SEPTEMBER 2024

Morningstar Industry Landscape

Semiconductors

The industry enabling the modern world and driving a new wave of AI innovation.

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Morningstar Equity Research

Eric Compton
Director, Technology

Brian Colello
Equity Strategist

William Kerwin
Equity Analyst

Kazunori Ito
Director, Asia

Javier Correonero
Equity Analyst

Phelix Lee
Equity Analyst

Executive Summary

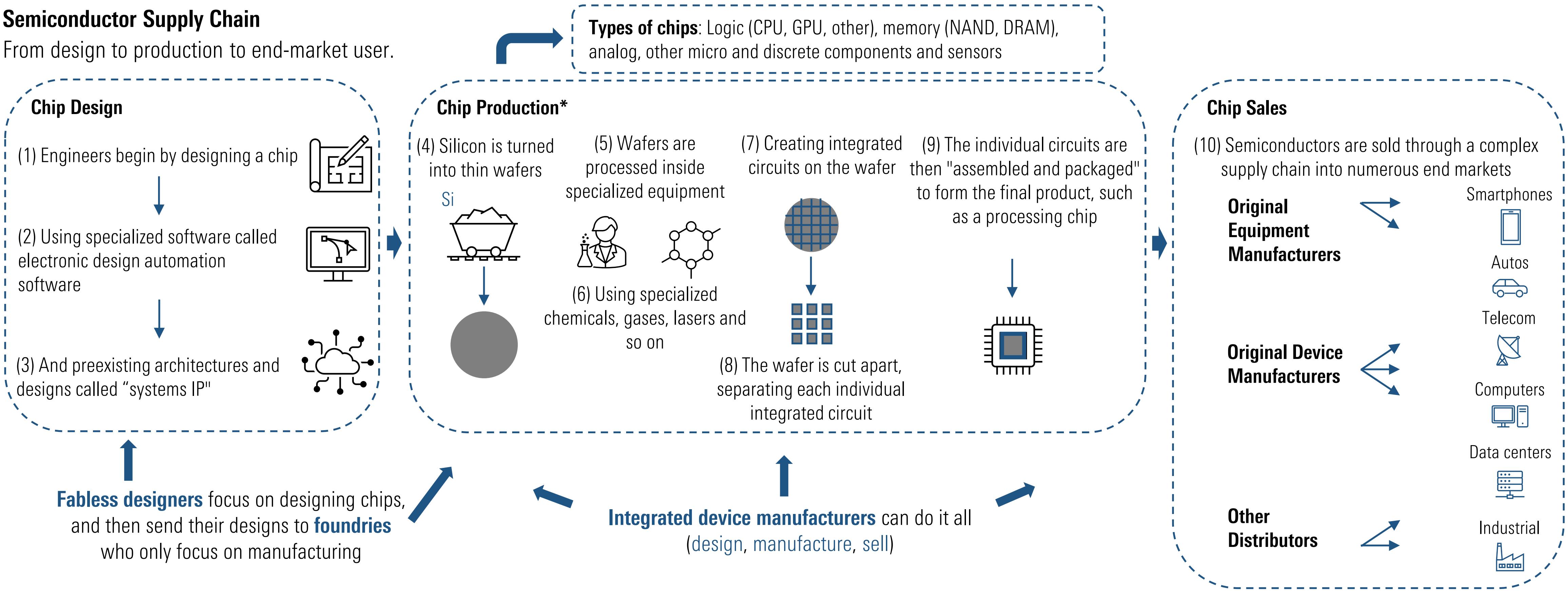
AI will be the key growth driver over the next several years for the broad and ubiquitous semiconductor industry.

Supply Chain Overview

The semiconductor industry is vast and complex. First, a semiconductor product must be designed, which involves highly skilled engineers, specialized software, and building off existing design standards. Once a chip is designed, it is then produced by a foundry using specialized equipment, chemicals, lasers, and more. Once the product is ready for use, it is sold and distributed into a wide variety of end markets. Each step in the process involves different specialized players, each adding value to the supply chain, and getting paid for that value.

Semiconductor Supply Chain

From design to production to end-market user.

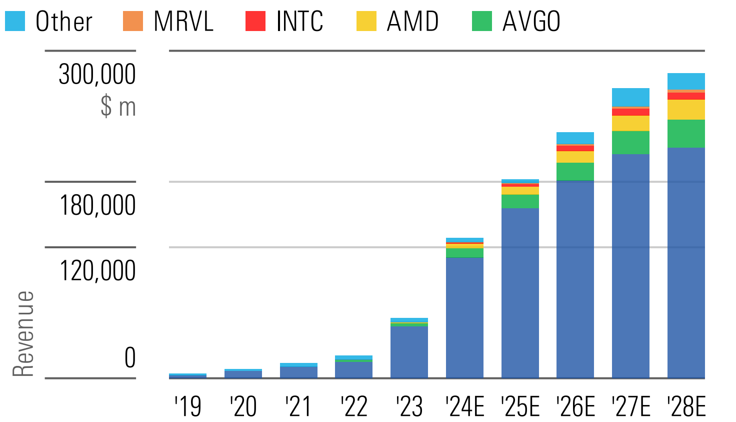


Source: Morningstar.

Note: not every semiconductor product is a chip manufactured on a silicon wafer, but because this is the most common method we use it to illustrate the basic concepts behind semiconductor production.

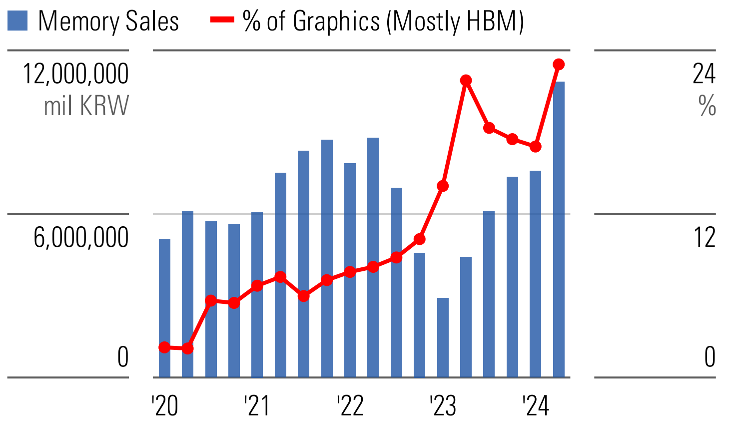
Key Industry Themes

Artificial Intelligence Is the Biggest Growth Driver



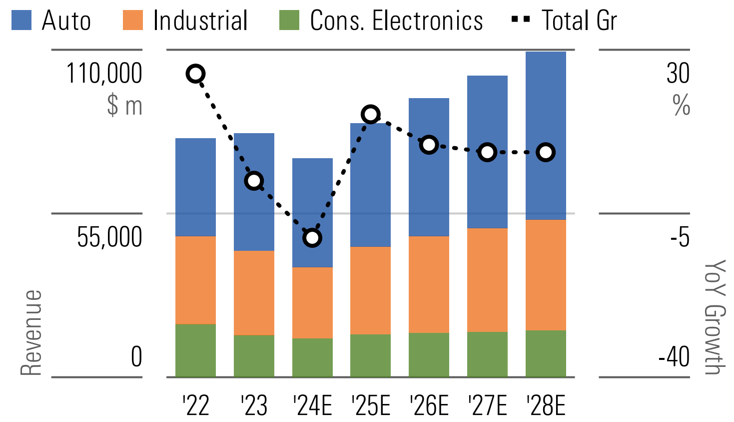
We expect AI accelerator (for example, chip) revenue will increase roughly four times over the next several years, making AI the largest growth driver in the semiconductor industry. This growth will be led by Nvidia. This firm will not be the only beneficiary as we see Broadcom as a strong second player, and AMD and others will also benefit. For many of these AI chip leaders, we expect AI accelerators to become primary growth drivers. AI is already Nvidia's primary valuation driver and we expect AI to be nearly 40%-50% of total company revenue for firms like Broadcom, AMD, and Marvell Technology.

AI-Related Growth Is More Than Just AI Accelerator



While the AI processing chips, especially those from Nvidia, are the most obvious beneficiaries of AI-related demand, there are also other parts of the value chain that will benefit. Specifically, we see material growth coming for networking firms (chips and ethernet connections), memory firms (high-bandwidth memory, as seen above), and equipment firms and foundries (rising complexity, increased structural demand). AI-related demand is expected to drive growth across a broad swath of the semiconductor value chain.

Analog Chips to Emerge From Cyclical Trough in 2025



Analog chip demand has suffered in 2023 and into 2024. This has been occurring across each key end market, but most especially across autos and industrial-related demand. We expect the current cycle to trough in 2024 and a pickup in demand to occur in 2025. Overall, we still like the long-term, structural growth tailwinds for analog chips that we see, including the increased number of chips per car, factory digitalization, and the rollout of 5G, among others.

Source: Morningstar, company filings.

Key Business Models

There are multiple key business models within the semiconductor industry. Fabless designers only focus on designing new products, contract manufacturers known as foundries operate fabrication plants, or fabs" and focus only on the manufacturing of products, and integrated device manufacturers are a combination of both, doing everything (design and manufacturing) in-house*. We also cover equipment makers, which make the equipment used by the manufacturers. There are other niches within the semiconductor ecosystem (software providers, wafer manufacturers, and packaging, assembly, and testing), but our breakout below covers the majority of the key models and differences you will see.

Fabless Designers, Foundries, IDMs, and Equipment Makers

Source: Morningstar.
Note that even IDMs technically do not do "everything" in house, and usually outsource certain parts of the manufacturing process where the investment in building out such processes outweighs any potential advantages of having those processes in house, such as packaging, assembly, and testing.

Industry Value Drivers—Foundries and Memory Makers

Simplified Financial Statements: TSMC (2023)

Pro Forma Income Statement (TWD millions)	2023	% of Sales
Revenue (1)	2,161,736	
Cost of Goods Sold (2)	986,625	46%
Gross Profit	**1,175,111**	**54%**
Research and Development (3)	182,370	8%
Selling, General, and Administrative	71,464	3%
Amortization, Restructuring, and Other	9,222	0%
Operating Profit	**912,055**	**43%**
Net Interest Expense	-42,215	
Pretax Profit	**954,270**	
Income Tax Expense (4)	144,776	
Minority Interest	-486	
Net Income	**809,008**	**37%**

Discounted Cash Flow	2,023	
Operating Profit	**912,055**	
Taxes and Others	129,926	
Earnings Before Interest	**782,129**	
(Capital Expenditures) (5)	-976,000	45%
Depreciation and Amortization (6)	532,191	
(New Investment in Working Capital and Others)	-109,969	
Net New Investment (NNI)	**-553,778**	
Free Cash Flow to the Firm (FCFF)	228,350	

(1) **Revenue:** Foundries sell processed disc-shaped wafers to customers while memory makers sell packaged memory chips. Foundry customers (the designers) are generally responsible for absorbing the costs of defective portions. Apart from wafers and chips, auxiliary revenue comes from mask-making and engineering services.

(2) **Cost of Goods Sold:** Key inputs are depreciation, labor, raw materials, and utilities. Depreciation and labor are fixed costs once new production lines start operations. Raw materials and utilities are semi-variable. Because fixed costs can be so high, margins can change materially depending on production volumes.

(3) **Research and Development:** The biggest portion of operating expenses as semiconductor manufacturers race to mass produce the next top-notch product. Commercial preparation starts years before production. While R&D is still important, it is generally relatively lower than for designers/IDMs.

(4) **Tax Rate:** Usually lower than statutory tax rates owing to tax credits on research and development and having local plants in high-cost regions.

(5) **Capital Expenditure:** Semiconductor manufacturers incur billions of dollars of capital spending a year. The biggest portion is spent on fabrication equipment, dwarfing buildings and land several times over. Capital intensity is HIGH.

(6) **Depreciation and Amortization:** Depreciation scales with equipment purchases of previous years. A typical depreciation schedule lasts 5 to 10 years. Amortization is limited as semiconductor manufacturers do not embark on large acquisitions. Software costs and intellectual property purchases are sometimes amortized.

Source: Morningstar, company filings.

Industry Value Drivers–Fabless Designers

Simplified Financial Statements: Qualcomm (2023)

Pro Forma Income Statement (USD millions)	2023	% of Sales
Revenue (1)	35,820	
Cost of Goods Sold (2)	15,869	44%
Gross Profit	**19,951**	**56%**
Research and Development (3)	8,818	25%
Selling, General, and Administrative	2,483	10%
Amortization, Restructuring, and Other	861	2%
Operating Profit	**7,789**	**22%**
Net Interest Expense	346	
Pretax Profit	**7,443**	
Income Tax Expense	104	
Discontinued Operations	107	
Net Income	**7,232**	**27%**
Discounted Cash Flow	**2,023**	
Operating Profit	**7,789**	
Taxes and Others	-752	
Earnings Before Interest	**8,541**	
(Capital Expenditures) (4)	-1,450	4%
Depreciation and Amortization (5)	1,809	
(New Investment in Working Capital and Others)	-1,791	
Net New Investment (NNI)	**-1,432**	
Free Cash Flow to the Firm (FCFF)	7,110	

(1) **Revenue:** Fabless designers sell finished chips to customers. They create chip designs, which are sent to foundry partners for manufacturing before going on to end customers. End-market clients can range from consumer electronics makers to data center infrastructure providers and more. Designers with the most in-demand designs can charge a premium and earn exceptional margins.

(2) **Cost of Goods Sold:** Primarily payments to foundries for their manufacturing services. There are minor costs like transportation and testing staff. Fabless companies bear defect costs if foundry production yields fall short. Importantly, manufacturing costs only begin once a designer is ready to go to market, and they are essentially variable costs. This makes initial startup costs much less burdensome than if the designer tried to do everything in-house.

(3) **Research and Development:** The biggest portion of operating expenses as fabless companies design more efficient chips to replace their predecessors. Fabless companies are adding engineers (and software seats) to ensure chips meet their time-to-market targets amid increasing chip complexity.

(4) **Capital Expenditure:** Fabless firms are light on capital intensity, having no manufacturing facilities to maintain.

(5) **Depreciation and Amortization:** Depreciation is low as there is no production involved. Fabless companies acquire smaller peers to supplement research and development efforts or gain access to untapped markets. Acquisitions give rise to noncash amortization of intangible assets.

Source: Morningstar, company filings.

Industry Value Drivers – Integrated Device Manufacturers

Simplified Financial Statements: Analog Devices (Fiscal 2023)

Pro Forma Income Statement (USD millions)	2023	% of Sales
Revenue (1)	12,306	
Cost of Goods Sold (2)	4,428	36%
Gross Profit	**7,877**	**64%**
Research and Development (3)	1,660	14%
Selling, General, and Administrative	1,274	10%
Amortization, Restructuring, and Other	1,120	9%
Operating Profit	**3,823**	**31%**
Net Interest Expense	-215	
Pretax Profit	**3,608**	
Income tax expense	293	
Net Income	**3,315**	**27%**

Discounted Cash Flow	2,023	
Operating Profit	**3,823**	
Taxes and Others	150	
Earnings Before Interest	**3,673**	
(Capital Expenditures) (4)	-1,261	10%
Depreciation and Amortization (5)	2,293	
(New Investment in Working Capital and Others)	-670	
Net New Investment (NNI)	**361**	
Free Cash Flow to the Firm (FCFF)	4,034	

(1) Revenue: Vertically integrated chipmakers earn revenue selling chips that they have both designed and manufactured. Products that use these chips can be cars, industrial machinery, consumer electronics, data center infrastructure, or others.

(2) Cost of Goods Sold: Depreciation and labor are the largest portions of COGS. Owning and operating large manufacturing facilities drives high depreciation and involves large fixed costs. A successful IDM model requires firms to achieve significant sales volumes to earn good gross margins. For wide-moat IDMs in our coverage we see gross margins in the 50%-60% range. For narrow-moat IDMs, gross margins can be in the 30%-40% range.

(3) Research and Development: Research and development is a vertically-integrated chipmaker's largest operating expense. With any type of chipmaker, continuous R&D investment is needed to remain on the edge of technology development. With analog chipmakers, human capital is scarce and requires high pay to retain top talent.

(4) Capital Expenditure: Vertically-integrated chipmakers require high capital expenses to build and maintain manufacturing facilities. These are typically in the low-double digit range as a percentage of sales.

(5) Depreciation and Amortization: Depreciation and amortization remain high as a result of high capital investments and acquisitions. We see depreciation scaling with prior years' capital expenses.

Source: Morningstar, company filings.

Industry Value Drivers–Semiconductor Equipment

Simplified Financial Statements: Applied Materials (Fiscal 2023)

Pro Forma Income Statement (USD millions)	2023	% of Sales
Revenue (1)	26,517	
Cost of Goods Sold (2)	14,133	53%
Gross Profit	**12,384**	**47%**
Research and Development (3)	3,102	12%
Selling and Marketing	776	3%
General and Administrative	852	3%
Operating Profit	**7,654**	**29%**
Net Interest Income	62	
Pretax Profit	**7,716**	
Income tax expense	860	
Net Income	**6,856**	**26%**

Discounted Cash Flow	2,023	
Operating Profit	**7,654**	
Taxes and Others	853	
Earnings Before Interest	**6,801**	
(Capital Expenditures) (4)	-1,106	4%
Depreciation and Amortization (5)	515	
(New Investment in Working Capital and Others)	934	
Net New Investment (NNI)	**343**	
Free Cash Flow to the Firm (FCFF)	7,144	

(1) Revenue: Chip equipment firms earn revenue by selling manufacturing systems and service contracts. They sell systems and services to foundries and vertically integrated chipmakers. Usually, services are about 20%-30% of total revenue.

(2) Cost of Goods Sold: Labor and depreciation are the largest portions of cost of sales for chip equipment firms. We generally see gross margins between 45% and 60% in chip equipment, with good pricing power offsetting high labor costs.

(3) Research and Development: This is the largest operating expense for chip equipment firms and primarily comprises labor costs. Engineering talent is critical for these firms to maintain technological leadership and earn placements at foundry customers. With a concentrated customer base, selling and marketing is a much smaller expense.

(4) Capital Expenditure: Chip equipment firms don't require significant capex despite being manufacturers. Low volumes and high complexity make R&D a more significant expense.

(5) Depreciation and Amortization: Depreciation scales with capital investments in prior years.

Source: Morningstar, company filings.

Key Markets and Share Concentrations

Semiconductors comprise myriad categories, including processors, connectivity, sensors, and memory. Each submarket has its own competitive dynamics, but we list the top 10 chipmakers by revenue below, alongside their primary technology, to show the breadth and size of this industry.

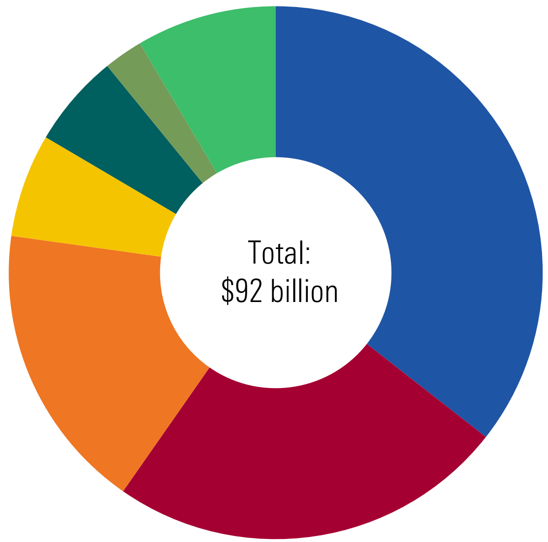
Memory chips are a critical category within semiconductors. The memory chip market is split between DRAM and not-and flash technologies, with both being consolidated. Samsung, Micron Technology, and SK Hynix are a dominant trio in DRAM, while Samsung, Kioxia, Western Digital, SK Hynix, and Micron lead NAND production.

Total Semiconductors Market Share in 2023 by Revenue

Revenue in USD millions

Company		Revenue	Market Share	Primary Product
Intel	$	49,117	9.3%	PC and server processors
Samsung Electronics	$	40,942	7.7%	Memory, smartphone processors
Qualcomm	$	29,225	5.5%	Smartphone processors, wireless connectivity
Broadcom	$	25,613	4.8%	AI processors, wired/wireless connectivity
Nvidia	$	25,053	4.7%	AI and graphics processors
SK Hynix	$	23,027	4.3%	Memory chips
AMD	$	22,307	4.2%	PC and server processors
Apple	$	18,052	3.4%	Smartphone and PC processors
Infineon Technologies	$	17,022	3.2%	Automotive and industrial power
STMicroelectronics	$	16,941	3.2%	Automotive and industrial power and sensors
All Other	$	262,665	49.6%	
Total	**$**	**529,964**		

Memory Semiconductor Market Share in 2023 by Revenue



Company	%
Samsung Electronics	35.58
SK Hynix	24.11
Micron Technology	17.52
Kioxia	6.28
Western Digital	5.65
Yangtze Memory Technologies	2.37
All Others	8.49

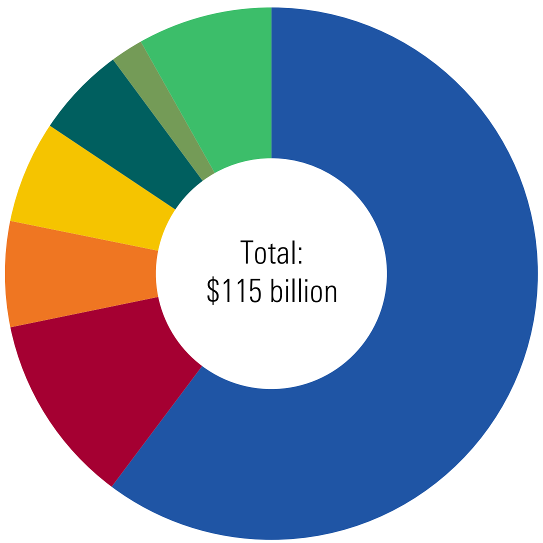
Source: Company filings, Gartner, Morningstar. Percentage values may not foot due to rounding.

Key Markets and Share Concentrations

TSMC is the world's largest foundry by far and is the go-to partner for designers looking to take advantage of the most advanced technology. TSMC's market share continues to grow even today. SMIC, GF, and UMC are all close in size, and are pure-play foundries, while Samsung has own-brand and foundry operations.

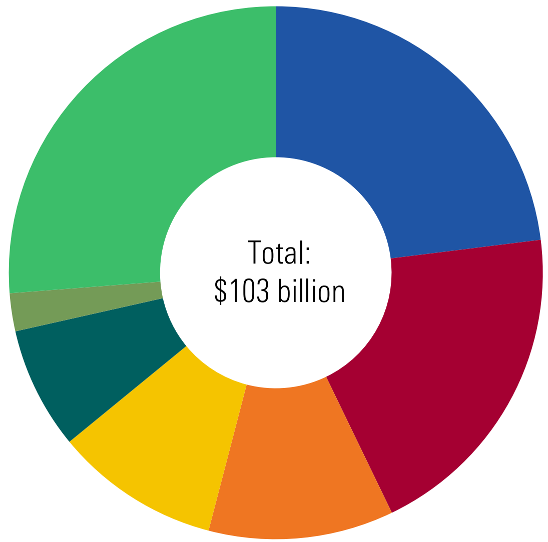
In wafer fab equipment for manufacturing semiconductors, we see about five primary players with a long tail of smaller competitors. High-share firms like Applied Materials have consolidated wide portfolios, but small niches still exist for smaller firms. ASML has grown to be the largest player with its monopolistic dominance of lithography.

Foundry Market Share in 2023 by Revenue



Foundry	%
TSMC	60.23
Samsung	11.54
GF	6.41
UMC	6.20
SMIC	5.49
Hua Hong	1.98
Others	8.15

Wafer Fab Equipment Market Share in 2023 by Revenue



Company	%
ASML	23.02
Applied Materials	19.82
Lam Research	11.21
Tokyo Electron	10.01
KLA	7.41
ASM International	2.30
All Other	26.23

Source: Company filings, Gartner, TrendForce, Morningstar.
Note: Samsung foundry excludes memory and own-brand businesses.

Coverage List and Ratings

Morningstar covers 48 companies that are part of the core semiconductor value chain. This coverage spans a wide variety of geographies, market caps, and subindustries. We break out our coverage below based on the key segments and subsegments.

