can leverage many strengths as it looks to grow its semiconductor sector including potential investments in advanced memory. The right ambition, combined with at-scale investments, and carefully crafted agreements with current policy levers, can catalyze Japan's journey toward the New Direction.



32. Based on analysis of a 25-nanometer memory fab established in 2015 in Korea, per IC Knowledge.



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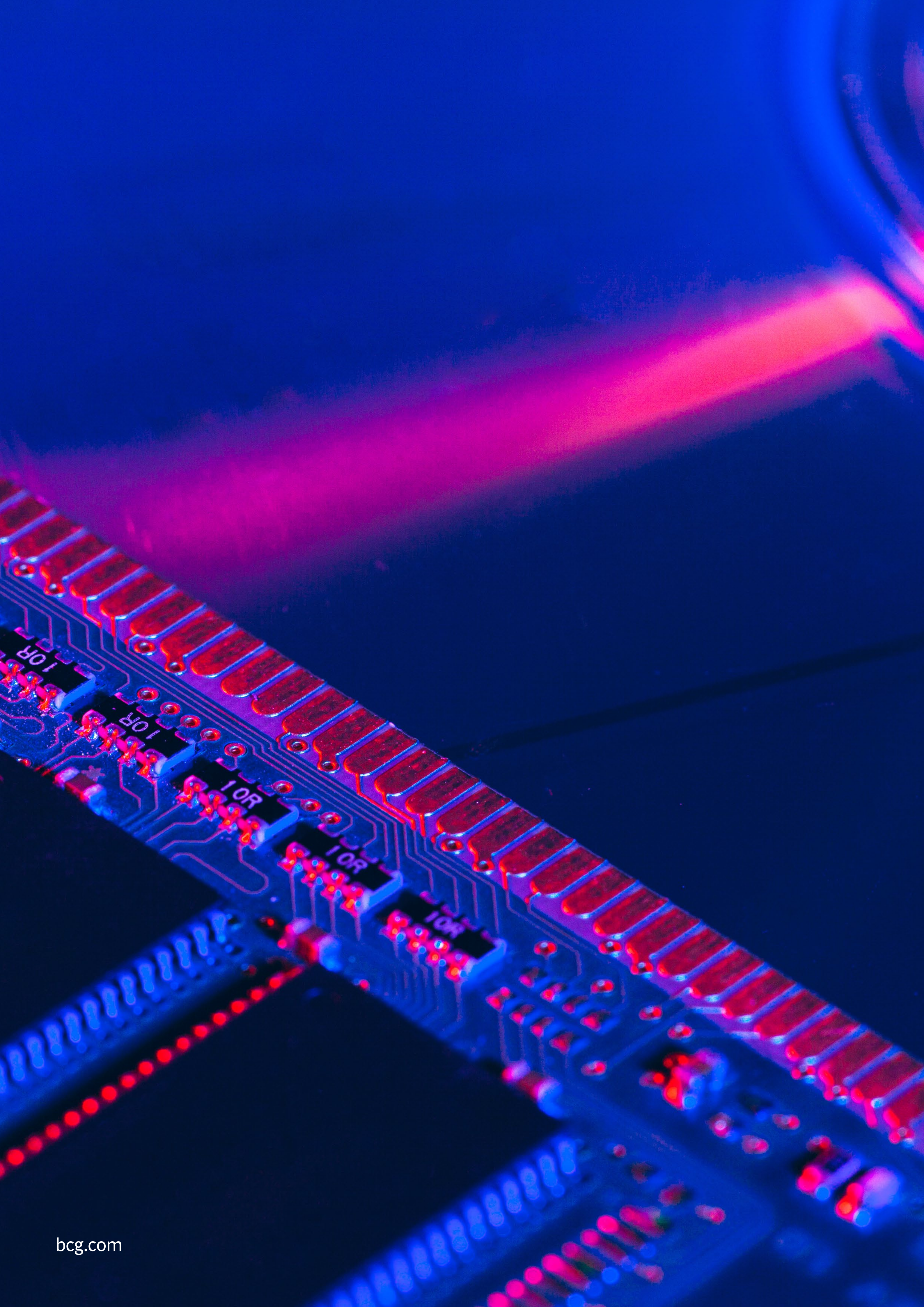

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