Equipment Makers, Electronic Design Automation Software, Architecture IP, and Packaging and Testing

Company (Ticker)	Subindustry (if applicable)	Market Cap (USD Billions)	Moat Rating	Uncertainty Rating	Last Close	Fair Value Estimate	Star Rating	P/FVE	P/E	EV/ EBITDA	Yield	1-Year Return
Semiconductor Equipment												
ASML Holding (AMS:ASML)	Photolithography	333 USD	Wide	High	757 EUR	900 EUR	★★★★	0.84	25.3x	35.6x	0.8%	+47.2%
Applied Materials (NAS:AMAT)	Wafer Fabrication	173 USD	Wide	High	205 USD	193 USD	★★★	1.06	21.0x	20.8x	0.8%	+52.8%
Lam Research (NAS:LRCX)	Wafer Fabrication	107 USD	Wide	High	827 USD	830 USD	★★★	1.00	23.2x	22.9x	1.1%	+36.1%
KLA (NAS:KLAC)	Wafer Fabrication	105 USD	Wide	High	782 USD	670 USD	★★	1.17	26.3x	28.6x	0.7%	+76.9%
ASM International (AMS:ASM)	Deposition	32.1 USD	Narrow	High	585 EUR	520 EUR	★★★	1.13	31.6x	34.4x	0.5%	+60.2%
Be Semiconductor Industries (AMS:BESI)	Assembly and Packaging	10.12 USD	Narrow	High	114 EUR	120 EUR	★★★	0.95	27.3x	42.6x	1.9%	+37.7%
ASMPT (HKG:00522)	Assembly and Packaging	4.93 USD	Narrow	High	92 HKD	90 HKD	★★★	1.03	20.4x	20.6x	0.7%	+36.4%
Market Cap-Weighted Average								**0.97**	**24.4x**	**29.5x**	**0.8%**	**+51.3%**
Design Software and Architecture IP												
ARM (NAS:ARM)	Architecture IP	153 USD	Wide	High	146 USD	66 USD	★	2.21	93.3x	400.9x	0.0%	+174.7%
Synopsys (NAS:SNPS)	EDA Software	78.9 USD	Narrow	High	513 USD	490 USD	★★★	1.05	34.6x	42.7x	0.0%	+14.9%
Cadence Design Systems (NAS:CDNS)	EDA Software	75.1 USD	Narrow	High	274 USD	240 USD	★★★	1.14	39.6x	51.7x	0.0%	+18.9%
Market Cap-Weighted Average								**1.65**	**65.1x**	**223.4x**	**0.0%**	**+5.1%**
Packaging and Testing												
Keysight Technologies (NYS:KEYS)		27.5 USD	Wide	Medium	159 USD	157 USD	★★★	1.01	22.7x	24.6x	0.0%	+21.7%
Teradyne (NAS:TER)		22 USD	Wide	High	135 USD	135 USD	★★★	1.00	29.0x	32.5x	0.4%	+40.0%
Market Cap-Weighted Average								**1.00**	**25.5x**	**28.1x**	**0.2%**	**+29.9%**

Source: Morningstar, PitchBook. Data as of Sept. 27, 2024.

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Fabless Design Firms

Company (Ticker)	Subindustry (if applicable)	Market Cap (USD Billions)	Moat Rating	Uncertainty Rating	Last Close	Fair Value Estimate	Star Rating	P/FVE	P/E	EV/ EBITDA	Yield	1-Year Return
Fabless Design												
Apple (NAS:AAPL)	Mobile Semis	3,463 USD	Wide	Medium	228 USD	185 USD	★★	1.23	30.4x	26.5x	0.4%	+34.2%
Nvidia (NAS:NVDA)	Logic	2,978 USD	Wide	Very High	121 USD	105 USD	★★★	1.16	43.0x	47.9x	0.0%	+185.9%
Broadcom (NAS:AVGO)	Networking and Mobile	807 USD	Wide	Medium	173 USD	155 USD	★★	1.11	27.9x	40.6x	1.2%	+114.0%
Advanced Micro Devices (NAS:AMD)	Logic	266 USD	Narrow	High	164 USD	145 USD	★★★	1.13	30.1x	63.2x	0.0%	+67.6%
Qualcomm (NAS:QCOM)	Mobile Semis	190 USD	Narrow	High	170 USD	180 USD	★★★	0.95	15.4x	17.4x	2.0%	+58.8%
MediaTek (TAI:2454)	Mobile Semis	63.4 USD	Narrow	High	1,260 TWD	1,400 TWD	★★★	0.90	17.6x	14.7x	4.4%	+81.8%
Marvell International (NAS:MRVL)	Networking	61.5 USD	Narrow	High	71 USD	75 USD	★★★	0.95	48.6x	67.5x	0.3%	+35.5%
Skyworks Solutions (NAS:SWKS)	Mobile Semis	15.8 USD	Narrow	High	99 USD	115 USD	★★★	0.86	15.5x	11.7x	2.8%	+5.5%
Qorvo (NAS:QRVO)	Analog	9.8 USD	None	High	104 USD	128 USD	★★★★	0.81	17.0x	21.0x	0.0%	+9.6%
Melexis (BRU:MELE)	Analog	3.4 USD	Narrow	Medium	75 EUR	100 EUR	★★★★	0.75	13.5x	11.0x	4.9%	+2.4%
Nordic Semiconductor (OSL:NOD)	Analog	1.95 USD	Narrow	High	106 USD	127 USD	★★★	0.83	45.7x		0.0%	+0.8%
Market Cap-Weighted Average								**1.17**	**34.5x**	**37.3x**	**0.4%**	**+101.9%**

Source: Morningstar, PitchBook. Data as of Sept. 27, 2024.

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Silicon Wafer Manufacturers and Semiconductor Foundries

Company (Ticker)	Subindustry (if applicable)	Market Cap (USD Billions)	Moat Rating	Uncertainty Rating	Last Close	Fair Value Estimate	Star Rating	P/FVE	P/E	EV/ EBITDA	Yield	1-Year Return
Silicon Wafer Manufacturers												
GlobalWafers (ROCO:6488)		6.92 USD	Narrow	High	461 TWD	620 TWD	★★★★	0.74	13.6x	8.2x	4.1%	+5.8%
National Silicon Industry Group (SHG:688126)		6.2 USD	None	High	15.82 CNY	3.70 CNY	★	4.28	164.3x	148.1x	0.3%	-14.0%
Soitec (PAR:SOI)		3.89 USD	Narrow	High	98 EUR	150 EUR	★★★★	0.65	23.1x	11.0x	0.0%	-32.6%
Sumco (TKS:3436)		3.8 USD	None	High	1,578 JPY	1,760 JPY	★★★	0.90	23.0x	6.6x	1.9%	-15.4%
Sino-American Silicon Products (ROCO:5483)		3.03 USD	Narrow	High	175 TWD	255 TWD	★★★★	0.69	9.2x	4.3x	5.0%	+19.3%
Market Cap-Weighted Average								**1.66**	**55.3x**	**0.1x**	**2.2%**	**-7.3%**
Manufacturing (Foundries)												
Taiwan Semiconductor Manufacturing Company (TAI:2330)		825 USD	Wide	Medium	1000 TWD	1,380 TWD	★★★★	0.72	18.6x	15.3x	1.6%	+98.0%
Semiconductor Manufacturing International (HKG:00981)		28.5 USD	None	High	19 USD	14.0 USD	★★	1.33	22.5x	163.7x	0.0%	-4.7%
GlobalFoundries (NAS:GFS)		22.6 USD	None	High	41 USD	42 USD	★★★	0.98	21.4x	9.4x	0.0%	-29.2%
United Microelectronics Corporation (TAI:2303)		21.6 USD	None	High	55 TWD	70 TWD	★★★★	0.79	11.3x	6.3x	5.5%	+32.9%
Hua Hong Semiconductor (HKG:01347)		5.08 USD	None	High	19 USD	16.50 USD	★★★	1.15	20.4x	8.2x	0.9%	+1.9%
Win Semiconductors (ROCO:3105)		1.81 USD	Narrow	High	136 TWD	202 TWD	★★★★	0.67	22.6x	11.8x	0.0%	+6.2%
Market Cap-Weighted Average								**0.75**	**18.7x**	**19.5x**	**1.6%**	**+89.3%**

Source: Morningstar, PitchBook. Data as of Sept. 27, 2024.

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Integrated Device Manufacturers

Company (Ticker)	Subindustry (if applicable)	Market Cap (USD Billions)	Moat Rating	Uncertainty Rating	Last Close	Fair Value Estimate	Star Rating	P/FVE	P/E	EV/ EBITDA	Yield	1-Year Return
Integrated Device Manufacturers (IDMs)												
Intel (NAS:INTC)	Logic	102.2 USD	None	Very High	24 USD	21 USD	★★★	1.14	22.1x	13.4x	2.1%	-29.5%
Samsung Electronics (KRX:005930)	Memory	325 USD	Narrow	Medium	64,200 KRW	90,000 KRW	★★★★	0.71	9.1x	5.8x	2.2%	-1.7%
Micron Technology (NAS:MU)	Memory	119 USD	None	High	108 USD	110 USD	★★★	0.98	11.9x	13.8x	0.4%	+58.3%
SK Hynix (KRX:000660)	Memory	96.2 USD	None	High	183,800 KRW	165,000 KRW	★★★	1.11	4.9x	8.5x	0.7%	+65.9%
Western Digital Technologies (NAS:WDC)	Memory	23.8 USD	None	High	69 USD	60 USD	★★★	1.16	8.9x	104.0x	0.0%	+55.8%
Texas Instruments (NAS:TXN)	Analog	191 USD	Wide	Medium	209 USD	175 USD	★★	1.20	33.3x	24.9x	2.6%	+35.5%
Analog Devices (NAS:ADI)	Analog	115 USD	Wide	Medium	232 USD	225 USD	★★★	1.03	31.7x	28.7x	1.6%	+36.4%
Sony (TKS:6758)	Analog	119 USD	Wide	Medium	2,861 JPY	3,600 JPY	★★★★	0.79	17.4x	8.1x	0.7%	+19.6%
NXP Semiconductors (NAS:NXPI)	Analog	62.4 USD	Wide	Medium	245 USD	320 USD	★★★★	0.77	15.9x	15.3x	1.7%	+26.6%
Infineon Technologies (ETR:IFX)	Analog	47.4 USD	Narrow	High	33 EUR	50 EUR	★★★★	0.65	15.9x	10.4x	1.1%	+13.6%
Microchip Technology (NAS:MCHP)	Analog	43.2 USD	Wide	Medium	81 USD	81 USD	★★★	0.99	40.1x	18.0x	2.3%	+7.7%
Monolithic Power Systems (NAS:MPWR)	Analog	45.1 USD	Wide	High	925 USD	700 USD	★★	1.32	52.9x	88.0x	0.5%	+110.7%
ON Semiconductor (NAS:ON)	Analog	31.9 USD	Narrow	High	74 USD	86 USD	★★★★	0.87	15.7x	11.5x	0.0%	-19.2%
STMicroelectronics (PAR:STMPA)	Analog	27.7 USD	Narrow	High	27 USD	48 USD	★★★★★	0.57	13.6x	4.7x	1.2%	-26.3%
Market Cap-Weighted Average								**0.94**	**19.4x**	**17.7x**	**1.6%**	**+22.7%**

Source: Morningstar, PitchBook. Data as of Sept. 27, 2024.

Economic Moat

Intangible assets based on differentiated technology drive semiconductor moat ratings.

Summary of Moat Ratings and Sources

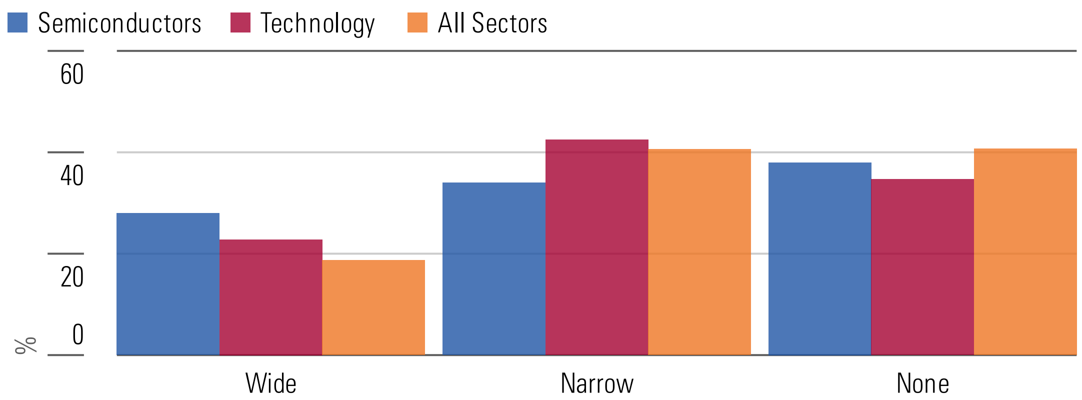
Semiconductor Moat Distribution

Across our semiconductor coverage, just over 60% of companies possess an economic moat. This is roughly in line with our total market coverage and the broader technology sector. However, within these moat ratings wide moats are more prevalent within semiconductors. Semiconductor moats are almost always the result of differentiated technology, in design and manufacturing. Higher complexity gives more room for companies to differentiate themselves. Often the widest moats involve the most complex and therefore the most differentiated technology and capabilities. Narrow-moat chip firms are differentiated, but might be trailing a larger leader (like Marvell), have a more fragmented competitive landscape (like Infineon), or have a smaller market niche. No moat firms might sell commoditylike products (like Micron) or erode shareholder value via execution missteps, which cause them to fall behind on innovation (like Intel).

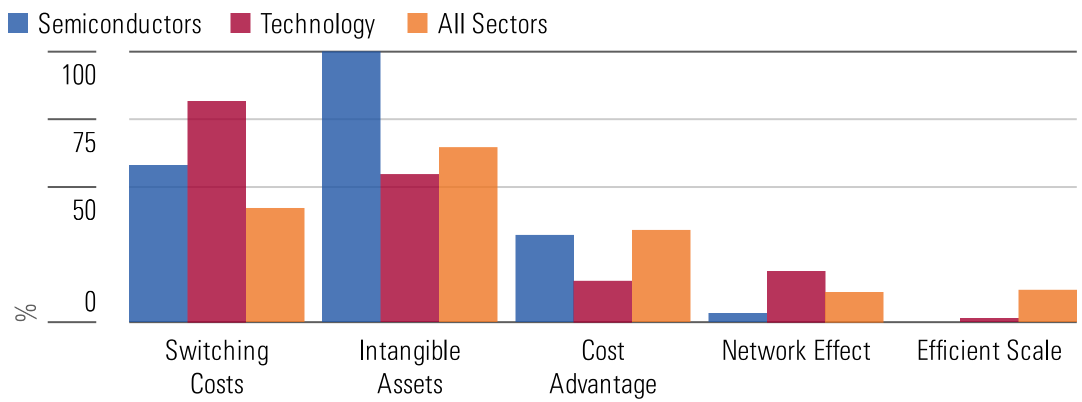
Semiconductor Moat Source Distribution

Differentiated technology is a prerequisite for semiconductor moats. Every moaty semiconductor firm under our coverage possesses intangible assets, be it in chip design, equipment design, or manufacturing prowess. Most moaty semiconductor firms also benefit from customer switching costs, be it from long product lifecycles, like in the automotive market, or software integration that further embeds chips, like Nvidia. All wide-moat semiconductor firms under our coverage possess at least two moat sources. Cost advantage is less common and primarily occurs with firms that manufacture their own products, like TSMC or vertically integrated power chipmakers like Onsemi and Infineon as the fixed costs for manufacturers are high.

Wide Moats Are More Prevalent in Semiconductors



Moaty Chipmakers Typically Exhibit Switching Costs and Intangible Assets



Source: PitchBook. Data as of Sept. 25, 2024.

How Moats Are Formed in Semiconductors: Differentiated Technology Is Key

The semiconductor industry is fundamentally about the underlying technology. Whether it is building more advanced processors that can digest more information, building the equipment that enables advanced chip production, designing chips that no one else can design, or integrating analog semiconductors into devices in ways that only your in-house knowledge allows. Having differentiated technological capabilities that lead to differentiated performance is key in the semiconductor industry. Beyond this, we also see scale mattering for fabs, where fixed costs are high, and switching costs matter for semiconductors that have complex integrations within the overall product architecture.

Intangible Assets via Differentiated Technology Is Key, While Switching Costs and Scale-Driven Cost Advantages Can Matter Too

No Moat	Narrow Moat	Wide Moat
Single-circuit diodes or power transistors, which are common, are made in large quantities by many competitors and sell at low prices	Marvell offers strong networking chip and accelerator designs, but does best in market niches while it trails Broadcom in the biggest portions of the market.	Nvidia designs GPU architectures and associated software that no one else does, leading to a performance advantage. Nvidia can charge high prices for this.
← Less complex, high standardization		More complex, more performance differentiation →
Memory is modular and standardized. You can plug new RAM into a PC. Combined with shorter product lifecycles and less performance differentiation, it makes memory more competitive.	Onsemi owns differentiated power chips for automotive applications, but its portfolio is balanced by portions of more basic, commoditylike transistors.	Texas Instruments has mastered overcoming obstacles when integrating analog semiconductors. Autos have long production cycles. Getting placement in a model creates sales for a decade.
← High modularity, shorter product lifecycle		Less modularity, more complex component integration, longer product lifecycle →
Fabless design firms have low capex requirements because they do not do the manufacturing, so they must differentiate on other factors.	Win Semi is the largest gallium arsenide foundry in the world. GaAs products are critical in telecom equipment, but less so in consumer-grade phones and routers.	Capex requirements are massive for the foundry TSMC. But its high production volumes (it's the largest foundry in the world) make its per-unit costs structurally lower than peers.
← Low fixed costs, low capex		High fixed costs, high capex →

Source: Morningstar.

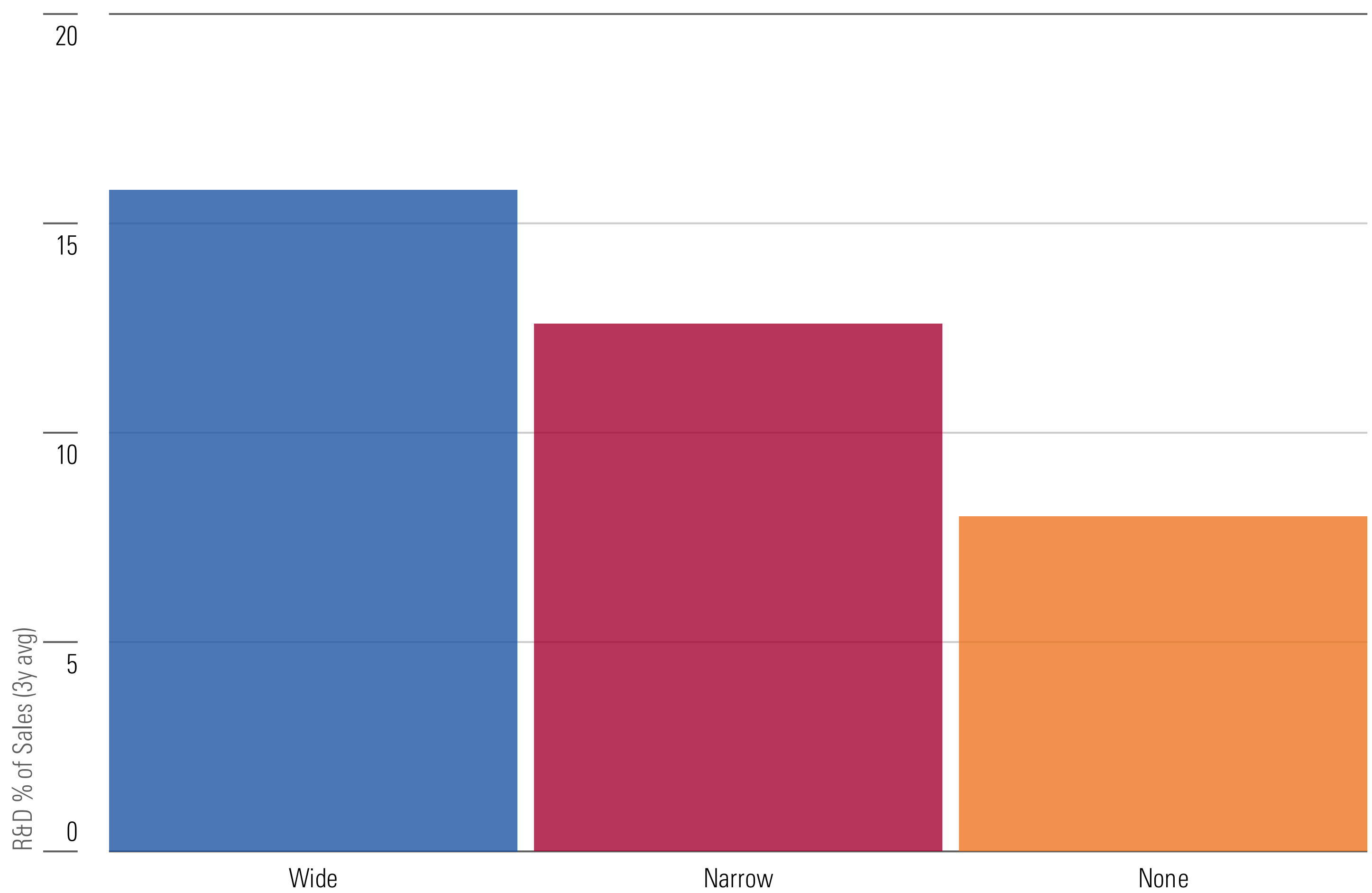
Intangible Assets Underpin Every Semiconductor Moat

Moaty Semiconductor Firms Possess Intangible Assets
Cutting-edge chips and chip equipment are extremely hard to design and manufacture as companies truly push the limits of physics and current science. Modern digital chips require precision down to the nanometer (less than the width of a human hair,) and feature billions of individual transistors on a single chip that can fit in the palm of one's hand. To earn a moat in semiconductors, a firm must be differentiated with their technology.

Better Technology Drives Better Performance
Semiconductor customers make buying decisions based on performance. Firms that can consistently stay on the cutting edge of performance can charge more for their products and earn economic moats.

R&D is Necessary to Build/Maintain a Moat
Research and development drives cutting-edge products and performance. We see a clear difference in the R&D budgets between wide-, narrow-, and no-moat firms. Wide-moat firms consistently spend more on R&D than narrow-moat firms, and narrow-moat firms spend considerably more on R&D than no-moat firms.

Research and Development Spending Carves and Fortifies Semiconductor Moats
R&D as a percentage of sales over the past three years.



Source: PitchBook. Data as of Sept. 25, 2024.

Switching Costs Often Supplement Intangible Assets for Chipmakers

Switching Costs Strengthen Moats

More than half of the moaty semiconductor firms under our coverage also exhibit customer switching costs. Broadly, we believe intangible assets in chip or equipment design earn placements in products, and switching costs help maintain those placements over a longer time horizon.

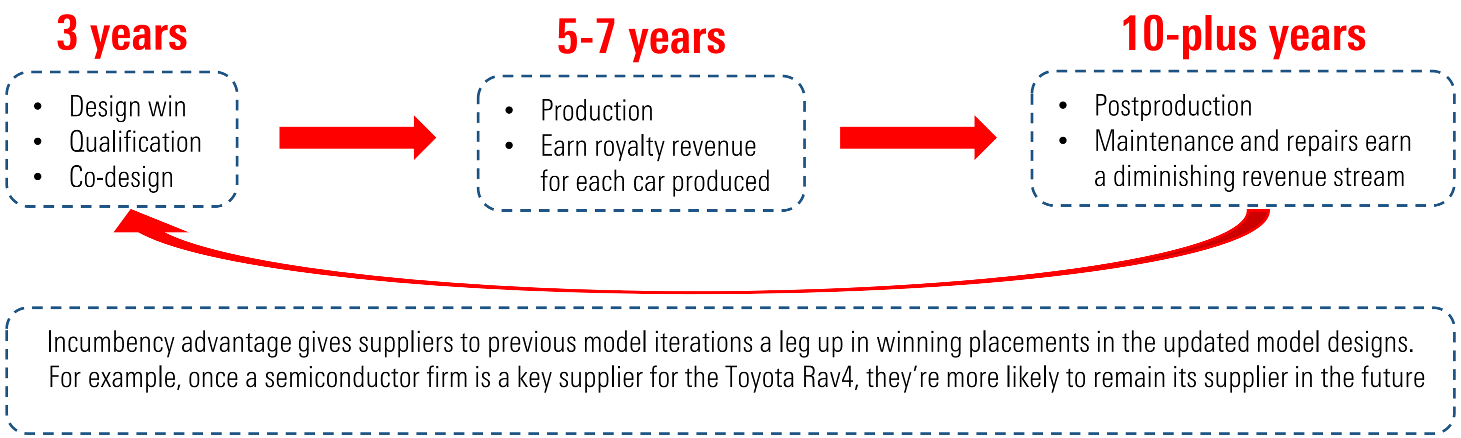
Look for Integration Complexity and Long Lifecycles

Switching costs can stem from software support, complex integration into workflows, or reliability and consistency. Usually, they're more prevalent in industries with long product lifecycles and risk-averse customers, like automotive chips.

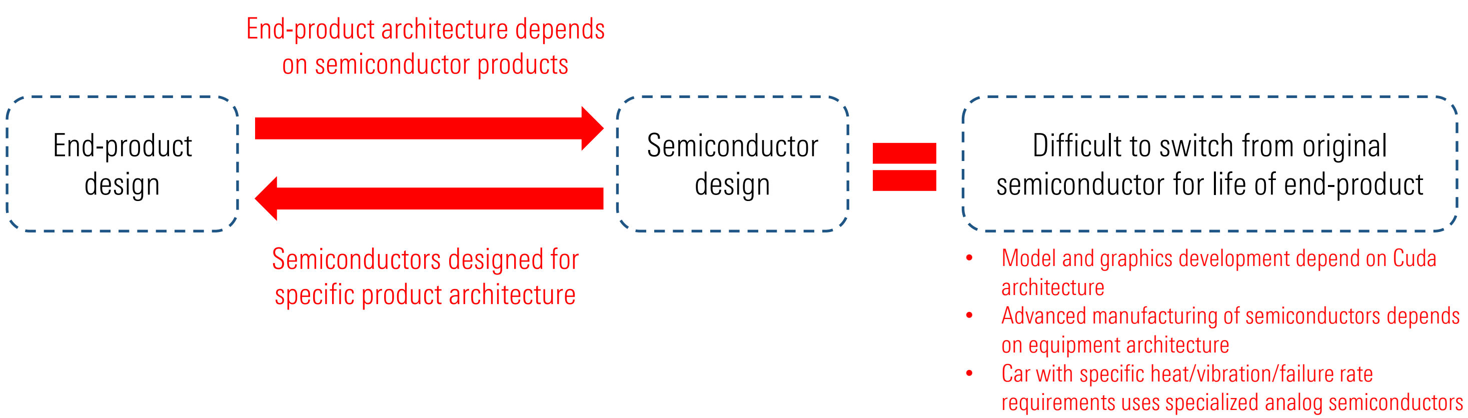
Beyond automotive, Nvidia uses software to make sticky customers. Its Cuda software helps engineers write programs on top of its GPUs, but only functions on Nvidia chips. To use a different GPU, engineers would have to rewrite their existing code, a huge switching cost.

Additional examples include manufacturers optimizing workflows around specific equipment, and analog chips requiring complex fine-tuning within each product placement, meaning neither can easily be changed.

Auto Chipmakers Enjoy Switching Costs Arising From Long Product Cycles and Risk-Averse Customers



Anytime Products "Designed Around" Semiconductor-Related Components, Expect Higher Switching Costs



Source: Morningstar.

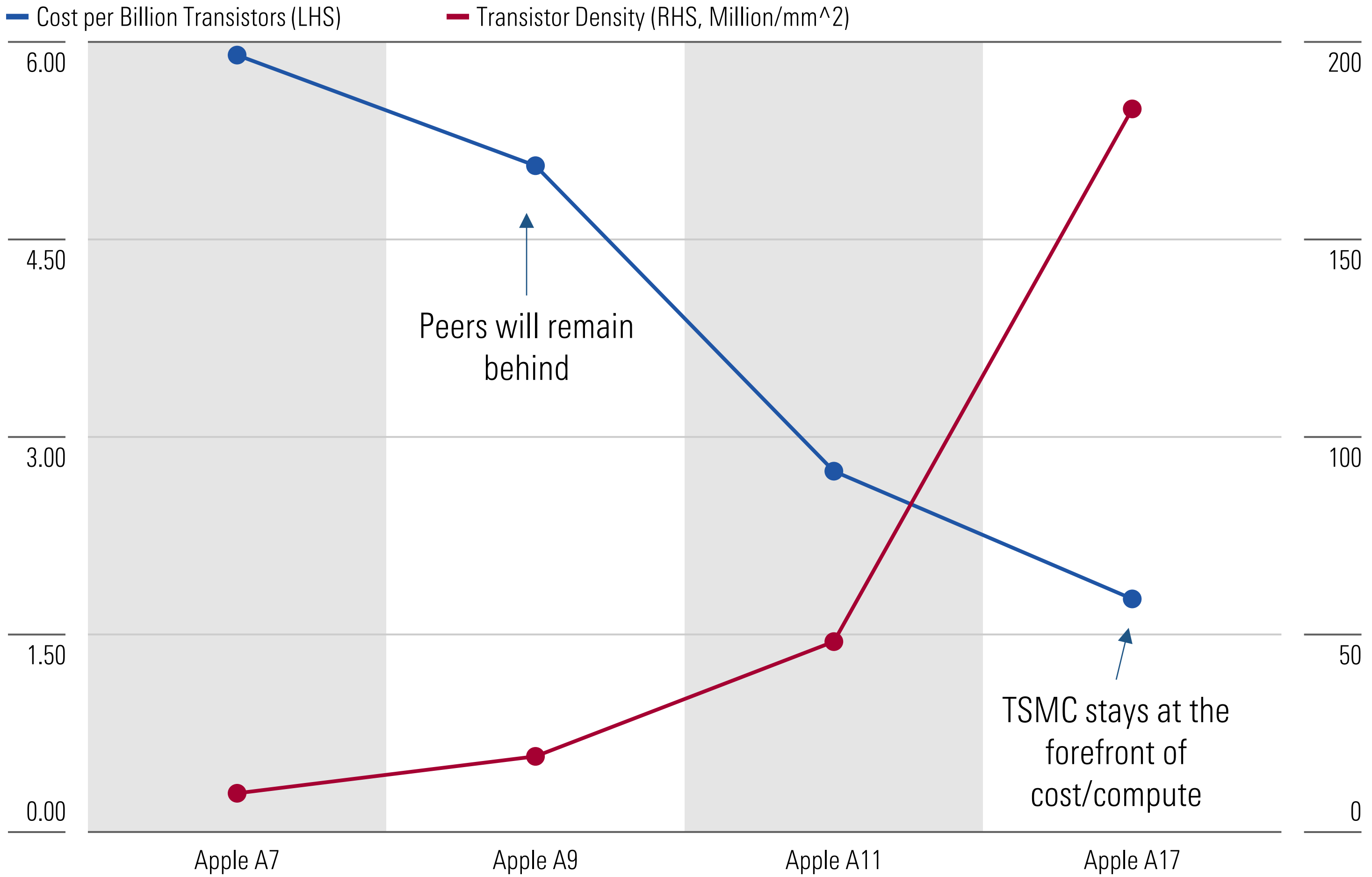
Cutting-Edge Technology Creates Cost Advantage With Superior Cost per Compute and Area

Cost Advantages Can Matter for Manufacturers
Cost advantages in semiconductors are rarer than intangible assets and switching costs, but can be found in manufacturers possessing cutting-edge technology.

TSMC Is the Marquee Example
TSMC's leading technology results in higher transistor density and lower cost per transistor. This means it is counterproductive to try to "stitch together" several cheaper, but weaker chips to provide the same amount of computational power. We estimate transistor density has gone up by 18 times and cost per transistor declined 70% from 2013-23.

Even if TSMC reduces cost per transistor minimally in the next decade, competitors are unlikely to catch up as their technology is comparable with TSMC's 2015 level (the year Apple A9 chip is released), with cost per transistor triple that of TSMC's.

TSMC Offers Cheaper Computing Power per Dollar as Tech Advances
Example using Apple iPhone processors.



Source: Anandtech, Morningstar.
Note: Calculations are performed on https://anysilicon.com/die-per-wafer-formula-free-calculators/ and are for illustrative purposes only.

Semiconductor Moats Generate Healthy Profits…

Moaty chip firms earn better profits. Higher gross margins are a classic tell of pricing power, rising in step with the width of a moat.

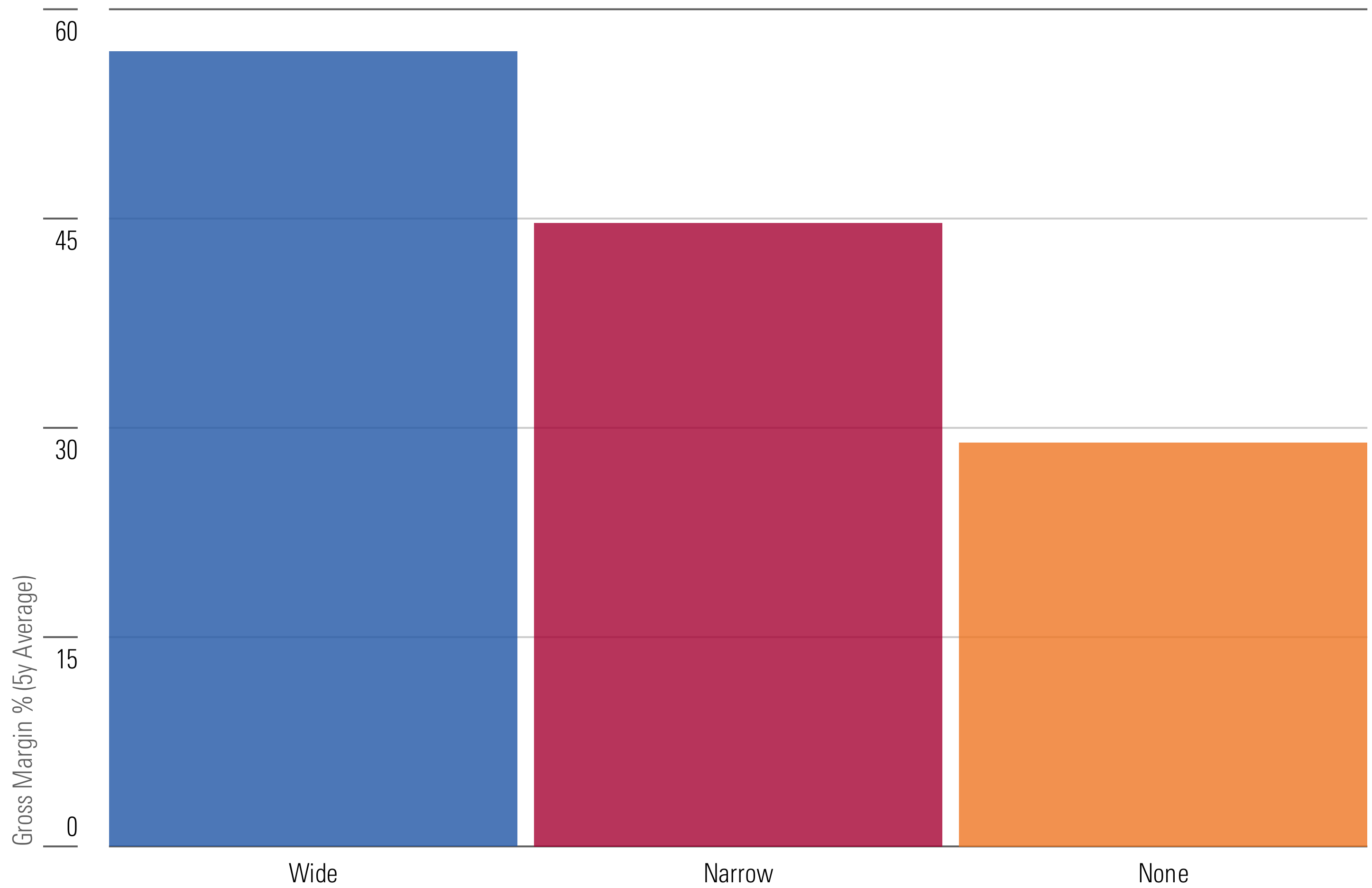
Wide-moat firms offer best-of-class, highly complex technology that merits high pricing. Nvidia and ASML are strong examples here. Less advanced technology, like analog chips, can also earn wide-moat profits via manufacturing efficiency and highly sticky, embedded products. We see this with firms like Analog Devices and Texas Instruments.

Narrow-moat firms earn pricing power and strong profits, but at a level below their wide-moat peers. These products might be a second source to wide-moat peers, such as AMD and Marvell Technology. The firm might simply operate in a more competitive market, like power management chips, with Infineon, STMicroelectonics, and Onsemi all earning narrow moats.

No-moat firms earn negligible pricing power and poor profits. No-moat foundries like GlobalFoundries lack the scale of wide-moat peer TSMC. Memory chipmakers like Micron and SK Hynix are subject to market pricing.

The Wider the Moat, the Better the Profitability

Based on aggregated average gross margin profiles over the past five years.

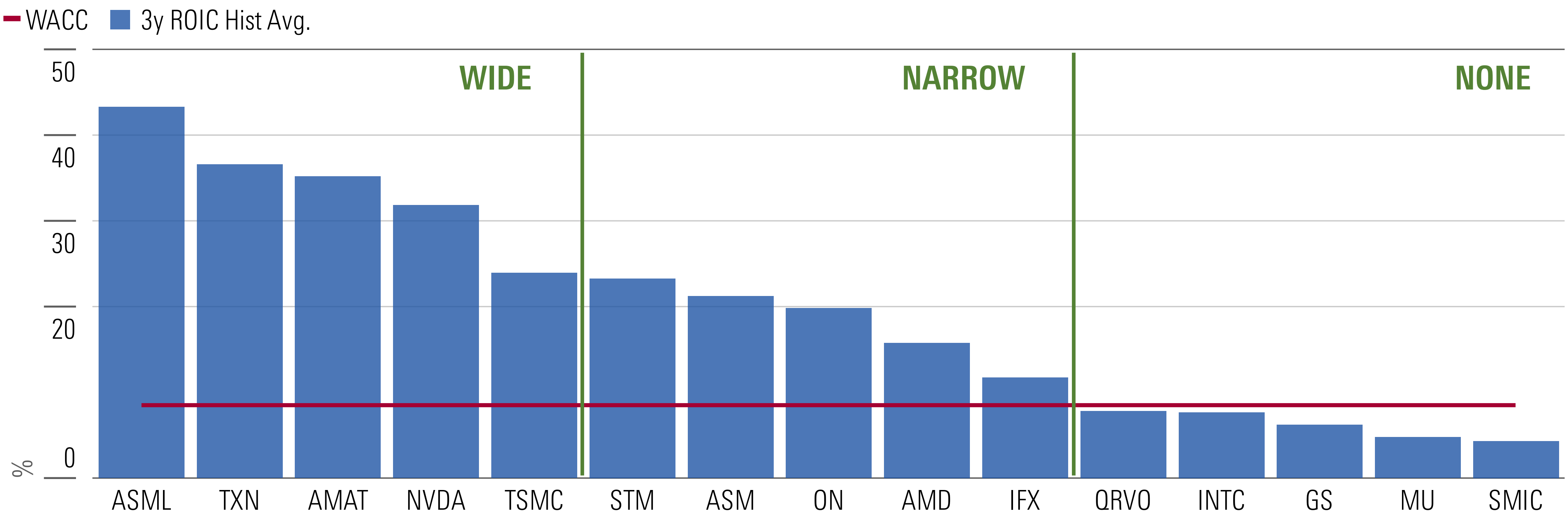


Source: PitchBook. Data as of Sept. 25, 2024.

…And Great Returns on Invested Capital

Firms with differentiated technology and robust manufacturing scale can consistently earn returns on invested capital above an average cost of capital of 8%-9%. Wider moats earn the strongest returns on invested capital and demonstrate more consistency in these returns over the course of chip market cycles. No-moat firms don’t earn adequate pricing power or sufficient manufacturing volume over the course of a cycle to earn returns consistently above their cost of capital.

Moaty Chip Firms Earn Consistently Stronger Returns on Invested Capital



Moats Aren’t Ubiquitous for Semiconductor Firms

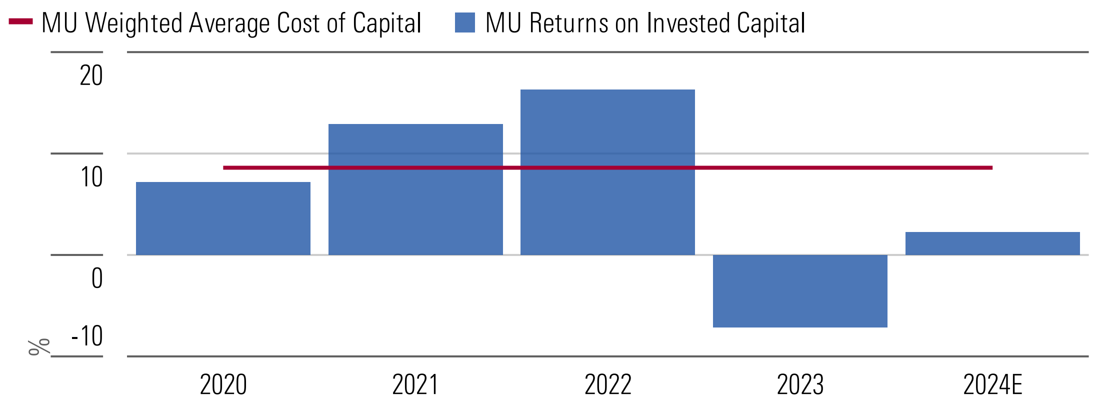
Semiconductors Remain Quite Competitive, Many Firms Do Not Have Moats
Nearly 40% of semiconductor firms under our coverage lack an economic moat. There are many ways to fail to earn a moat, but generally we see these firms as less differentiated, lacking intangible assets, or lacking scale.

Failing at Differentiation Kills Moats
Commodity-like products that require high fixed costs and are prone to cyclicality, like memory chips, often fail to earn a moat. We see this for firms like Micron and SK Hynix. Despite being two of the largest vertically integrated producers of dynamic random access memory STMicroelectronics chips globally, these firms are prone to steep cyclical downturns that can erode returns on invested capital and a would-be moat.

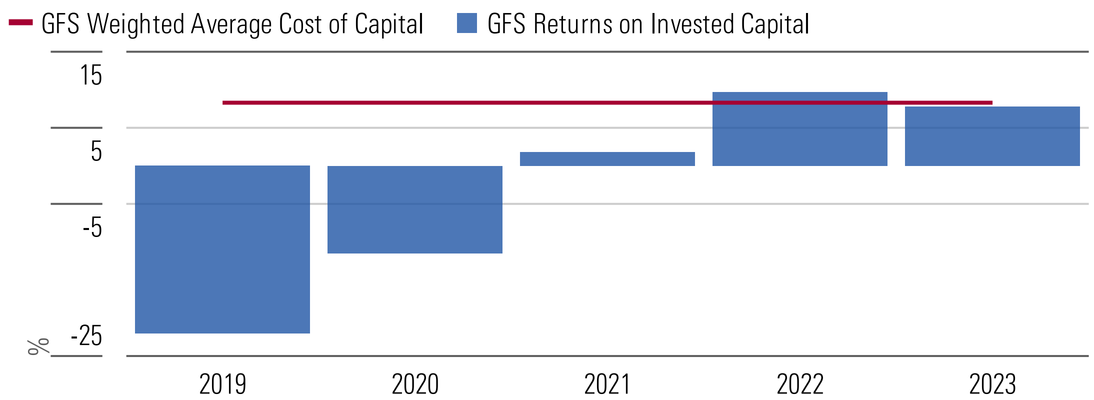
Lack of Scale for Manufacturers Is Also Problematic
We also assign no moat ratings to several subscale foundries under our coverage, like GlobalFoundries. GlobalFoundries lacks the scale of a wide-moat peer like TSMC to earn consistent returns on its large fixed-capital investment.

Even Previously Differentiated Firms Can Eventually Fall Behind on Innovation
Chip vendors can also lose a moat with operational mismanagement, like Intel. In Intel’s case, it lost its innovation lead in manufacturing to TSMC. It is also losing market share to AMD in computer processor chips. After it lost its innovation lead, we determined that Intel eroded its intangible assets and Intel no longer merited a moat. Maintaining a lead at the cutting edge of technology is not easy.

Cyclicality Can Erode ROICs for Commoditylike Memory Chips



Subscale Foundry Production Fails to Earn Consistent ROICs



Source: Company documents, Morningstar estimates. Data as of Sept. 25, 2024.

Industry Basics: Underlying Technology

Get to know logic, memory, and analog semiconductors.

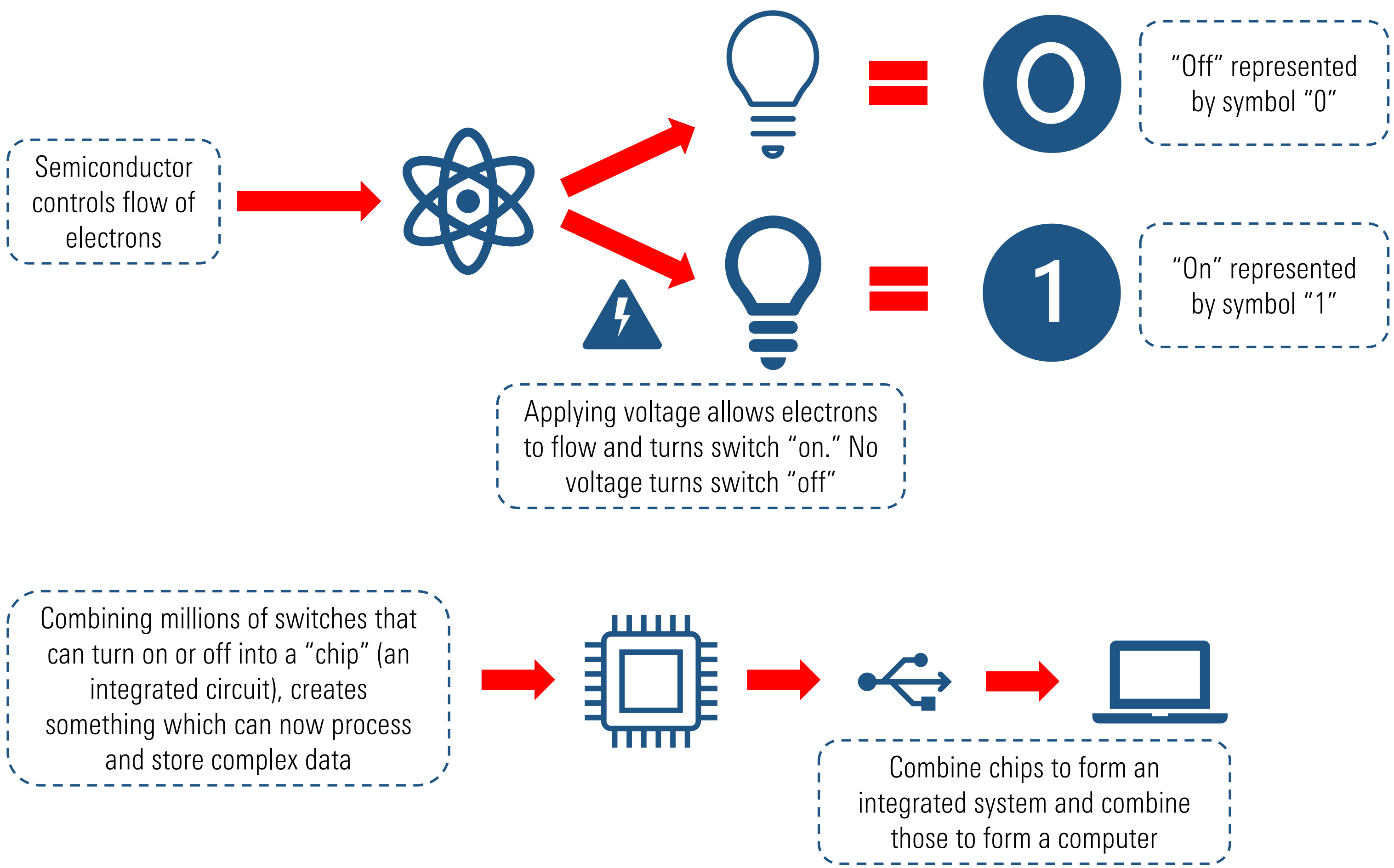
What Semiconductors Do and Why the Industry Is So Important

Why Are Semiconductors So Important?
One of the most important capabilities in the modern world is the ability to process and store information. Ultimately, information can be encoded in sequences of signs and logic. Having the ability to efficiently process and store data and logic becomes quite powerful. Semiconductors enable exactly this.

It's Hard to Process and Store Data and Logic
As humans have tried to accomplish these tasks, they run into many issues. Machines break down. The speed of information processing is limited by the physics of the medium by which you are processing it. Machines can quickly become impractically large. The first computers were made of light bulbs and took up whole rooms.

Semiconductors Solve Key Constraints
Semiconductors allow the expression of logic without any mechanical moving parts (less breakdown) at a microscopic scale (makes size practical) by controlling the flow of electrons (enables very fast speeds). This is not easy to accomplish and the semiconductor industry pushes the limits of physics to enable the modern world. Next, we will cover some of the basics, showing how they do this.

Semiconductors Control the Flow of Electrons, Enabling the Modern World

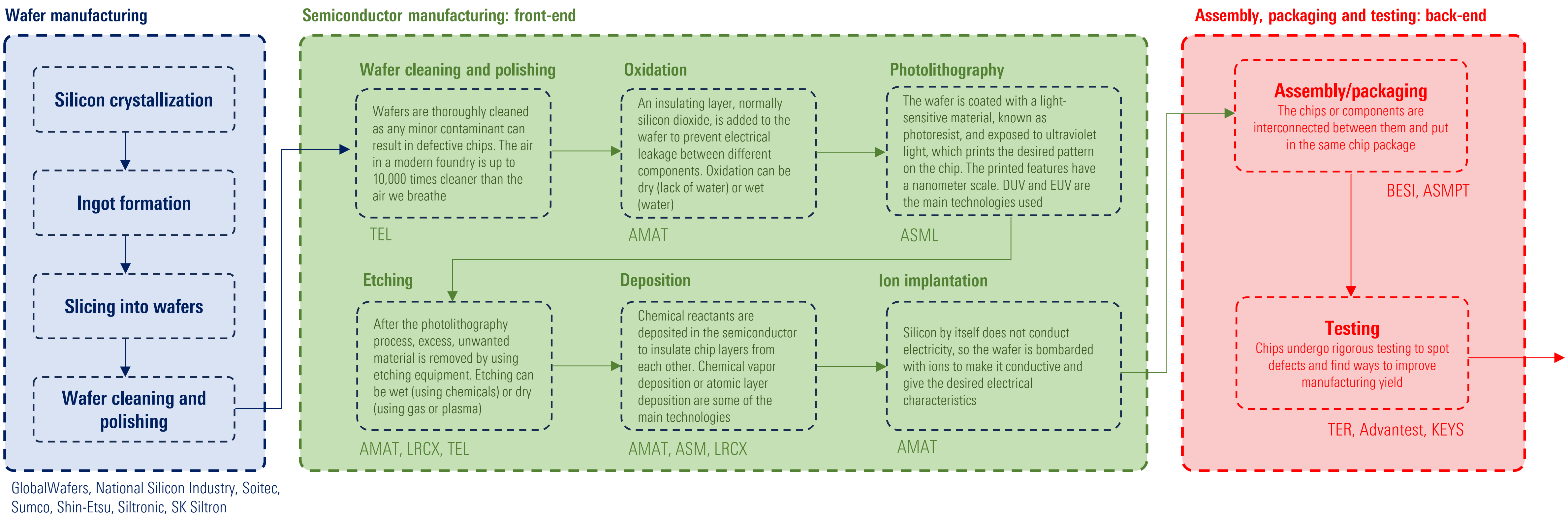


Source: Morningstar.

Highly Specialized Manufacturing Results in Highly Specialized Firms, Rewarding Innovation

Semiconductor Manufacturing Is an Extremely Technical and Intricate Process, Where Distances and Patterns Are in the Nanometer Range

The air in a semiconductor foundry (front-end) can be 10,000 times cleaner than in a hospital operating room. Only 2-3 firms dominate each subprocess, given high specialization needed.

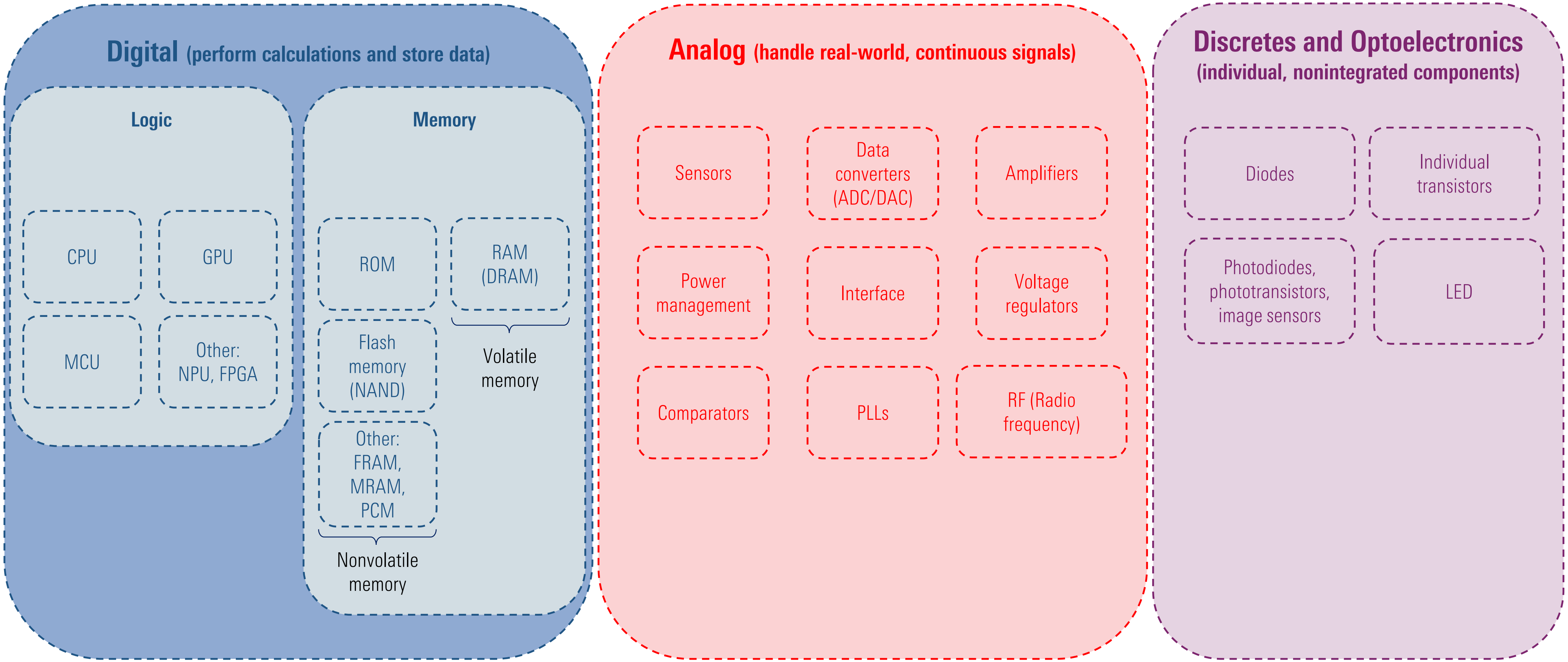


Source: Morningstar, company documents.
Note: The list of companies for each step in the manufacturing process is not exhaustive, but does cover most of the main players.

There Are Many Types of Semiconductor Products

Different Applications Require Different Types of Semiconductors and Many Times a Combination of Them

We will dive into logic and memory, the largest combined categories, and the smaller, but still important analog category. We will not cover discretes/other in-depth.



Source: Morningstar.

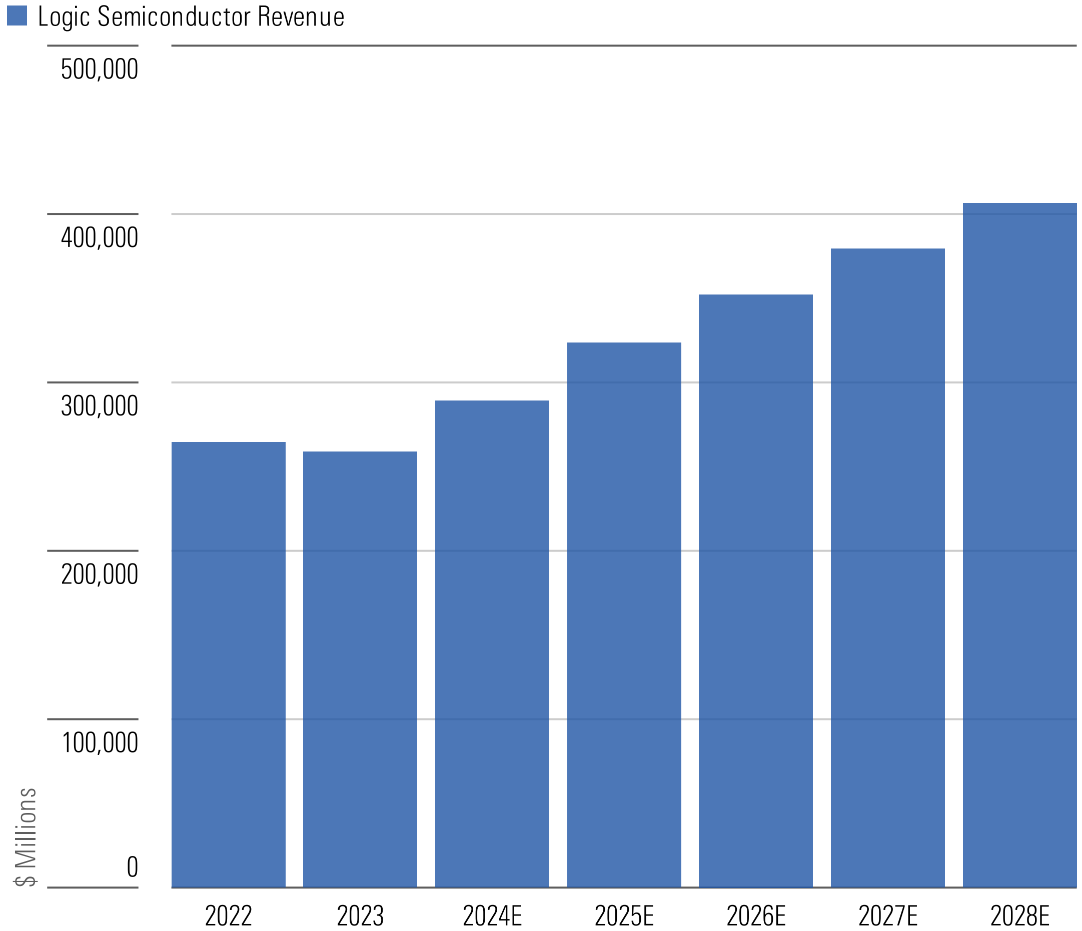
Introduction to Logic: These Are the Chips the World Is Most Familiar With

Logic Semiconductors Process Digital Information
Logic semiconductors often come to mind when people envision a chip—the "Intel inside" a PC, Apple's smartphone processor, or Nvidia AI-focused graphics processing units.

Computers to Toothbrushes, Logic Semiconductors Are Everywhere
Logic semiconductors use transistors and gates to build digital circuits that process the 0s and 1s needed for computation. Toward the low end, a simple microcontroller might be used to activate the circuit board on an electric toothbrush. At the higher end, a leading-edge processor may have tens of billions of transistors to conduct the most complex processing needs—computing engines, graphic processing units, and neural processing units to offload AI workloads on a device. Logic devices might be programmable (such as field programmable gate arrays) or built for specific applications (application-specific integrated circuits). Because logic is such a broad category, it can be hard to fully summarize with so many end markets and products.

Logic Semiconductors Most Prevalent in Computers, Servers, and Communications
Logic semiconductors are everywhere, being the largest semiconductor product category. They are most concentrated in the PC, server/IT infrastructure, and communication end markets. Intel dominates the PC CPU market with AMD in second place, Nvidia now dominates the server market with Intel and AMD in second place, and Qualcomm and Apple are key suppliers in mobile. Because of their importance, the geopolitical race to build the most advanced semiconductors in the US, Taiwan, China, and elsewhere is centered on logic chips, which help run the digital and physical world.

Logic Semiconductor Growth Should Rise With the Proliferation of AI
Growth in general purpose servers, mobile phones, and PCs also play a role.



Source: Morningstar, company financial filings.

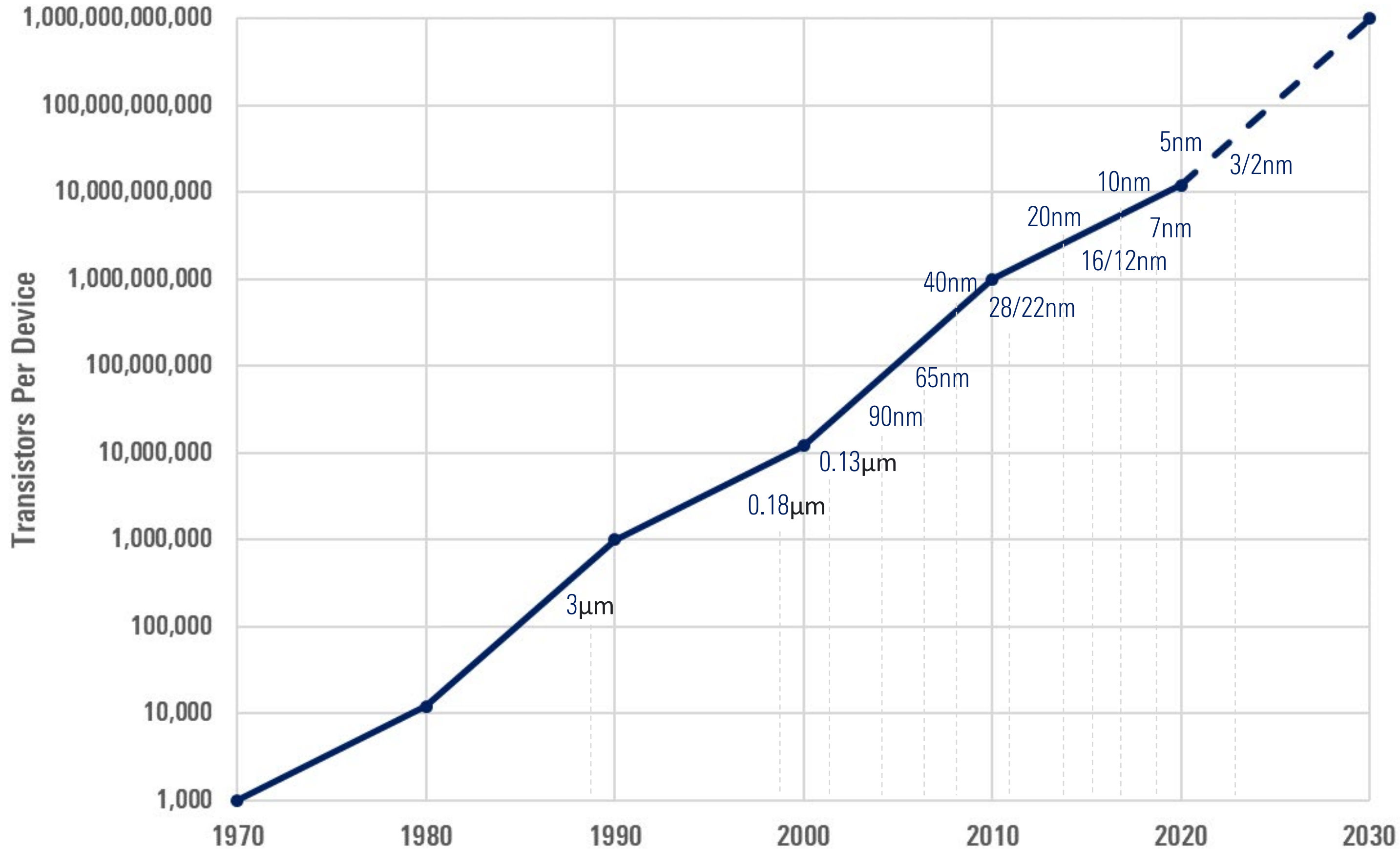
Thinking About Innovation: Meet Moore's Law, the Driving Force Behind Digital Semiconductor Innovation

All Semiconductor Investors Must Know Moore's Law
In 1965, Intel's co-founder Gordon Moore observed that the number of transistors in an integrated circuit roughly doubled every two years. This became arguably the most recognized measure of advancement within the semiconductor industry. In short, smaller transistor sizes mean chips are getting better.

Key Intuition: Firms That Enable Innovation Do Succeed
Moore's Law is not an iron law of nature, but more an observation of how the industry has tended to work. We bring it up because it highlights a key concept: the industry keeps innovating and making more advanced products. Successful innovations are rewarded with additional revenue and profits. While the original focus was on increasing transistor density, improvements in energy efficiency, new materials, and new packaging techniques have become paramount.

Still Room to Innovate
A big question that looms over the industry is "when can it no longer innovate?" At least for now, there are still pathways forward, including smaller geometries and new architectures through 2030 and even into 2040.

According to Moore's Law, the Number of Transistors per Device Doubles Every Two Years
In the last decade new transistor structures, materials, and packaging techniques have allowed its continuation.

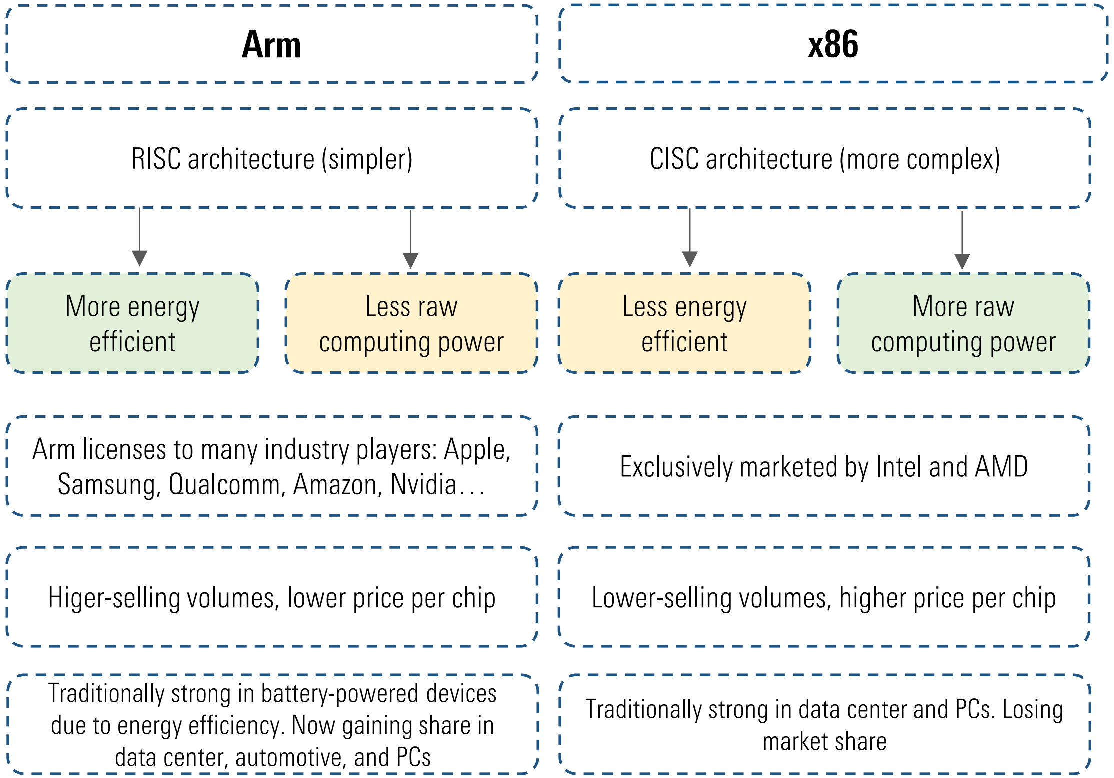


Source: Intel Innovation 2023, TSMC, Morningstar. Chart shows logarithmic scale.

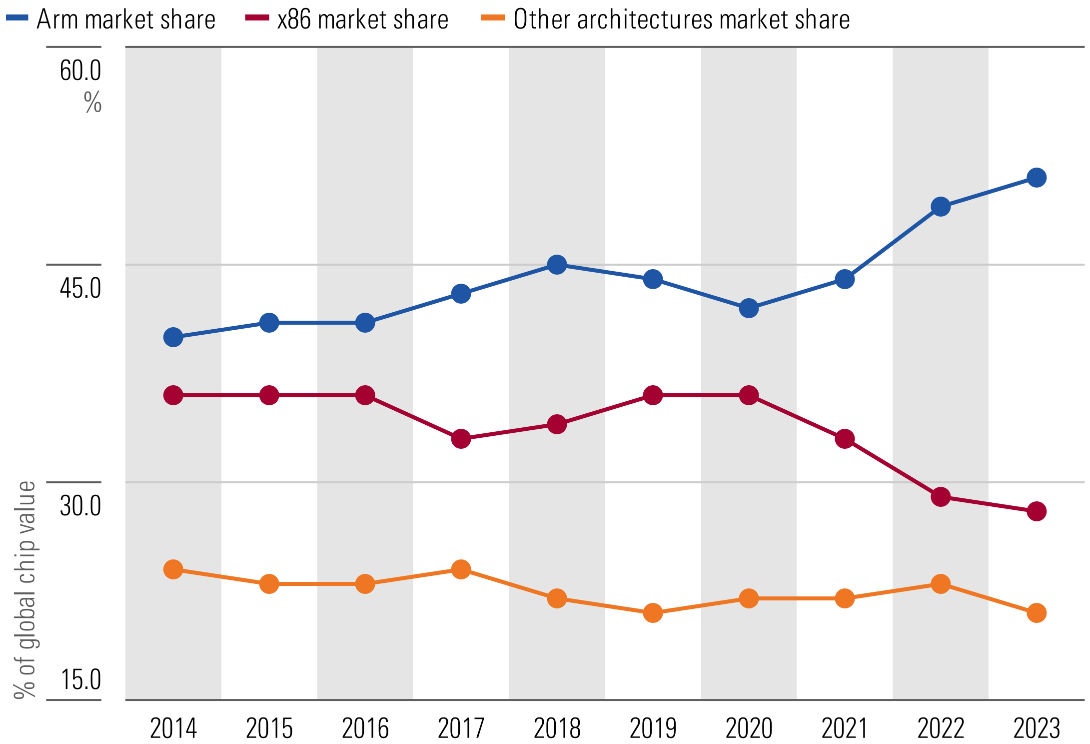
Arm Holdings Architecture: The New CPU Partner of Choice for AI Data Centers, Electric Vehicles, and PCs

Instruction set architecture defines how software interacts with semiconductor hardware like processors and memory. There are different architectures in existence. The dominant architecture was x86, but with the advent of smartphones and a focus on energy efficiency, Arm is now the dominant architecture, notably in smartphone CPUs and other battery-powered devices. Arm is also gaining market share in the data center, electric vehicle, and PC markets. Again, the focus on energy efficiency is a key driver here. As more end markets increasingly focus on energy efficiency/heat generation needs, Arm-based architectures should keep gaining share.

Arm Is Now Well Suited to Many Different Types of Computing Workloads



Arm Is Gaining Market Share Thanks to New Investment and Innovation



Source: Morningstar, Arm Holdings.

Introduction to Memory: Get to Know DRAM and NAND

DRAM for Processing, NAND for Storage

The two primary types of semiconductor memory are DRAM and NAND. DRAM is short-term memory used for application processing across servers, PCs, and smartphones. NAND is used for long-term storage of files and applications—this is what enables solid-state drives in PCs and servers.

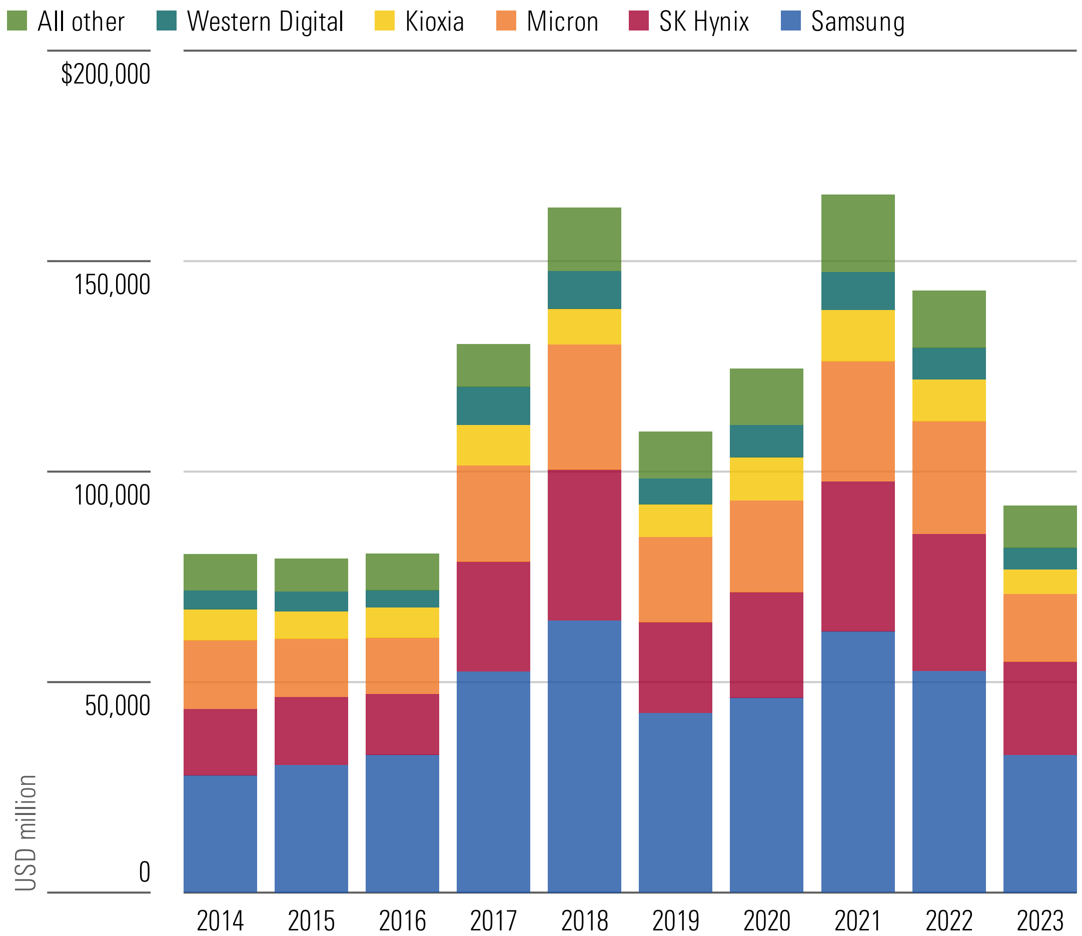
Memory Chips Are Cyclical Commodities

We see memory chips as commodities. The DRAM or NAND on offer from different competitors is fungible. This leads to high cyclicality in the semiconductor memory industry, with memory prices being driven by market supply/demand. When demand is strong and supply is tight, memory prices rise and suppliers build out more capacity—this is an upcycle. Eventually, demand will fall, leading to oversupply, falling prices, and slowing capital investment—this is a downcycle. This price elasticity and investment cycle defines the semiconductor memory cycle, which is known to repeat itself approximately every four years.

Despite Market Consolidation, Price Swings Can Still Be Volatile

High capital requirements for vertically integrated memory suppliers and cyclical dynamics have led to consolidation in the memory market. In DRAM, Samsung, SK Hynix, and Micron are the only major suppliers. NAND is more fragmented, with six major suppliers: Samsung, Kioxia, Western Digital, SK Hynix, Micron, and Yangtze Memory Technologies. Even with current industry consolidation, prices can still swing dramatically as supply/demand cycles persist.

The Memory Chip Industry Is Consolidated and Highly Cyclical



Source: Gartner, Morningstar.

Introduction to Analog: Digital Chips Represent Data in Zeros and Ones, Analog Chips Sense Real-World Signals

For Digital Semiconductors, Think Ones and Zeros

Digital integrated circuits process information using discrete, binary signals (zeros and ones, off and on). Digital chips can be logic chips like CPUs or GPUs, which process information and perform calculations, or memory chips like RAM or NAND, which store information.

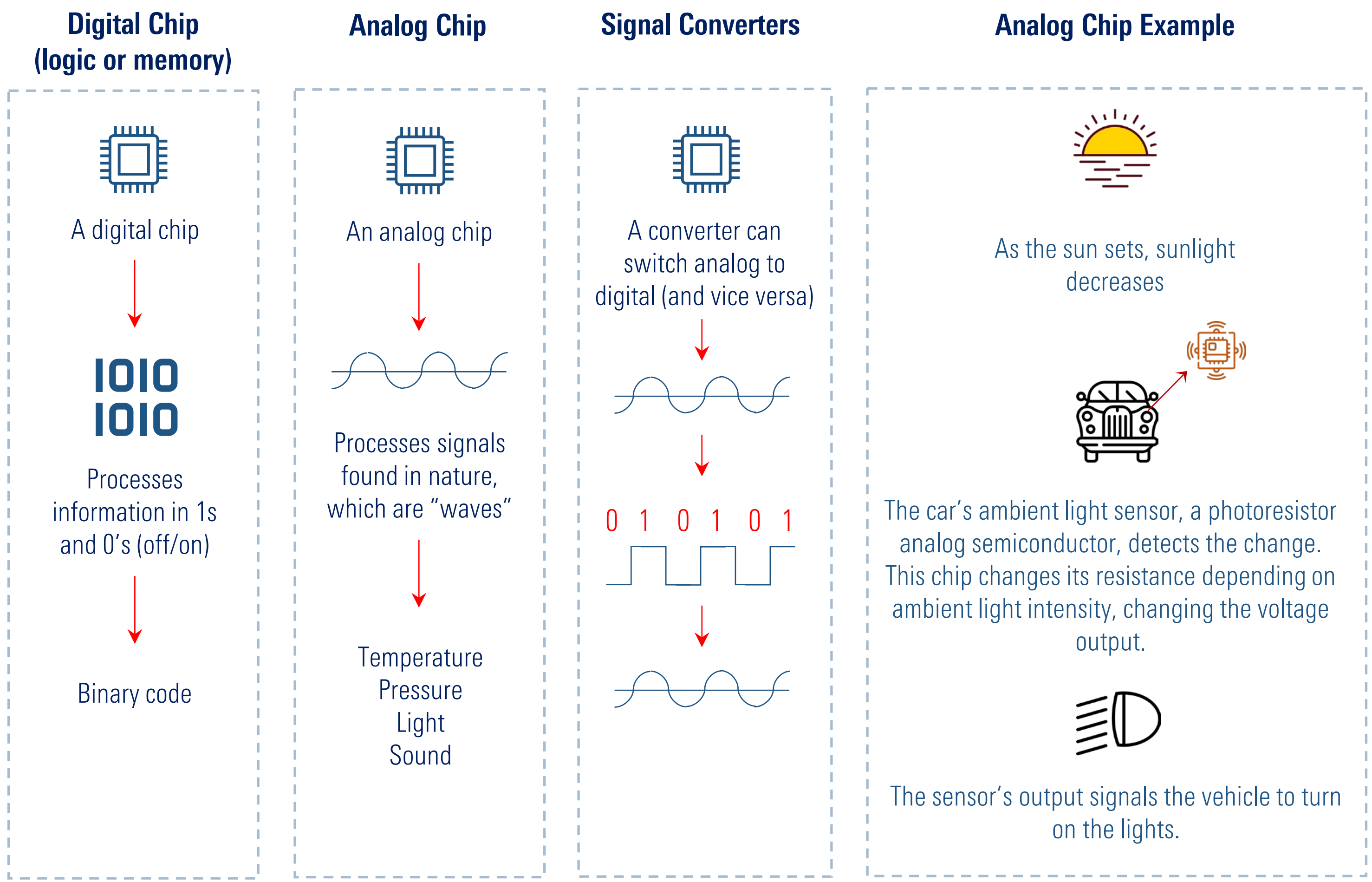
For Analog Semiconductors, Think Waves

Analog chips deal with real-world parameters like pressure, temperature, or light. Real-world signals are continuous (not discrete), can be expressed as wave functions with frequencies and amplitudes, and can take an infinite number of different values (there are infinite possible values between 0 degree Celsius and 5 degrees Celsius). Chips that include analog and digital circuitry are known as mixed-signal.

Analog Chips Can Be More Difficult to Integrate/Optimize

Although digital chips are more expensive and demanding technologically, their design can be more straightforward. Binary signals have just two states and signals are immune to noise or degradation. On the contrary, analog chips deal with noise or interference, and engineers might need many trial-and-error cycles to get the optimal performance for an application.

Analog Chips Convert Real-World Signals to Digital Signals; Digital Chips Operate With Binary Code



Source: Morningstar. Icons from Freepik.

Industry Basics: Market Dynamics and Cycles

Understand key end markets, growth characteristics, cyclicality, and valuation drivers.

Semiconductor Product Type Market Size: Logic and Memory Are Largest Product Categories

Logic Is Most Important Overall Category

Logic is a broad description and can be broken into many different subtypes (application-specific standard products, application-specific integrated circuits, general purpose, and microcomponents). Do not get lost in these details. Rather, on a high level, logic products tend to be the processors many people are already familiar with (CPUs and GPUs), and other processor-like chips that may be more/less flexible, designed for more/fewer product applications, and for one or many clients.

Memory

Memory stores information as opposed to processing it. The most common memory products are NAND (a type of flash memory) and DRAM (a type of RAM).

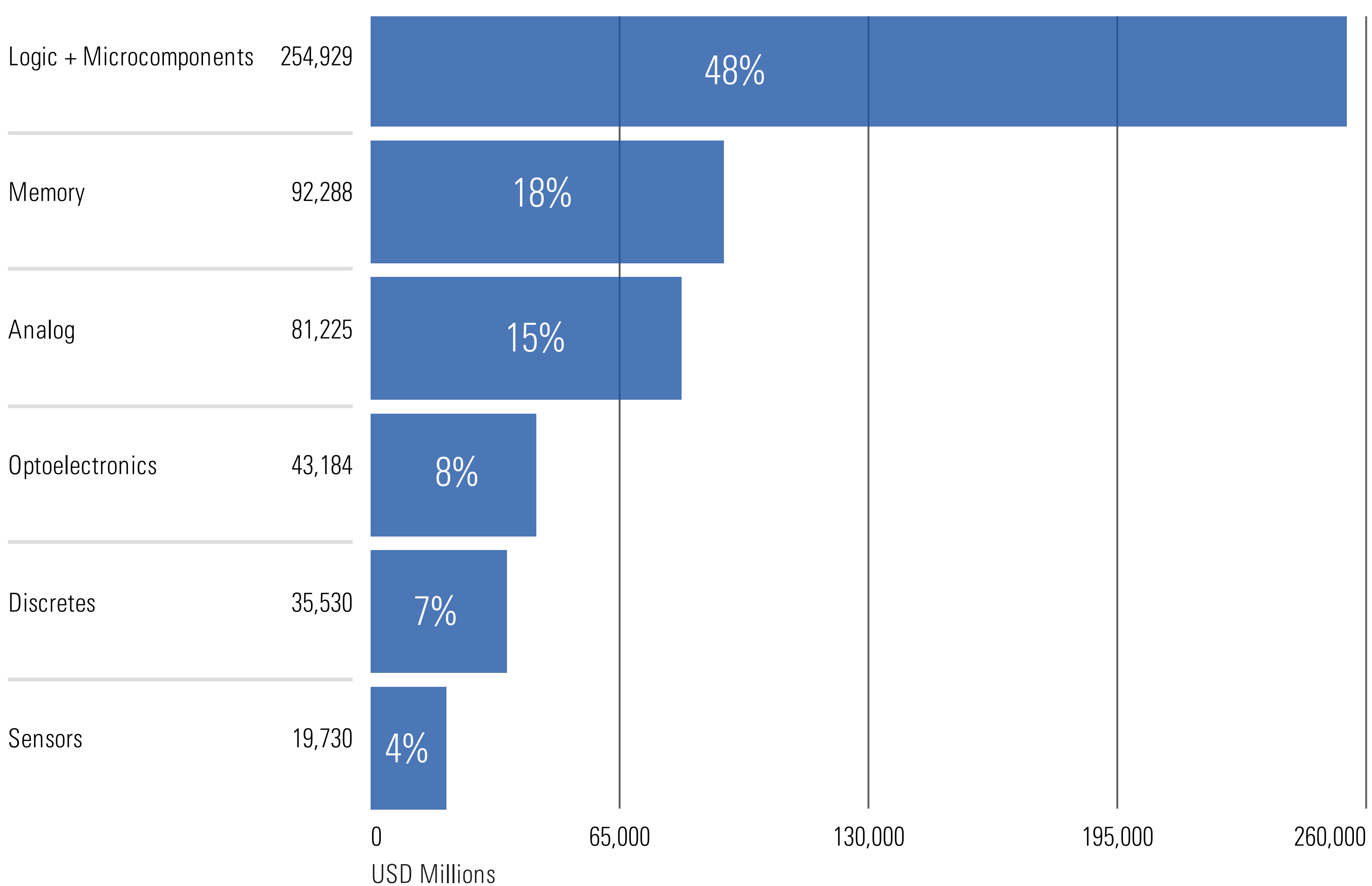
Analog

Analog is another broad category, typically defined by its ability to process real-world/wave signals.

Optoelectronics/Discretes/Sensors

These include image sensors, laser diodes, LEDs, different sensors (pressure/temperature, and so on), and singular components such as diodes or unintegrated transistors.

2023 Global Semiconductor Billings by Type—WSTS



Source: World Semiconductor Trade Statistics, Morningstar.

Key End Markets

Computers, Servers, and Storage Is the Largest End Market

Unsurprisingly, semiconductors are extremely prevalent in personal computers, servers, and storage infrastructure. These applications should already be familiar to most readers, including the processors and storage/memory products in your PC, and the servers that power enterprise IT and cloud infrastructure.

Communications Is the Second-Largest End Market

Communications include semiconductors used to power networking (routers, modems, wireless access points, and so on), telecom infrastructure (such as optical fiber networks), and mobile handsets (like smartphones).

Automobiles Are an Important Sector for Semiconductors

Automobiles use numerous electronic components. Some are more obvious, such as the visible infotainment and instrument clusters (entertainment systems or driver-assistance capabilities), and some are less obvious, such as the different sensors and control systems (like antilock brakes) throughout the vehicle.

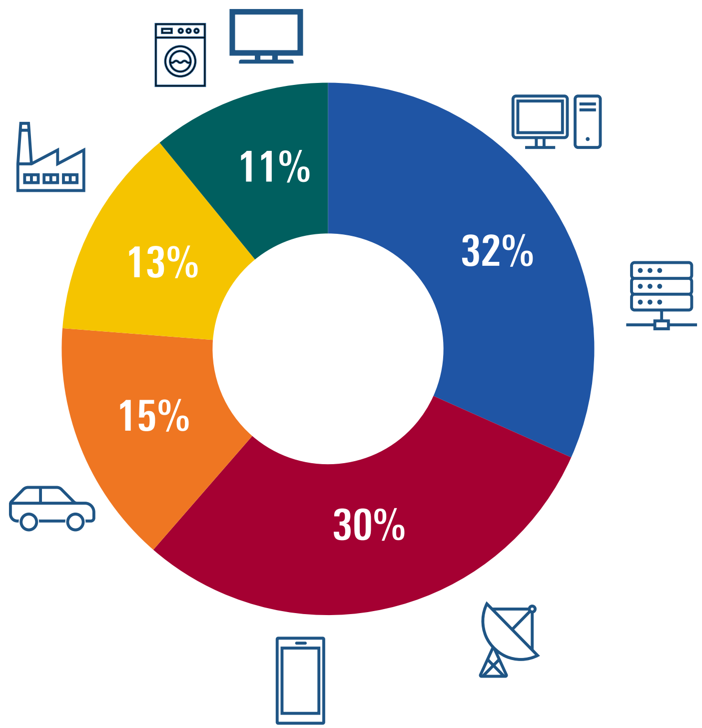
Industrial/Military Applications Are Primarily Industrial (Military Is Fairly Small)

This is a very broad category and can include electronic components that help power automation in commercial activities (such as the Internet of Things), transportation applications (fleet monitoring), security, military weapons, and more.

Consumer Electronics a Final Key End Market

Consumer electronics include TVs, video games, appliances, wearables, and so on.

Semiconductor End Markets Based on 2023 Vendor Revenue



Application	%
Compute/Storage	31.68
Communications	29.70
Autos	14.85
Industrial/Military	12.87
Consumer	10.89

Source: Morningstar, Gartner.
Note: Percentage values may not equal 100% due to rounding.

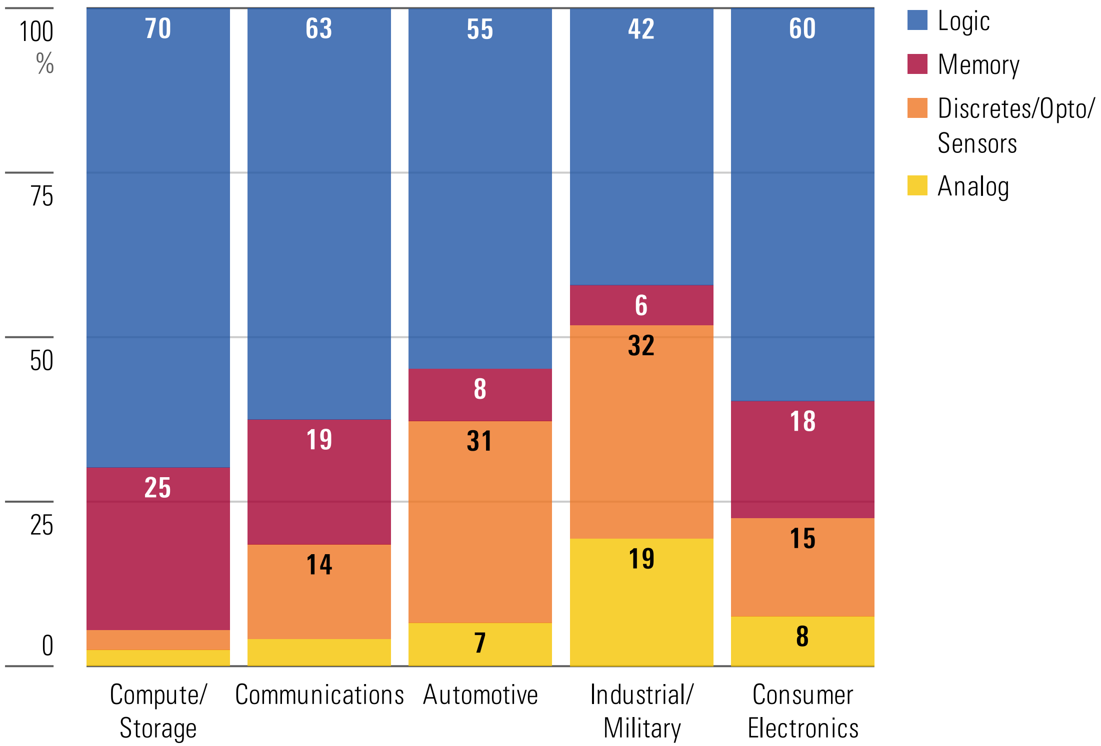
Product Type by End Market: Logic and Memory Most Prevalent in Compute/Storage and Communications

When looking at each end market, logic and memory products are most prevalent in compute/storage applications and communications. Automotive and Industrial applications tend to use more analog and discretes/sensors/optoelectronic products. Still, each end market uses a mix of products.

Logic is the largest product category and nearly 70% of logic production goes toward compute/storage and communications end markets. Memory is even more concentrated here. Discretes/sensors/optoelectronics and analog tend to be the exact opposite, with over half of production going toward automotive and industrial applications.

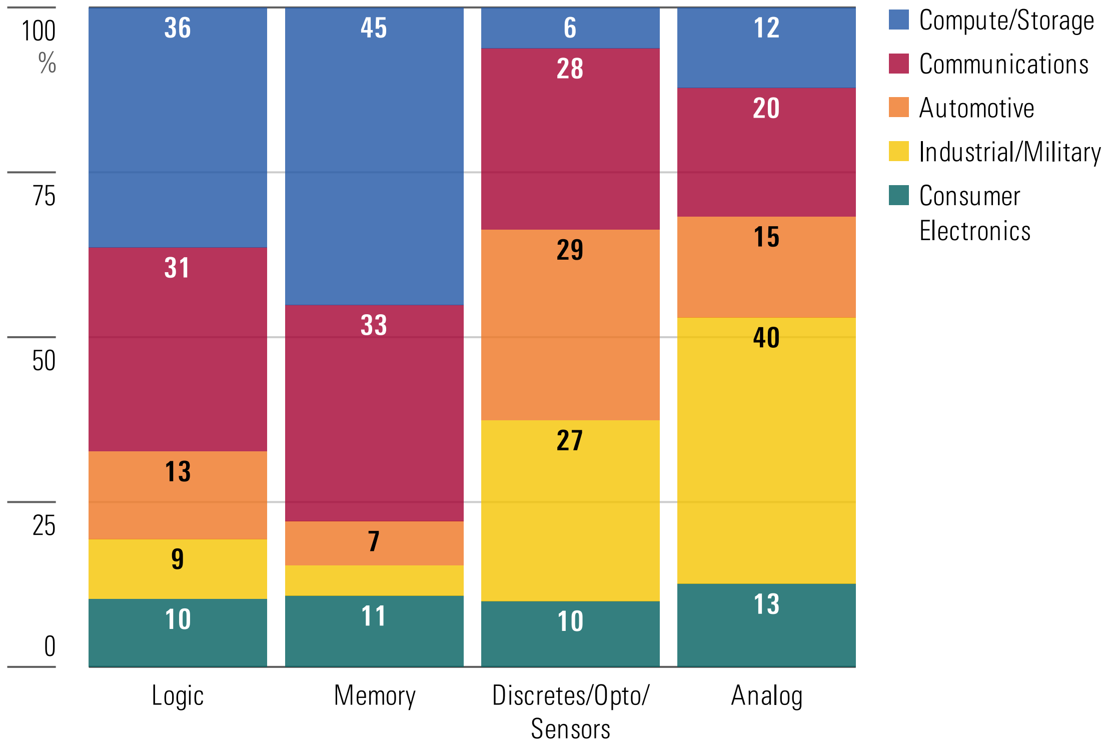
2023 Product Revenue Mix by End Market

Which products are used by which end markets?



End-Market Mix by 2023 Product Revenue

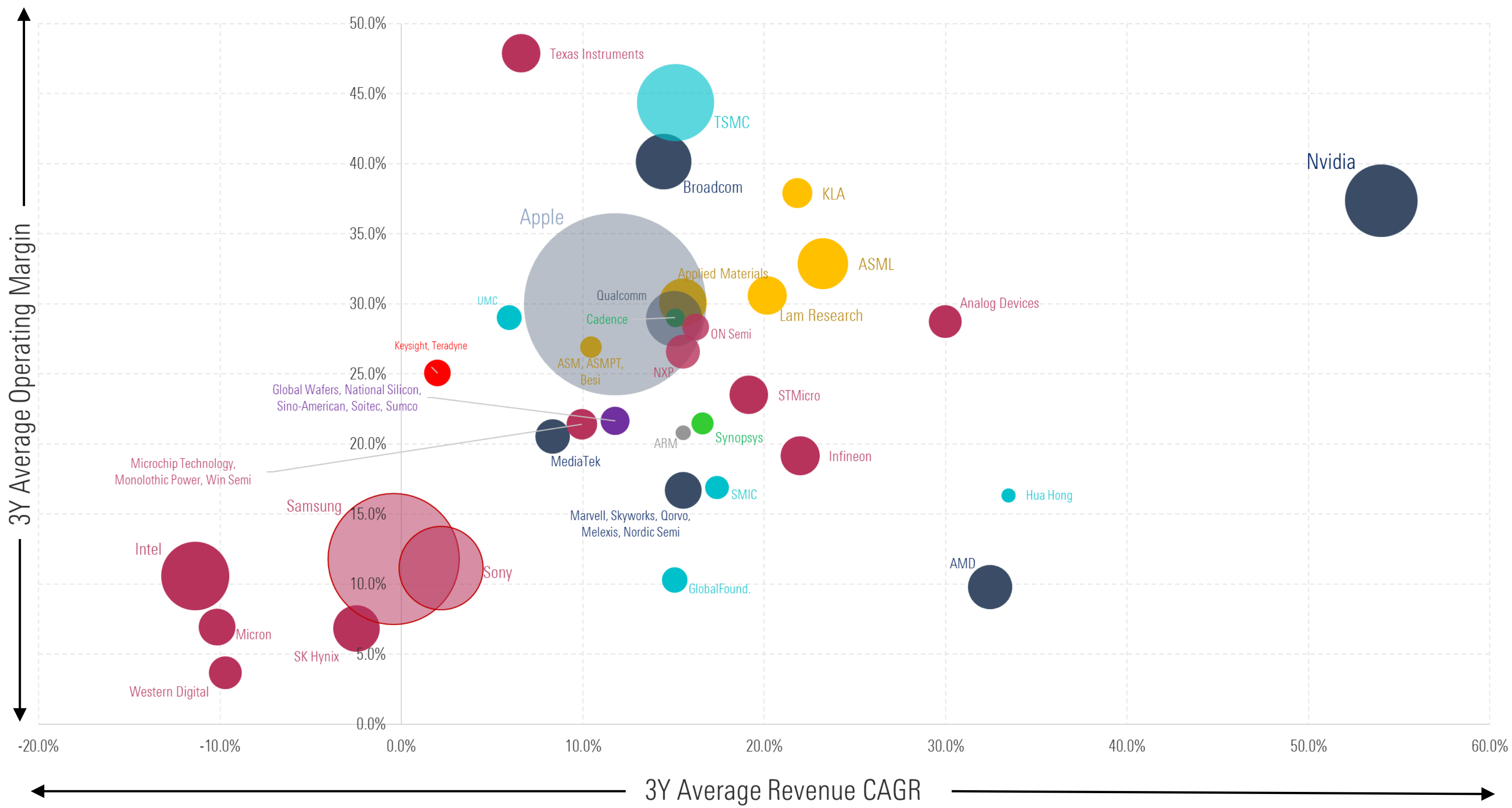
To which end markets does each product go?



Source: Gartner, Morningstar.

Most Semiconductor Subindustries Show an Oligopolistic Structure, With a Few Players Dominating

Bubble Size Represents Fiscal 2023 Fiscal Revenue in USD million



Company	Revenue ($million)	Subindustry
ARM	2,679	IP
Applied Materials	26,517	Equipment
ASML	29,820	
ASM, ASMPT, Besi	5,354	
KLA	10,496	
Lam Research	17,429	
Cadence	4,090	Software
Synopsys	5,843	
Global Wafers, National Silicon, Sino-American, Soitec, Sumco	9,633	Wafers
AMD	22,680	Fabless
Apple	383,285	
Broadcom	35,819	
Qualcomm	35,820	
MediaTek	13,916	
Nvidia	60,922	
Marvell, Skyworks, Qorvo, Melexis, Nordic Semi	15,848	
GlobalFound.	7,392	Foundries
Hua Hong	2,286	
SMIC	6,322	
TSMC	69,402	
UMC	7,144	
Intel	54,228	IDMs
Micron	15,540	
SK Hynix	25,061	
Samsung	198,046	
Western Digital	12,318	
Analog Devices	12,306	
Infineon	17,402	
Microchip Technology, Monolithic Power, Win Semi	10,768	
NXP	13,276	
ON Semi	8,253	
Sony	81,062	
STMicro	17,286	
Texas Instruments	17,519	
Keysight, Teradyne	8,140	Packaging

Source: Morningstar, PitchBook data.
Note: (1) Some firms can belong to more than one subindustry, but they are classified according to their most important subindustry. (2) Some firms are aggregated into the same bubble.

Industry Growth: Mid- to High-Single-Digit Percentage Is Typical, Driven by Innovation and Increasing Complexity

Semiconductors Still Growing Consistently

The semiconductor industry has been around for a while, from transistor radios in the 1950s to personal computers gaining popularity in the 1980s to today. Over the last couple of decades, a mid- to high-single-digit percentage level of growth has been typical.

Increasing Electrification, Complexity Drives Growth

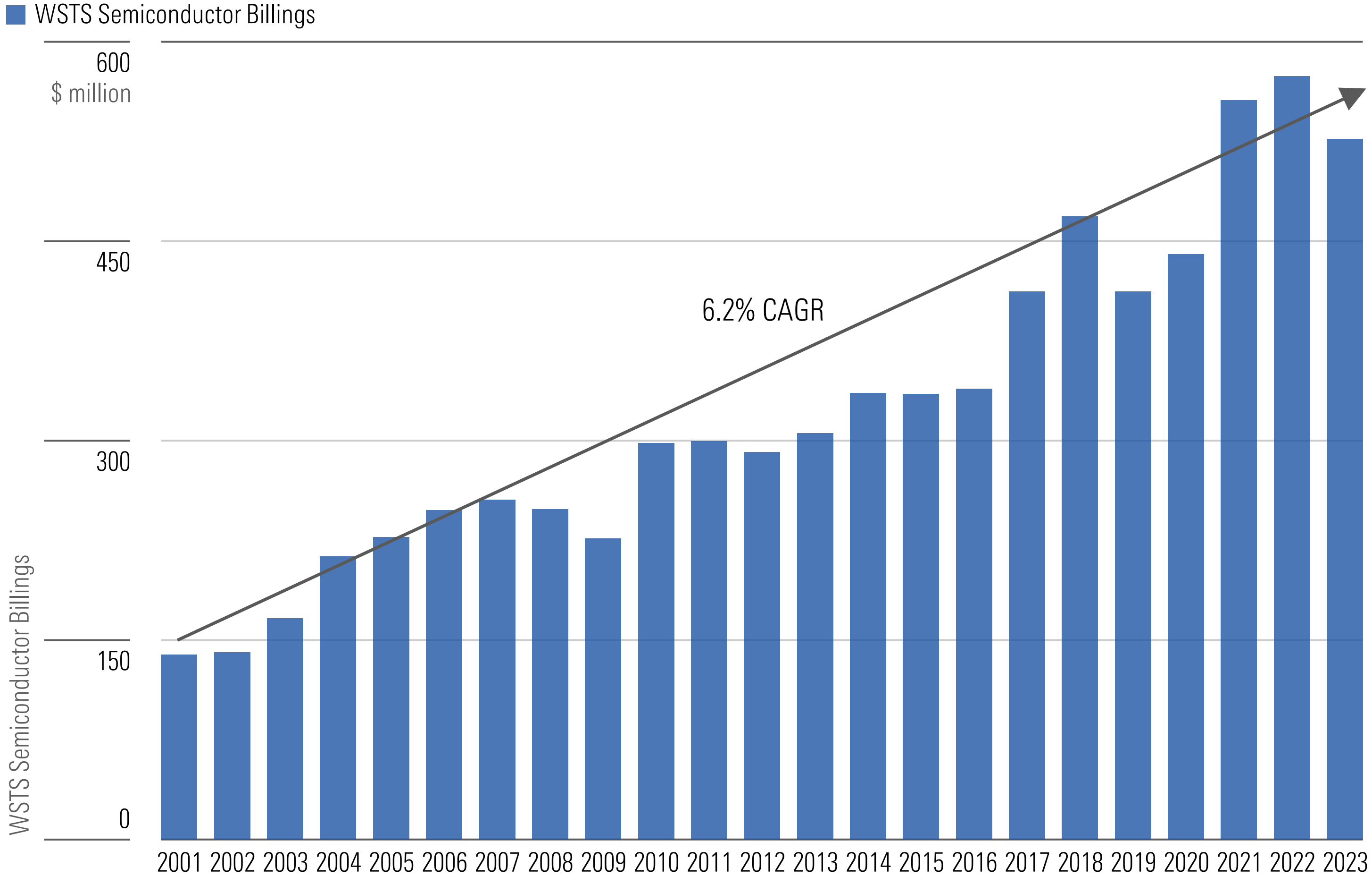
Over time, the world around us has become more integrated with electronics (which require semiconductors) and our electronics become more complex (compare a phone today with one from 5-10 years ago). These are long-term, structural trends that have driven continued growth for the industry. It does not appear that these trends are about to end anytime soon.

Growth Rates Can Vary by End Market and Product

Within the semiconductor industry, there are many different subindustries, product types, and end markets. Each of these can grow at different rates. For example, AI-optimized servers are growing exponentially currently, while general-purpose servers are growing at a low-single-digit pace, and automotive semiconductors are in a cyclical trough.

Semiconductor Industry Typically Grows at a Mid- to High-Single-Digit Pace

Although, these growth rates can vary greatly by end market and product type.



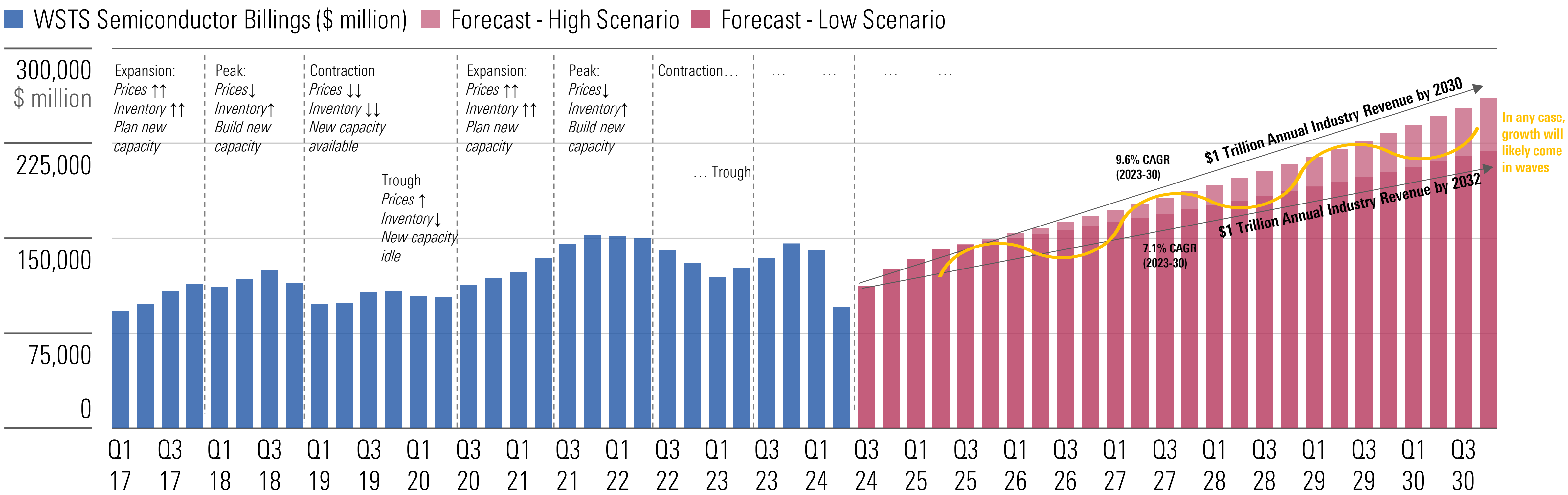
Source: WSTS.

Industry Cycles: Semiconductors Are Also Cyclical, so Expect a Bumpy Ride

Morningstar estimates the industry could grow at a 7.1%-9.6% compound annual growth rate up to 2030, powered by incremental demand in artificial intelligence, autonomous driving, automation, and higher semiconductor content per device. This is the “structural growth” aspect of the industry. However, expect a bumpy ride along the way as the industry remains cyclical. There is a boom-and-bust cycle that lasts approximately four years, which coincides with the time it typically takes to respond to a shortage (plan, build, and ramp up new capacity) followed by inevitable changes in demand and potential overbuilding. Firms with a strong moat often exhibit smaller earnings and share price volatility.

A Typical Semiconductor Cycle Has Four Phases

Structural demand growth results in higher peaks and troughs in subsequent cycles.



Source: WSTS, Morningstar.

Revenue Cyclicality Drives Cycles in Profitability

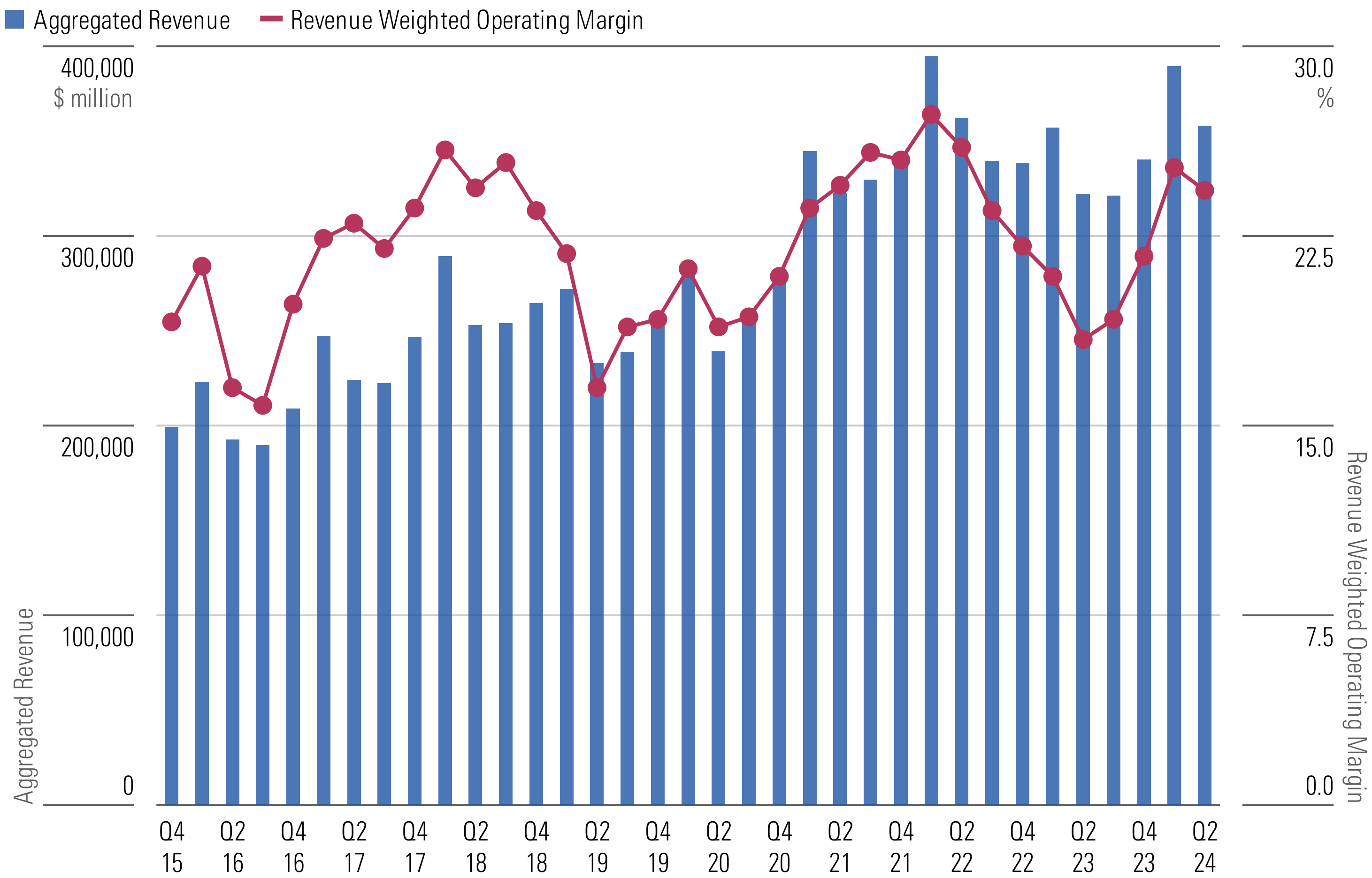
Semiconductor Firms See Margin Cycles Too

Unsurprisingly, for an industry that sees revenue cyclicality, there is also margin cyclicality. Most semiconductor firms have a material level of fixed costs, whether through capex requirements for manufacturers, or research and development requirements for designers (and fabs too) trying to stay on the cutting edge of technology. As a result, when revenue goes through cycles, there is usually a material degree of operating leverage.

Profitability Cycles Can Be Material

Based on our weighted average operating margin for our semiconductor coverage, operating margins can swing dramatically from trough to peak, going from just over 15% at a trough to almost 30% at a peak. These swings are often worse for no-moat firms, which are more subject to market pricing and order volatility. Historically, violent cycles in certain industries, such as memory, have driven companies out of business or forced consolidation.

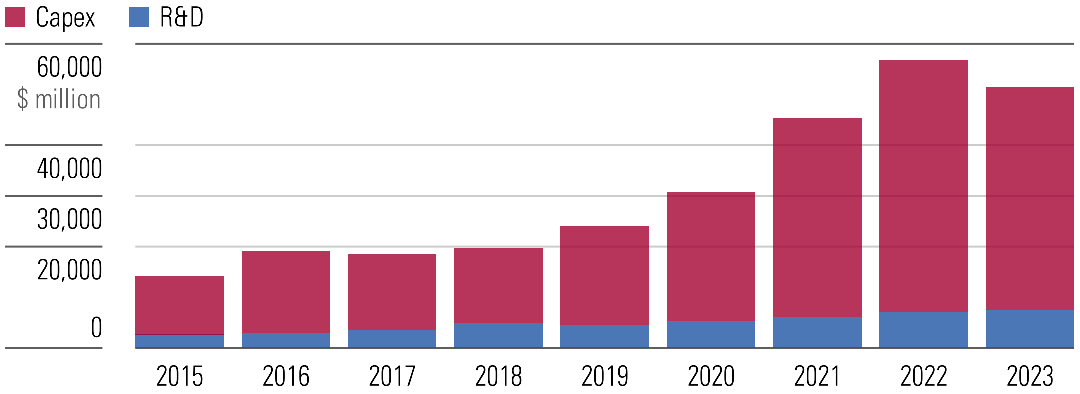
Margins Go Through Cycles, Along With Revenue, Leading to Cycles of Profitability



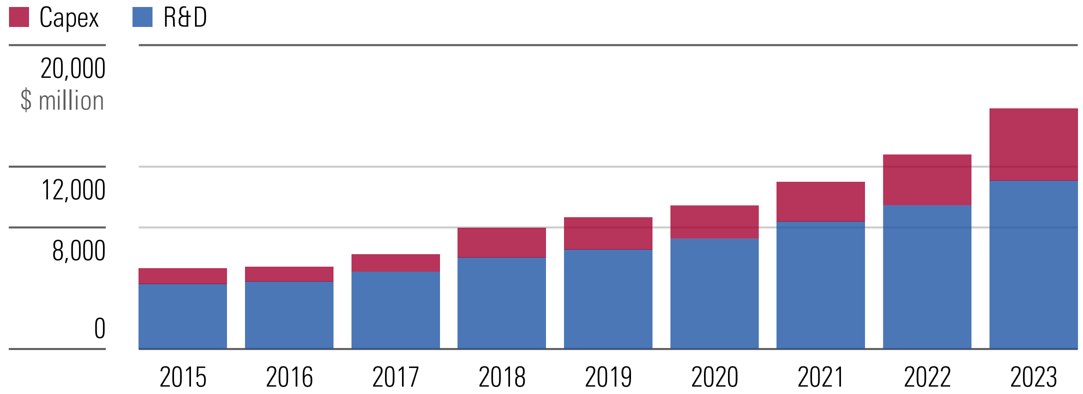
Source: Morningstar, company financial filings.

Even in Periods of Economic Uncertainty, Capacity and R&D Keep Rising, Underpinned by Industry Growth

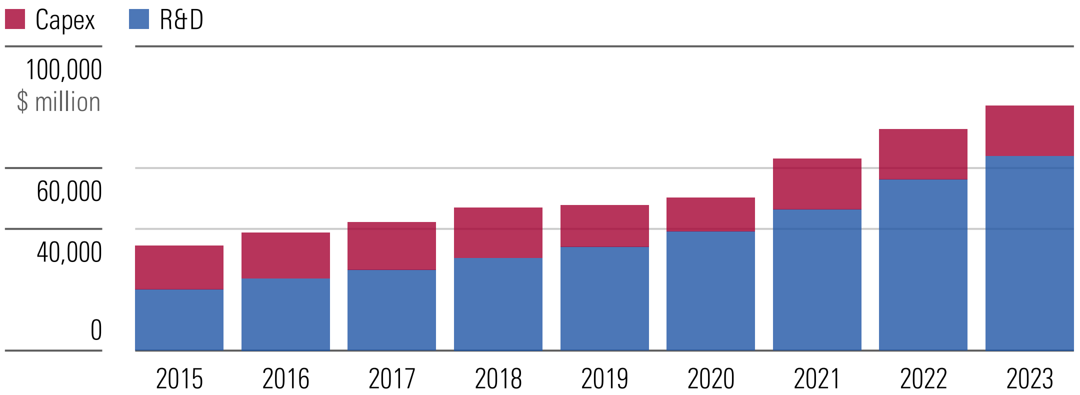
Foundries: Investments Focused on Capacity Expansion for Leading-Edge Nodes



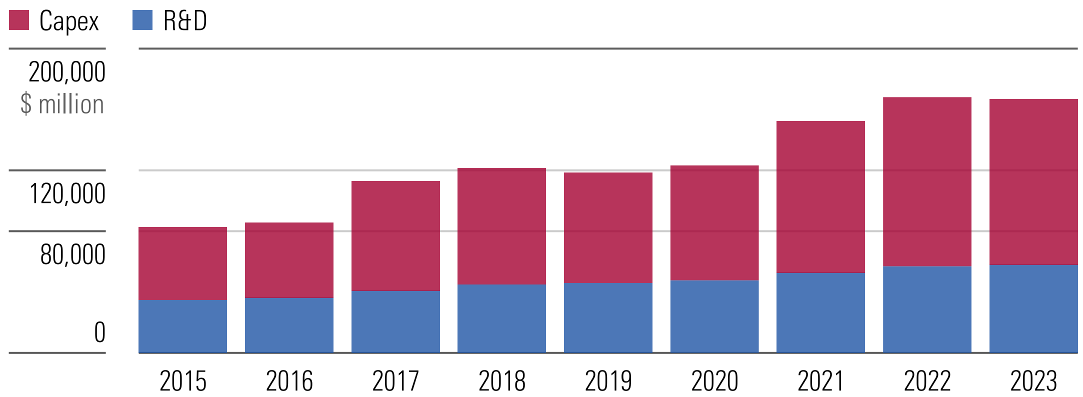
Equipment: R&D Investment to Bring Innovations and Continue Moore's Law



Fabless: R&D Investments to Design More Powerful, Energy-Efficient Chips



IDMs: The Integrated Business Model Requires High Capex and R&D



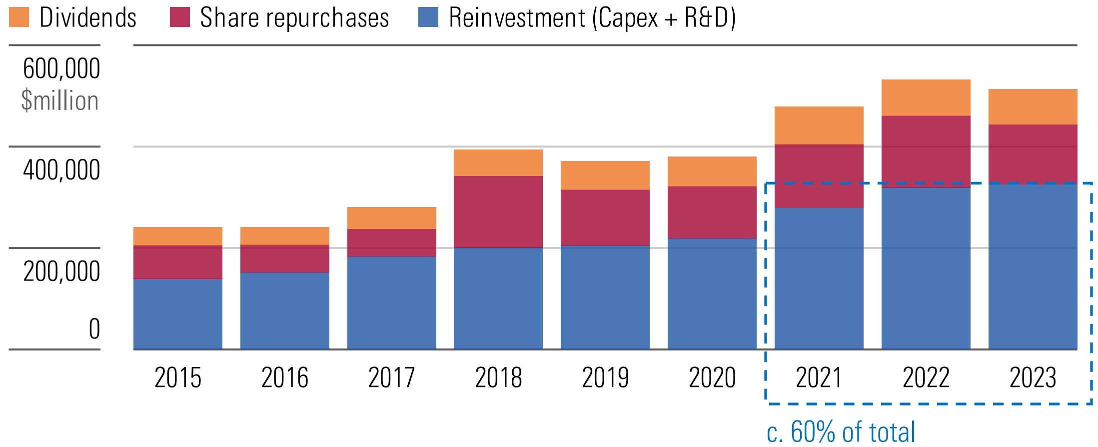
Source: Morningstar, company financial filings.

Sixty Percent of Distributable Capital Is Reinvested, Highlighting an Abundant Number of Growth Opportunities

Semiconductor Firms Must Invest to Stay Relevant, Pursue Future Growth

Most semiconductor firms have sufficient reinvestment opportunity, making this the priority when allocating capital. Reinvestment normally goes into R&D and engineering talent for fabless, software, and semiconductor equipment firms, and new capacity for foundries like TSMC or Samsung. The 9% CAGR in reinvestment dollars is in line with the overall growth of the industry, given we expect the industry to grow by up to 9.6% per year until 2030. Once reinvestment needs are covered, firms make share repurchases their second priority with most firms buying back shares systematically rather than opportunistically. Given the cyclical nature of the industry, dividend policies are normally based on a payout ratio, so absolute dividends per share can fluctuate each year.

Reinvestment Is the First Priority, Doubling in The Past Eight Years at a 9% CAGR



Many of the Largest Firms Invested Successfully In Exceptional Innovation

Twenty-one out of 48 semiconductor firms in our coverage have an Exemplary Morningstar Capital Allocation Rating, mainly belonging to the semiconductor equipment, software, and fabless subindustries. Exemplary firms are highly resourceful, deciding to invest in technology well over a decade before their products achieved commercial success. Nvidia's GPUs or ASML's EUV technology are clear examples of this. Most of the sector enjoys clean balance sheets with little to no debt, a positive for companies operating in a cyclical industry. Dividends and buybacks are at an appropriate level for most firms, taking second place compared with reinvestment, given we expect the industry will grow at high-single-digits in the long term.

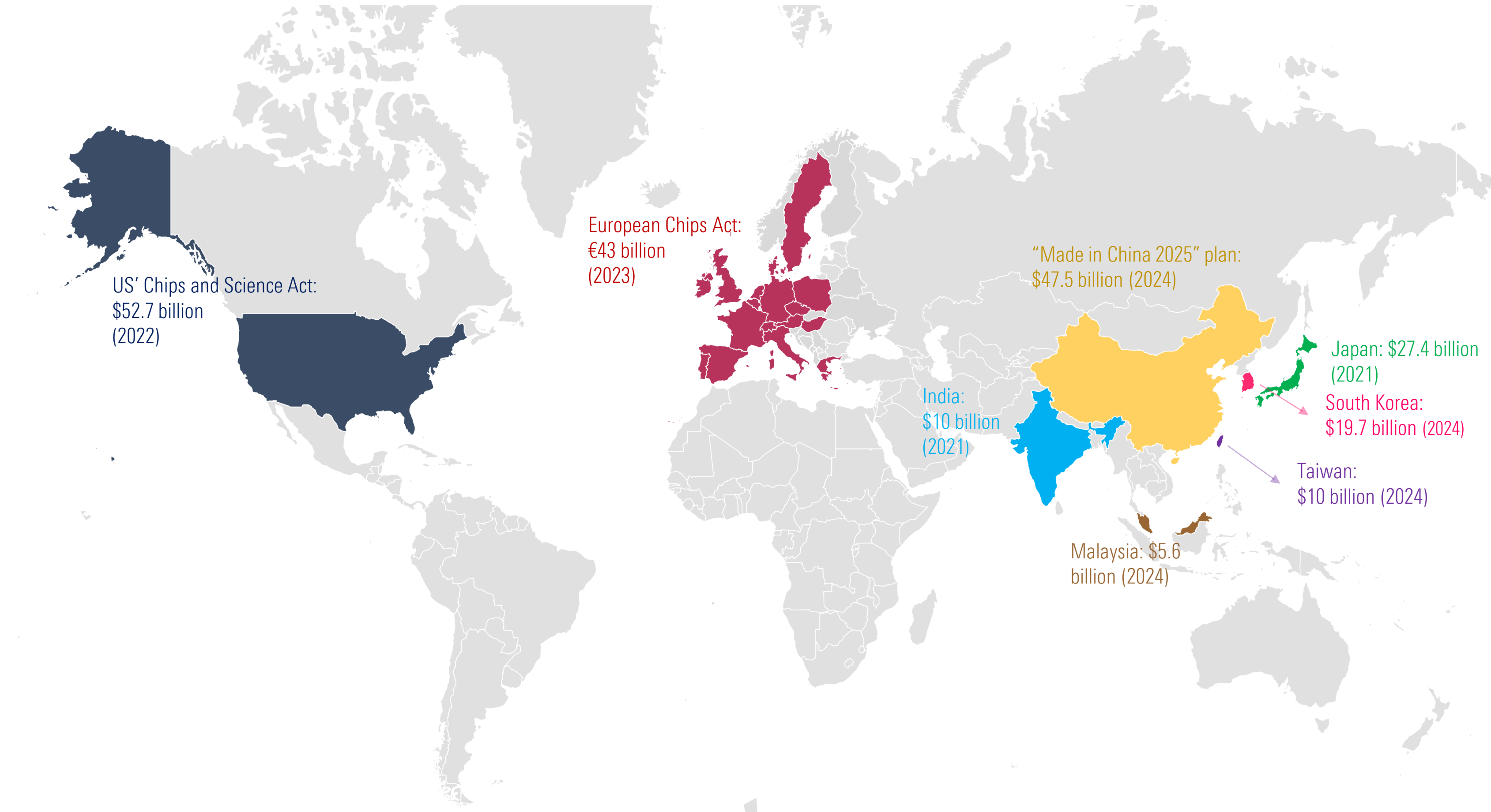
Most Players Show Clean Balance Sheets and Appropriate Distribution Policies

Capital Allocation Rating	Count	Constituents
Exemplary	21	Applied Materials, ASM International, ASML, ASMPT, BESI, KLA, Lam Research, Cadence, Synopsys, AMD, Apple, Broadcom, Marvell, Melexis, Nvidia, Skyworks, TSMC, Analog Devices, Microchip Technology, Sony, Texas Instruments
Standard	25	ARM, GlobalWafers, Sino-American Silicon, Soitec, Sumco, Qorvo, Qualcomm, MediaTek, Nordic Semiconductor, GlobalFoundries, Hua Hong, UMC, Intel, Micron, SK Hynix, Samsung Electronics, Western Digital, Infineon, Monolithic Power Systems, NXP Semiconductors, ON Semiconductor, STMicroelectronics, Win Semiconductors, Keysight Technologies, Teradyne
Poor	2	National Silicon Industry Group, SMIC

Source: Morningstar, PitchBook.

Countries Have Realized the Strategic Importance of Chips, Launching Multibillion-Dollar Support Plans

The Aim Is to Support New Manufacturing Capacity, R&D, and Attract Talented Workforce Through Attractive Loans or Subsidies

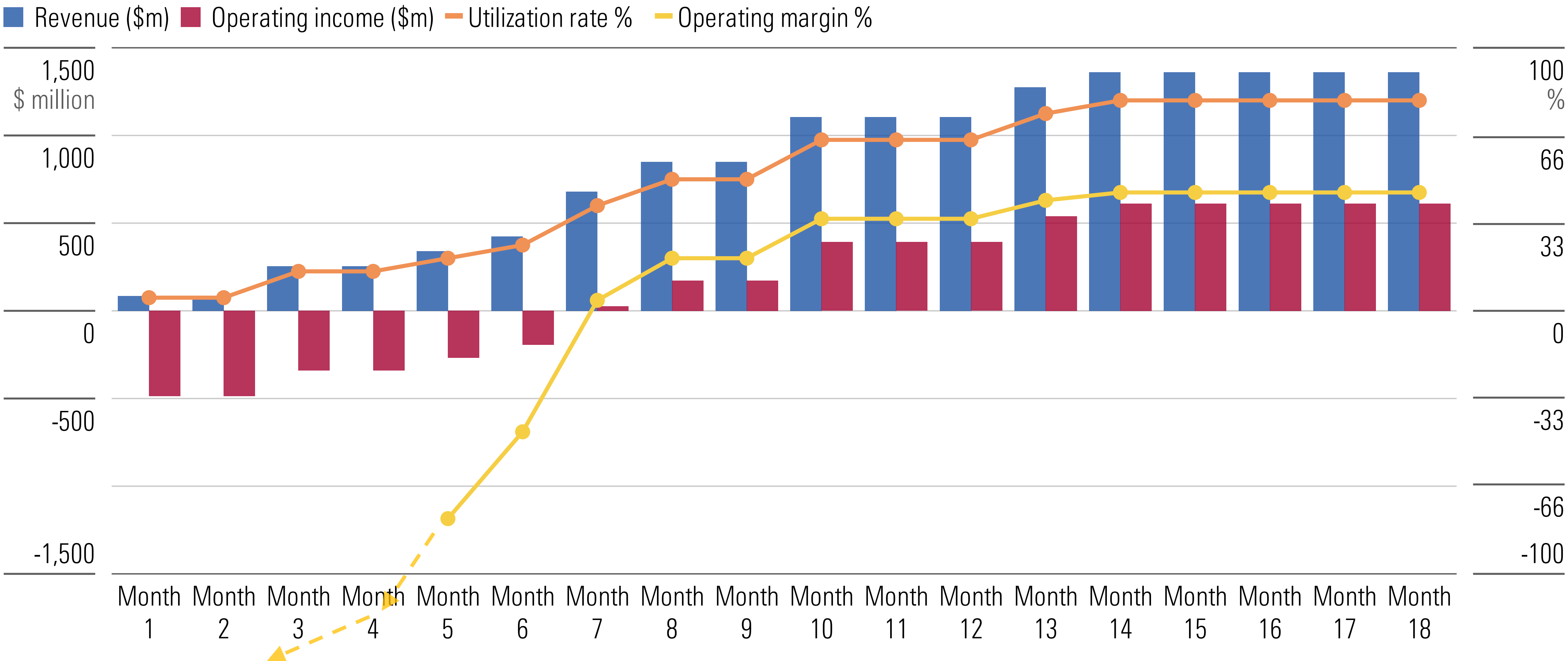


Source: Oval Office, European Commission, DigiTimes Asia, Reuters, Bloomberg, Nikkei Asia.

Semiconductor Foundries Need Huge Economies of Scale to Be Profitable

Foundries Have Huge Fixed Cost Bases, so They Need to Function 24-7 at High Utilization Rates; Reliable Chip Manufacturing Is an Extremely Complex Process

Ramping up utilization rates and manufacturing yield is a lengthy process that can take several months. Foundry customers normally assume the cost of defective chips.



Source: Morningstar, DigiTimes Asia, Center for Security, Emerging Technology.

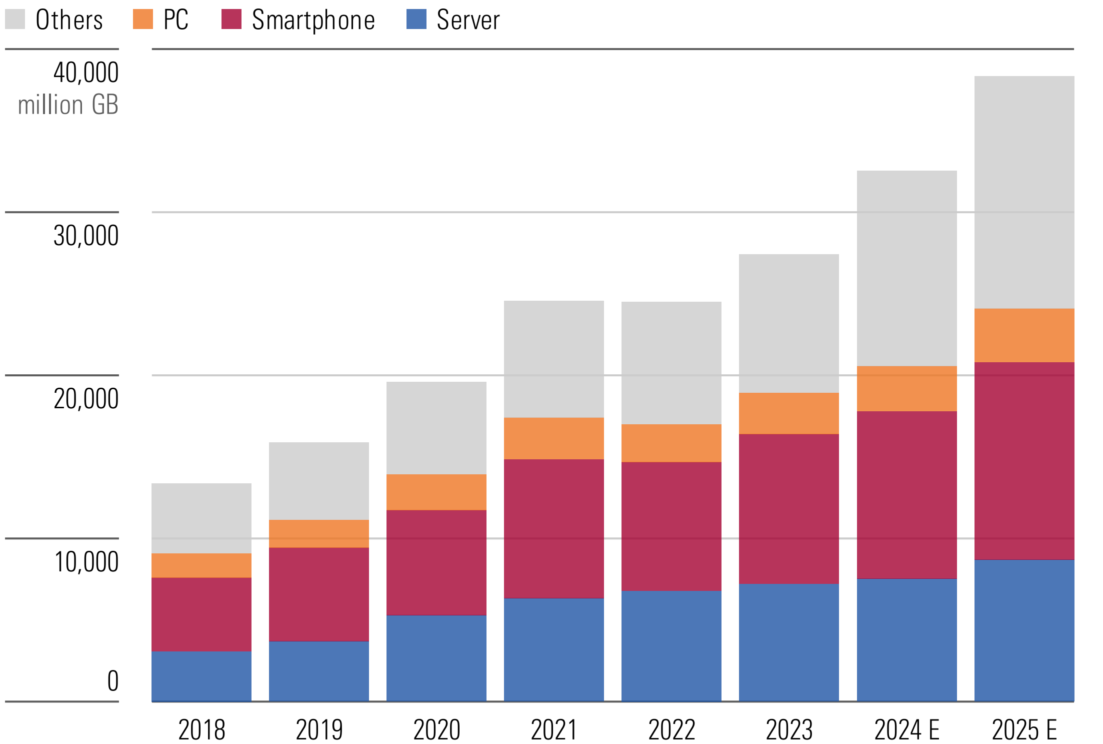
Note: This example represents a theoretical 5 nm gigafab, with capacity for 100,000 wafers per month, sale price per wafer of $17,000. Assumes 75% of total costs are fixed and 25% variable.

Servers, Mobiles, and PCs Are the Main Memory Applications: Growth in Content per Box Driving Demand

Semiconductor memory is primarily used in servers, smartphones, and PCs. Although shipments of PCs and smartphones have plateaued, the amount of memory installed per device continues to grow as data traffic and processing speeds increase. We expect this trend to continue and believe that the proliferation of AI will accelerate demand for semiconductor memory in the future. These are all very similar patterns to what we see in the logic market.

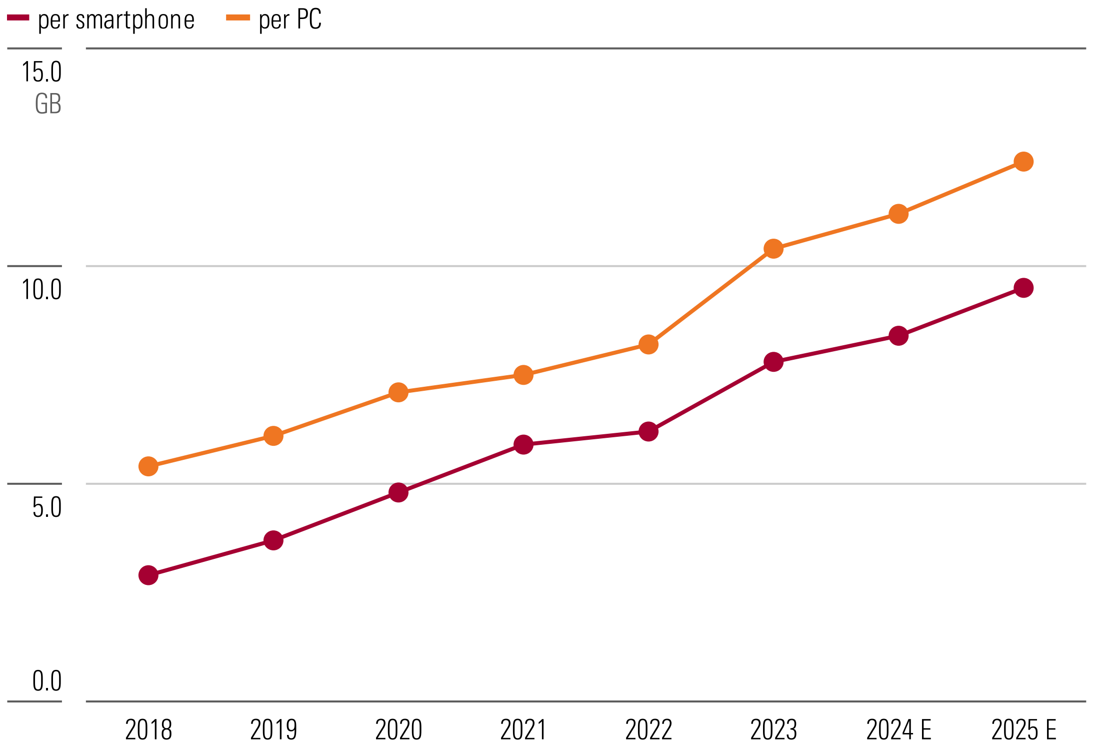
Servers, Mobiles, and PCs Account for 60%-70% of DRAM Demand

DRAM capacity measured in gigabytes (GB)



Content per Box Increases More Than 10% per Year

DRAM capacity measured in GB



Source: Gartner.

Analog Chips Are Cyclical, Driven by Automotive, Industrial, and Communications End Markets

Analog Chips Have Structural Growth Drivers

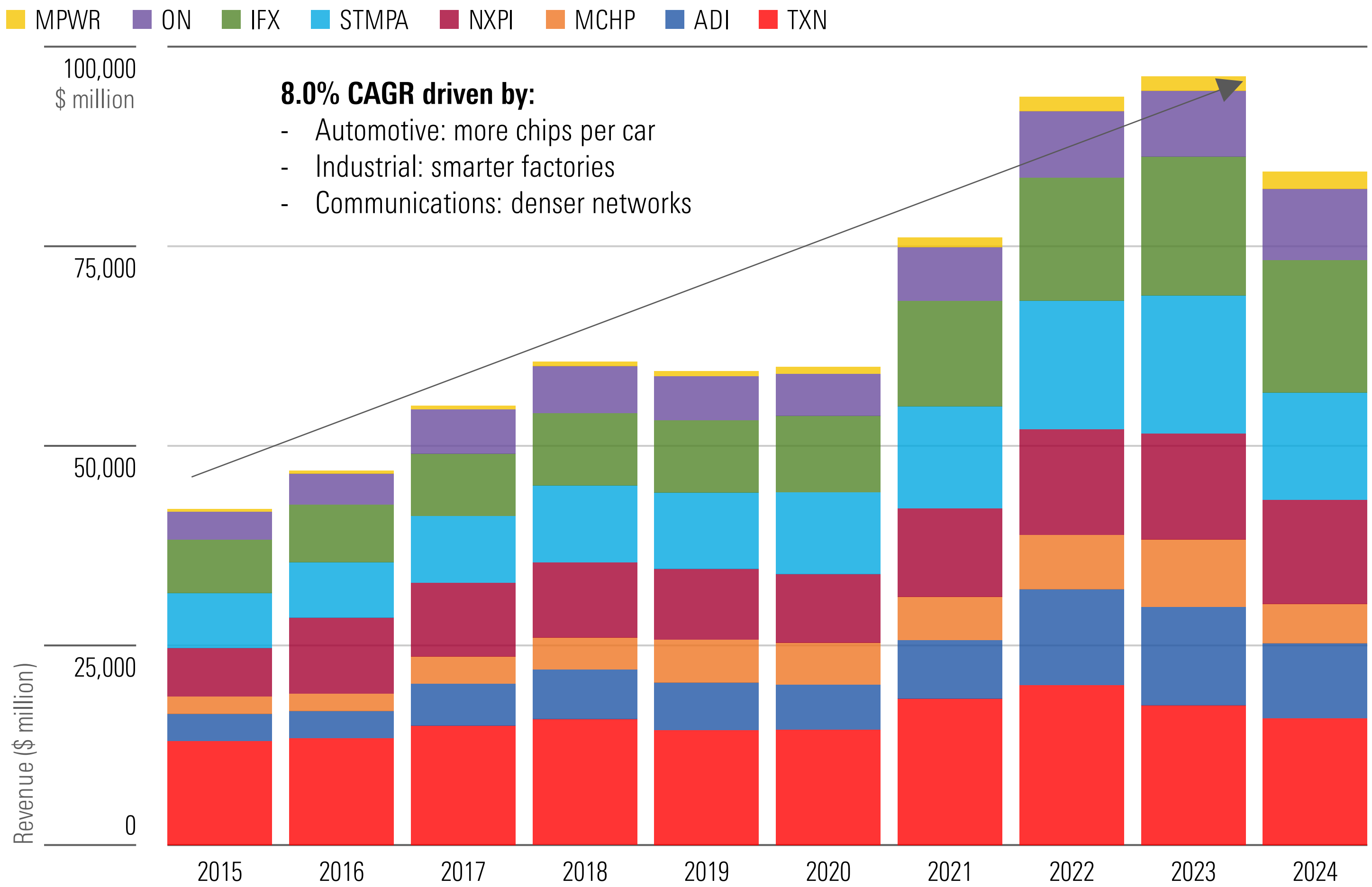
Analog firms have performed exceptionally well since the pandemic due to a very high demand profile with limited supply. We expect analog firms will keep growing revenue at mid- to high single digits in the long term due to structural tailwinds like rising chip content per car, smarter factories that require more semiconductors, and denser communications networks.

The automotive sector is one of our preferred long-term industry trends, given we see strong tailwinds, inclusive of electric and hybrid vehicles. Even if worldwide car production barely grows, we expect the number of chips per car will grow at high single digits as cars incorporate more electronics and safety features.

Cyclicality of Analog End Markets Matter

Analog chip sales are also cyclical and go through correction periods when demand for end products is slow. Original equipment manufacturers or car firms can reduce chip orders when there's too much inventory in the supply chain. It can take a few quarters until inventory levels normalize and end customers increase orders. A weak 2024 is developing into a good example of this cyclicality.

After Years of Strong Growth, We Anticipate an Analog Correction in 2024

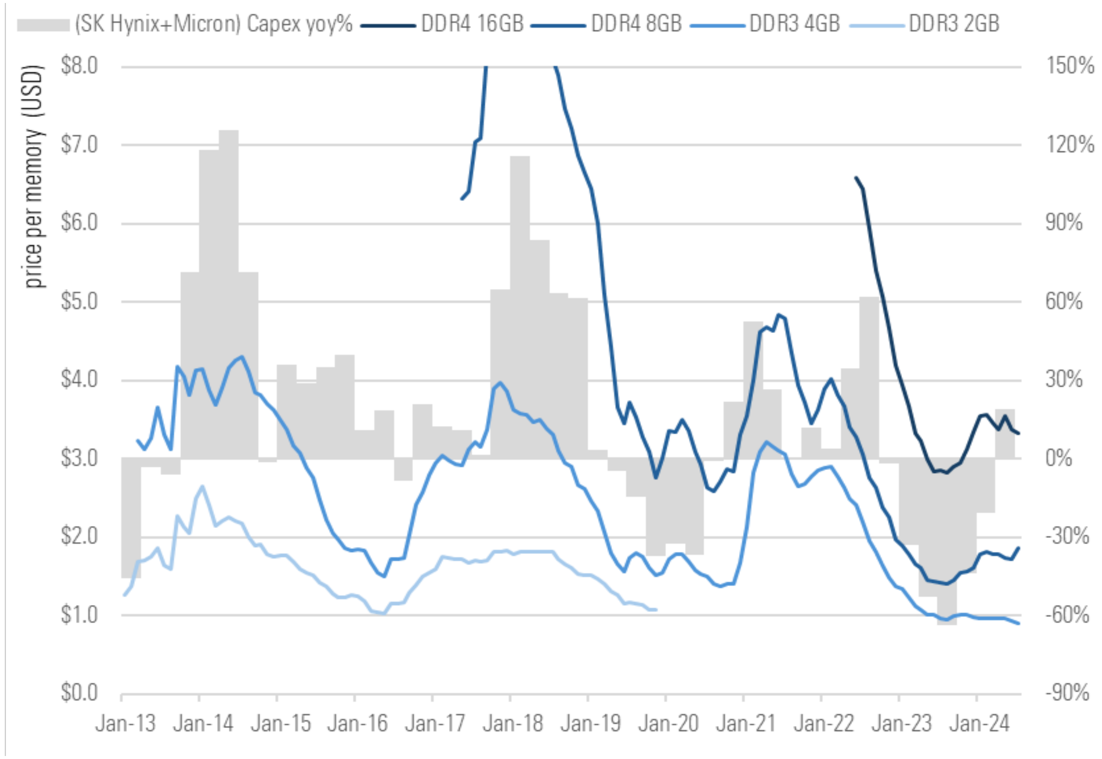


Source: Company filings, Morningstar.

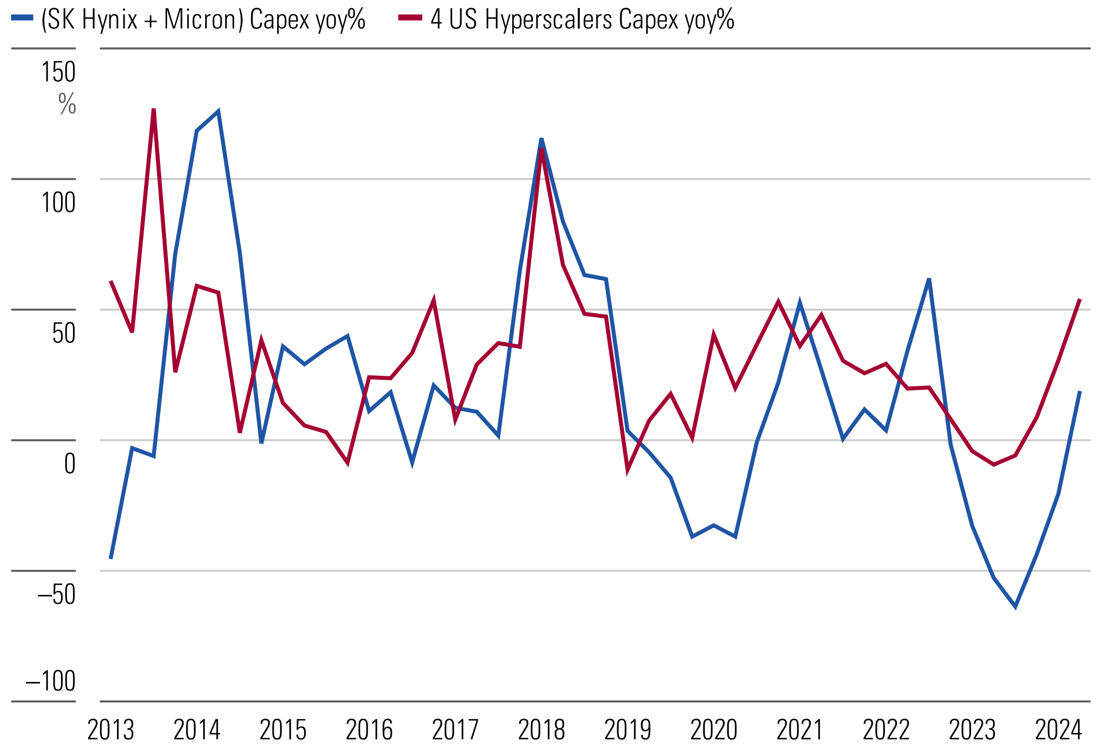
Memory Prices and the Investment Cycle Are Highly Correlated: Repeated About Every Four Years

While each cycle is different, there are certain patterns which tend to be repeated. When supply is tight and memory prices rise, suppliers increase their capex and a few quarters later, as new capacity comes online and memory supply exceeds demand, memory prices begin to fall. During periods of low memory prices, suppliers hold off on investment, waiting for inventories to be digested and demand to recover. This price elasticity and investment cycle defines the semiconductor memory cycle, which is known to repeat itself approximately every four years.

Memory Suppliers' Capital Spending Picks Up as Memory Prices Recover



Hyperscalers' Capex Is a Leading Indicator of Storage Suppliers' Capex



Source: Company filings, Bloomberg, Morningstar.

Analog Chipmakers Enjoy Lower R&D Intensity Due to Longer Shelf Life of Chips Compared With Digital

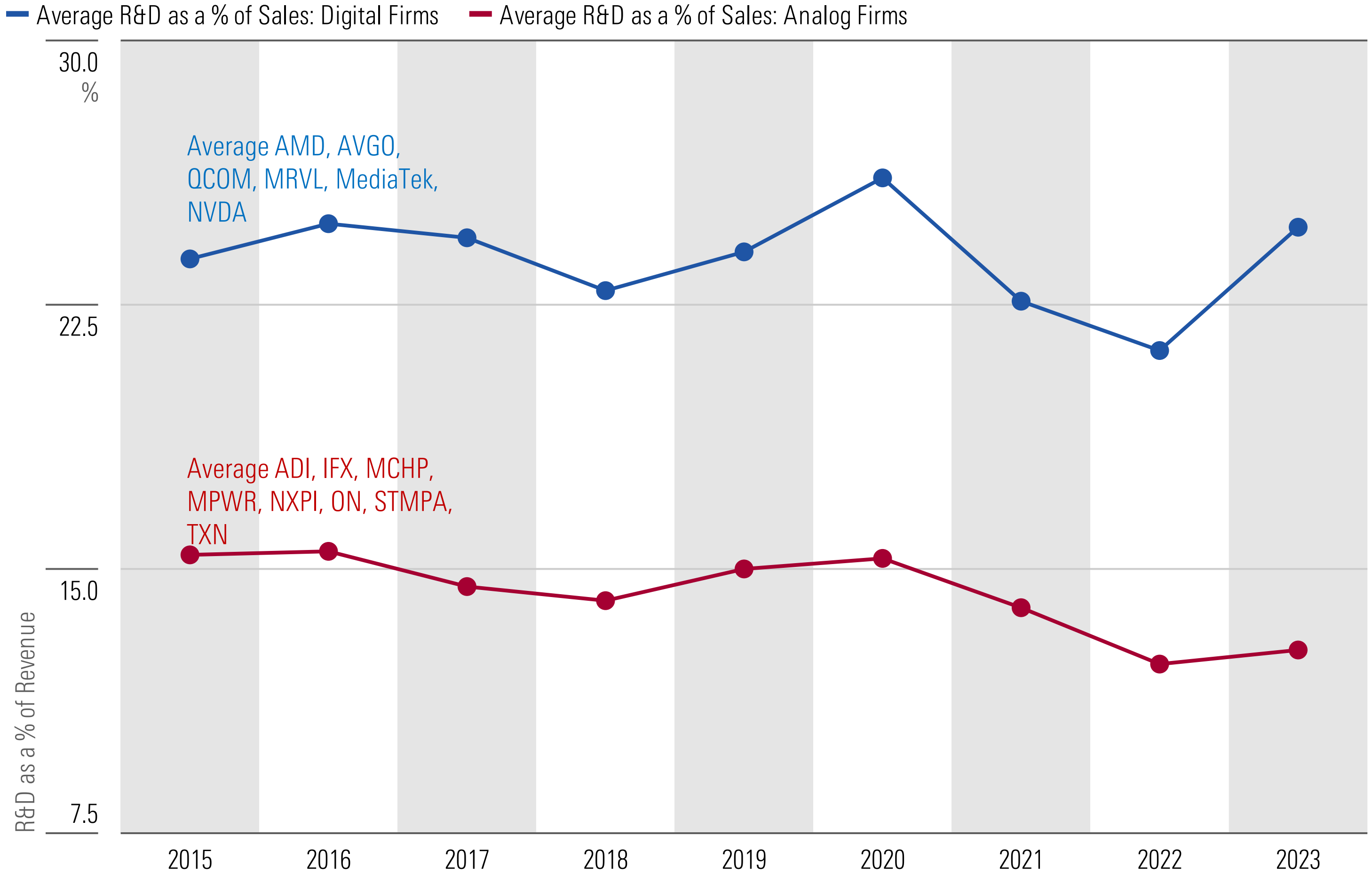
Analog Chips Benefit From Long Product Lives

Analog chips normally have longer shelf lives compared with digital chips. Improvements in analog chipmaking are normally evolutionary, rather than revolutionary. The second generation of a chip design will include incremental improvements without needing large investments. Analog chips are also exposed to end markets with longer lifecycles than digital chips: the useful life of a car or a factory can be up to 20 years, much longer than the 3-4 year lifecycle in end markets like smartphones, PCs, or servers.

Analog Chips Still Require Special In-House Knowledge

Even if Analog chips are less R&D intensive, they are more difficult to integrate in devices in the real world because engineers must deal with signal degradation, interference, and more. Successful firms have large IP libraries of chip designs and special in-house engineering know-how to overcome these obstacles. The lower R&D intensity helps promote favorable returns on capital. Although analog designers normally have lower revenue growth rates than digital ones, they still benefit from long-term tailwinds like increased number of chips per car, factory digitalization, or 5G, among others.

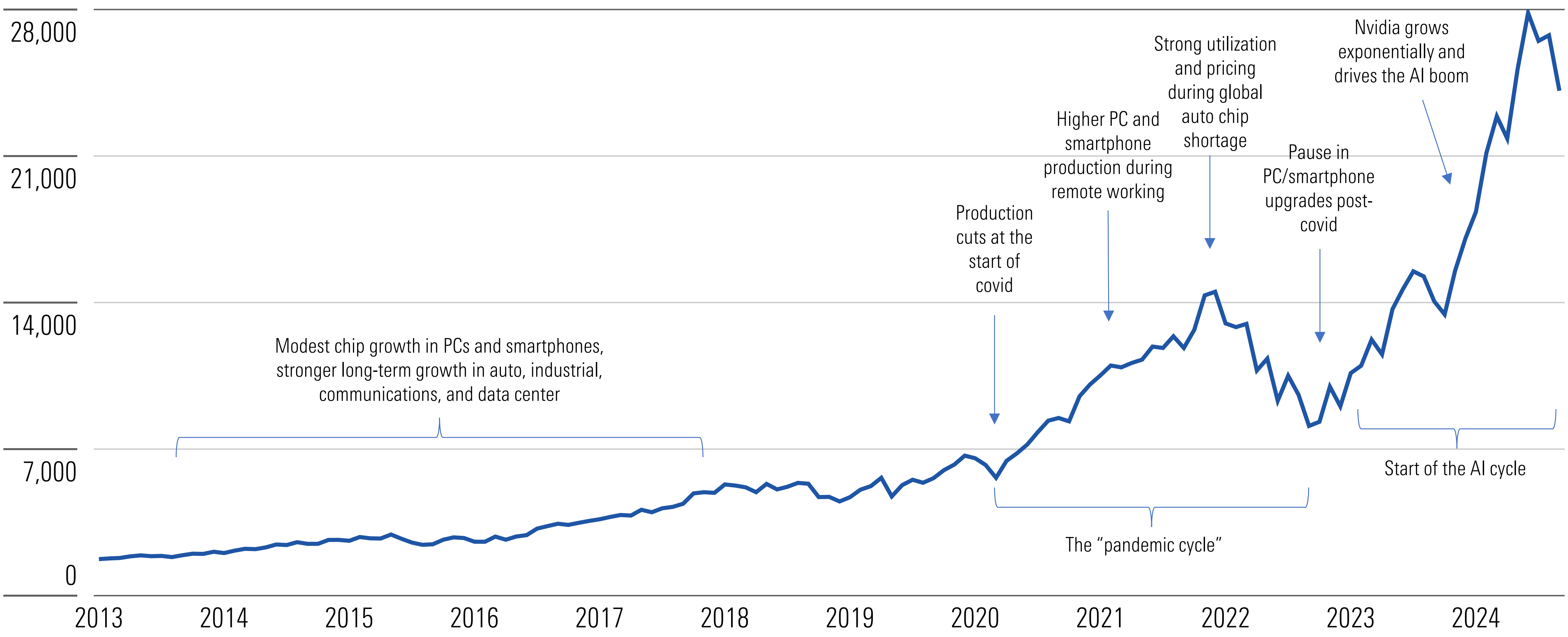
Constant Consumer Demands Result in Higher R&D Intensity for Digital Chip Designers



Source: Company filings, Morningstar, PitchBook.

Valuations Tend to Be Driven by the Industry's Cyclicality and Major Shifts in Demand Drivers, Like the AI Boom

Morningstar Global Semiconductor Index Returns Over the Past 11 Years



Source: Morningstar.

Industry Basics: Technology Outlook

Understanding the current innovations in semiconductor technology, including an introduction to AI.

Innovation Enablers: New Transistor Architectures

Innovation Is Tough, but It Continues Even Today

Investors constantly wonder if a slowdown in innovation is around the corner. When do we simply reach the limits of physics, with no more room for improvement? The industry is constantly investing in R&D to find new ideas to continue scaling down semiconductor patterns and enhance computing performance.

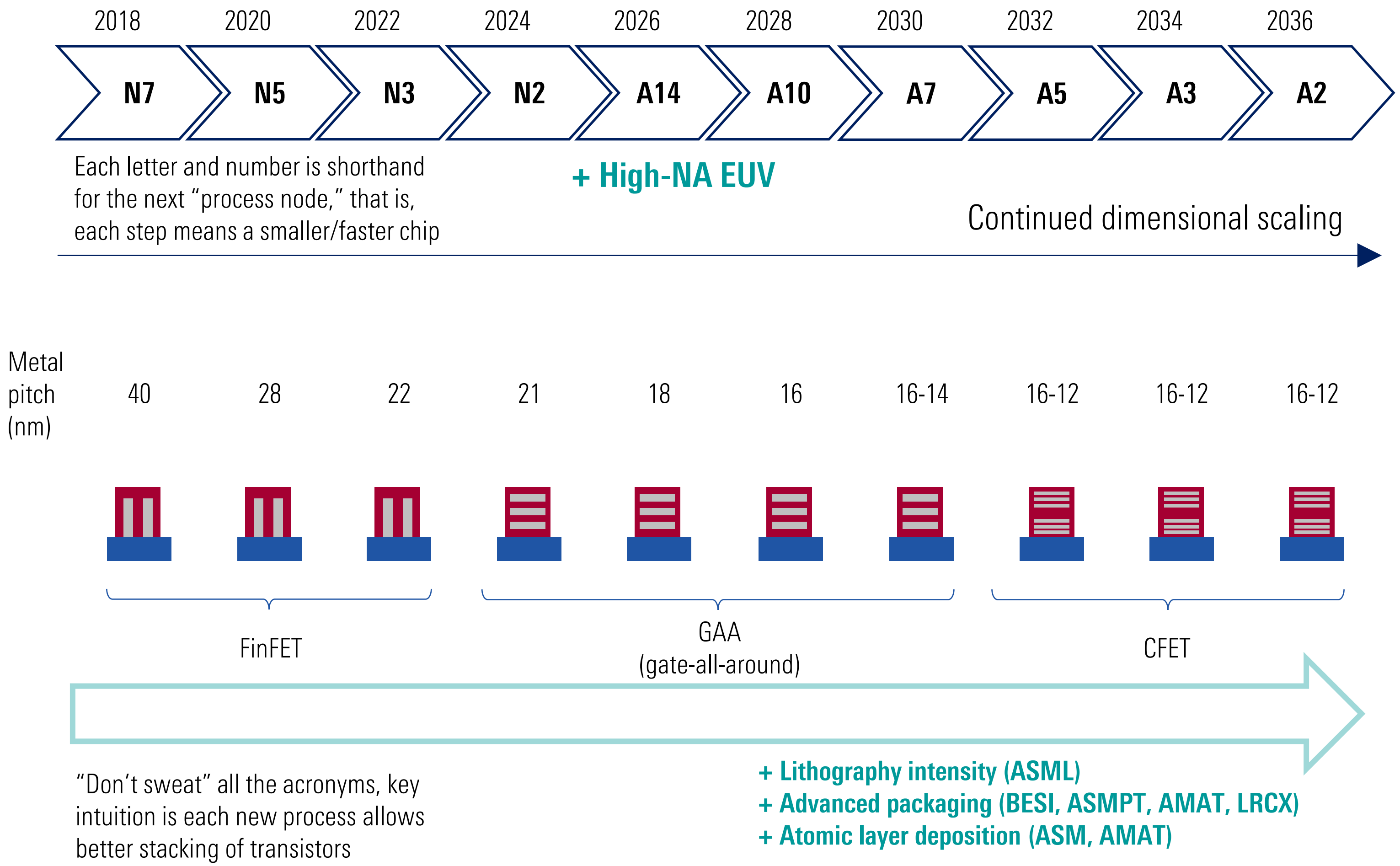
New 3D Architectures Enable Next-Gen Innovation

Research center IMEC proposes a chip scaling road map that would reach the 0.2 nanometer (2 angstrom or A2) semiconductor process node by 2036. This will be done by switching to new 3D transistor architectures like GAA and CFET. TSMC and Samsung intend to introduce GAA in high volume manufacturing by 2025.

Key Innovators Will Be the Next-Gen Winners

Shrinking patterns and transistor architectures are a long-term tailwind for equipment firms like ASML, Applied Materials, Lam Research, and ASM International. These transistor structures require newer technology such as High-NA extreme ultraviolet lithography or atomic layer deposition equipment. TSMC could introduce High-NA-EUV Lithography into high-volume manufacturing in 2028.

Despite Some Investor Concerns, the Industry Has Plenty of Ideas On How to Continue Moore's Law



Source: IMEC, Morningstar.

Innovation Enablers: Extreme Ultraviolet Technology

EUV Helps Make Patterns at Nanometer Scale With Mind-Boggling Complexity

Extreme ultraviolet lithography is cutting-edge technology crucial to making the most advanced semiconductors with nanometer-scale transistors. Wide-moat ASML has a monopoly on EUV lithography systems, a position it reached through decades of R&D and billions of dollars in investment. EUV works essentially like a projector, with the silicon chip being the projector screen, but it makes images smaller, not larger. These images help "burn" the transistor designs into the silicon wafer.

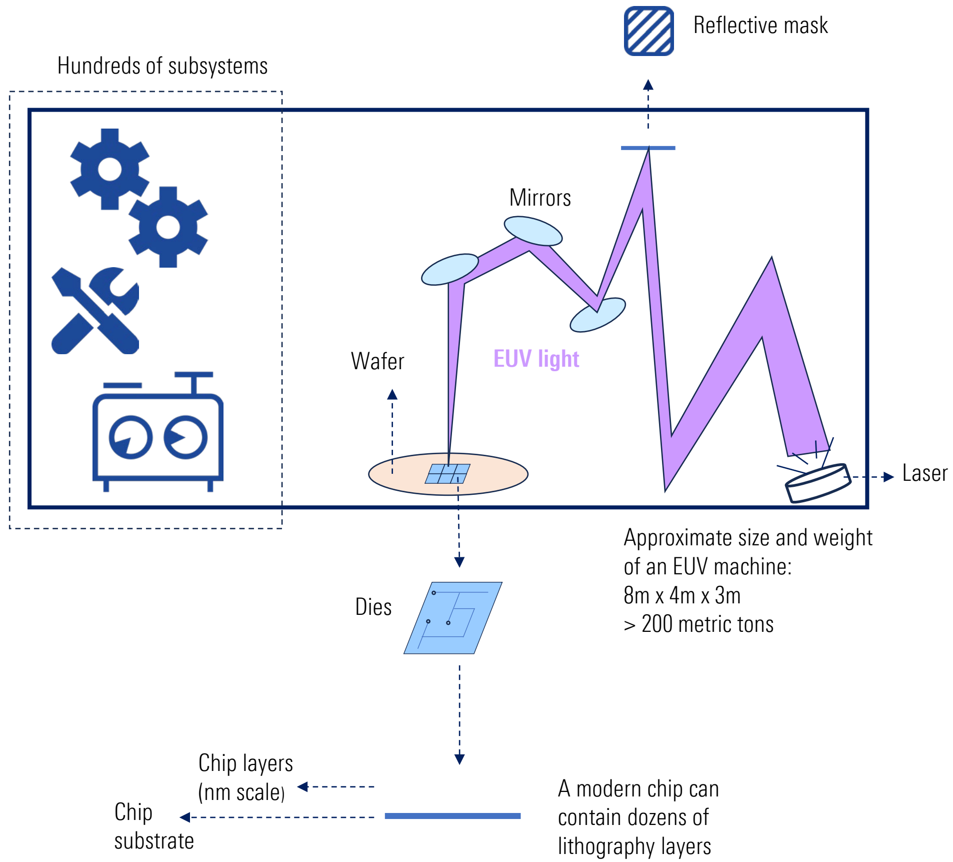
The EUV process is extremely complex and precise. Light generation is the most challenging part of the process. 50,000 droplets of molten tin are fired into a vacuum chamber every second. Each droplet is hit twice by a CO_2 laser. The tin explodes into plasma, emitting EUV light with a wavelength of 13.5 nm. EUV light is collected and conducted through a series of tubes containing highly precise mirrors, exclusively manufactured by narrow-moat Carl Zeiss. The entire process occurs in a vacuum environment, otherwise EUV light would be absorbed instead of being reflected, preventing the light rays from reaching the wafer surface.

EUV Still Has More Room to Help Chip Innovation

EUV is a crucial technology to continue shrinking semiconductor patterns. It enables the production of more powerful, more energy-efficient chips for applications like high-performance computing, smartphones, or 5G, among many others. Current EUV technology should enable chip production of roughly 1 nm, and after that high-numerical aperture extreme ultraviolet should help chips to become even smaller.

EUV Requires the Collaboration of Hundreds of Engineers in Different Subfields

Machines are so complex that one engineer can't understand the whole machine.



Source: ASML, Morningstar.

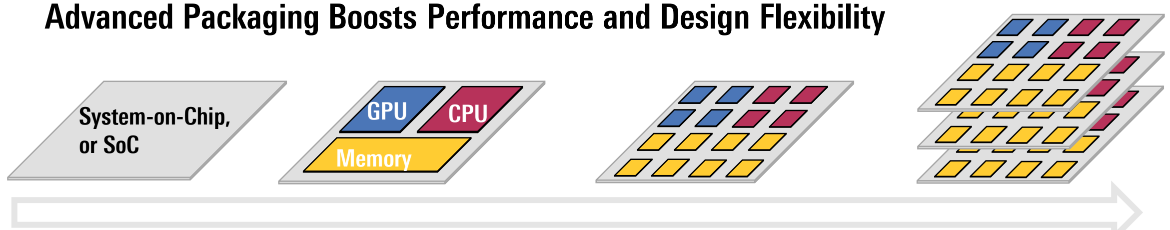
Innovation Enablers: Advanced Packaging

How Chips Are Connected Together Also Determines System Performance
Rather than focusing on shrinking transistor size, semiconductor packaging focuses on how multiple chips or chiplets can be interconnected to work together as a system. Historically, packaging was considered a lower priority and more commoditized part of the supply chain due to its simplicity when compared with front-end fabrication processes.

As the limits of transistor scaling are approached, advanced packaging techniques are becoming increasingly important, serving as key enablers of Moore's Law. Advanced packaging increases data bandwidth rates, improves energy efficiency, and reduces heat. Instead of fitting more transistors into the same silicon piece, chips can now be stacked and interconnected using 3D structures like through-silicon-vias. These structures result in shorter, finer interconnections, meaning data needs to travel shorter distances, which boosts performance, reduces chip size, and improves energy efficiency.

ASE Technology, Amkor, and ASMPT Semiconductor Solutions Lead In Packaging
In monolithic semiconductors, all components are fabricated on a single die using the same process node (10 nm, 5 nm, 3 nm, and so on). Advanced packaging allows heterogeneous integration, where chips manufactured in different process nodes can be interconnected in the same package. Advanced packaging reduces cost as there is no need to produce a chip that meets performance standards at the 20 nm node using a more expensive 5nm node process, for instance. It also increases flexibility as chip designers have now a wider range of options. Examples of advanced packaging techniques are flip-chip, thermo-compression bonding, or hybrid bonding.

Advanced Packaging Boosts Performance and Design Flexibility



SoC: Monolithic, all components built on a single silicon die, using the same technology node. At some point, it presents limitations

Multichip module: Combines different chiplets (GPU, CPU, memory). Design broken into modular components. Chiplets can be manufactured in different process nodes, adding flexibility and saving costs

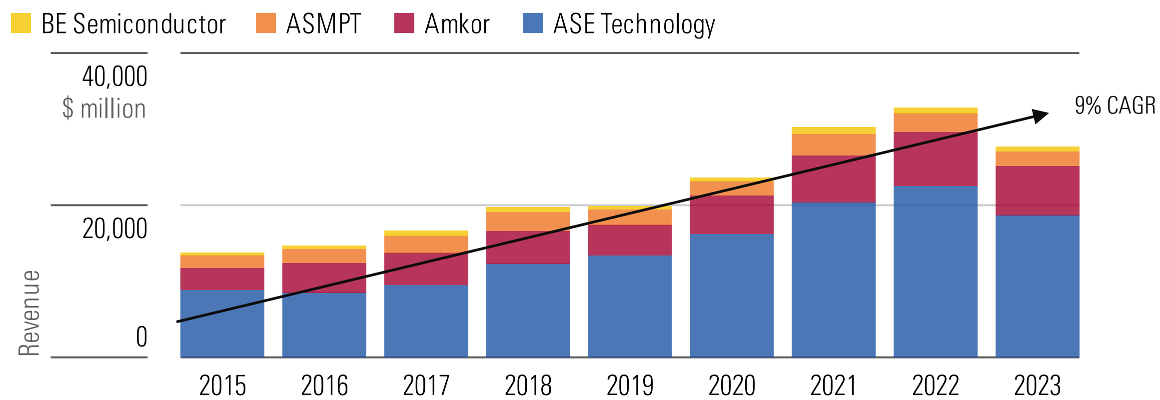
Multichiplet system: Combines multiple chiplets, adding more processing power or memory capacity.

As the industry moves to the right:
- Cost ↑↑
- Flexibility ↑↑
- Computing power ↑↑

3D structures: Systems can be stacked vertically, forming 3D structures that save space and improve performance

Advanced packaging: Enables this transition with more accurate and finer chip interconnections, allowing faster data bandwidth and lower heating and energy consumption

Packaging Firms Are Growing at the Same Pace as the Overall Industry



Innovation Enablers: New Materials

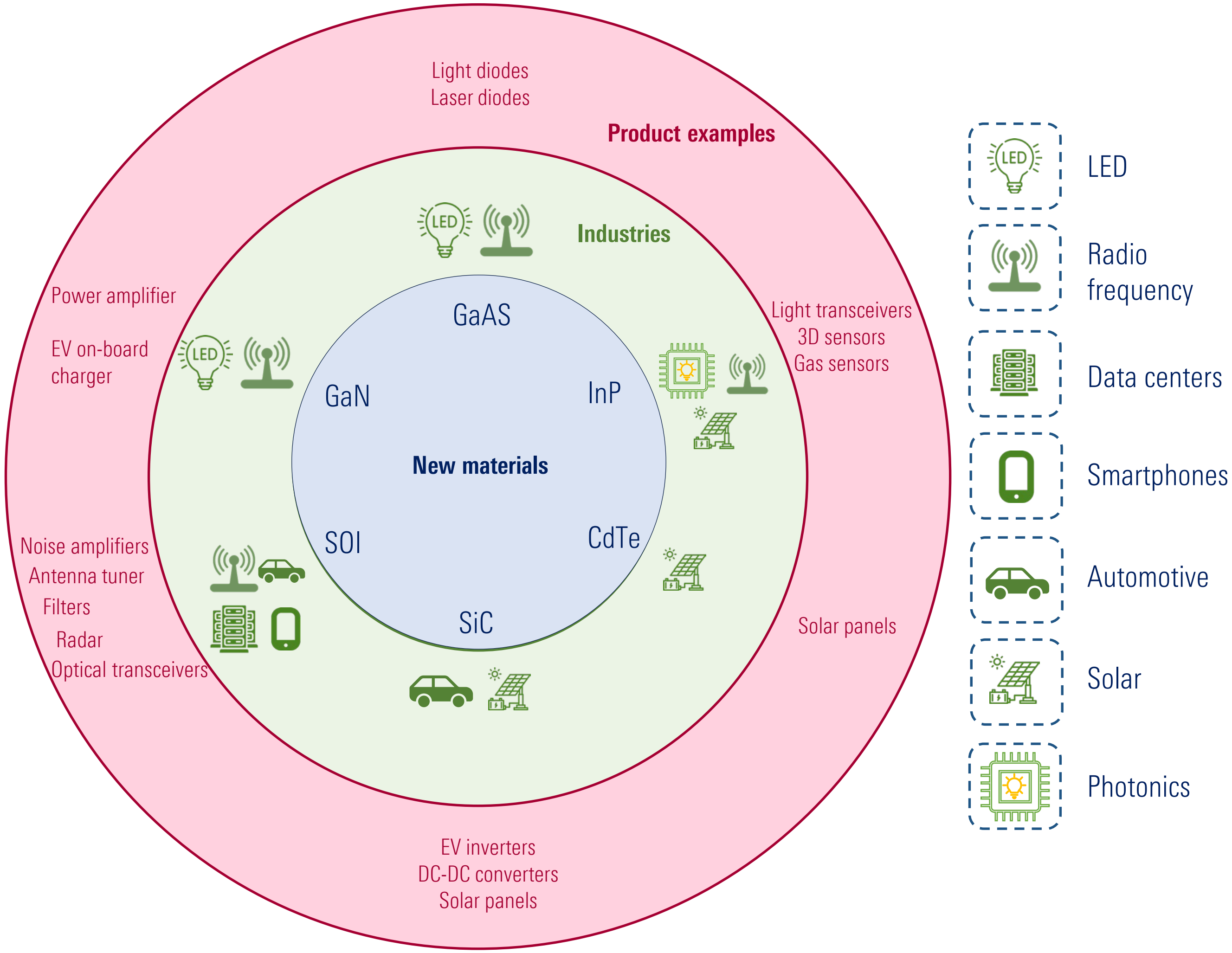
There's More to Semiconductors Than Silicon

While traditional silicon remains the backbone on which most semiconductor devices are built, in some cases it can be ideal to reengineer plain silicon wafers by incorporating composites or doping materials to improve its electrical properties. Examples of new materials include silicon-on-insulator, silicon carbide, and gallium arsenide, among many others. New materials are mainly used in the automotive and radio frequency end markets.

New Materials Enable New Capabilities

New materials can address problems like current leakage or lower electron mobility, which can arise in some semiconductors as transistors scale down. Silicon-carbide is a widely known example, used in the automotive industry, given it tolerates higher voltages, temperatures, and power levels compared with traditional silicon, resulting in better battery life. GaN and GaAs are used in radio frequency applications due to their ability to operate at high frequencies with minimal power loss. With photonics, data is transmitted using light. Photonics is gaining traction in data centers, where operators need to minimize energy losses due to the power constraints introduced by the power demands of AI workloads.

Layers of Materials Are Added to Silicon to Improve Its Properties for Certain Applications



Source: Morningstar, Soitec.
Note: SiC=silicon carbide, SOI=silicon-on-insulator, GaN=gallium nitride, GaAS=gallium arsenide, InP=indium phosphide, CdTE=cadmium telluride. The diagram shows a handful of new materials. Many others are being used or investigated.

Latest Structural Demand Driver, Artificial Intelligence: Nvidia and an Overview of Serial vs. Parallel Computing

GPUs Perform Parallel Processing, Which Is Ideal for Building LLMs

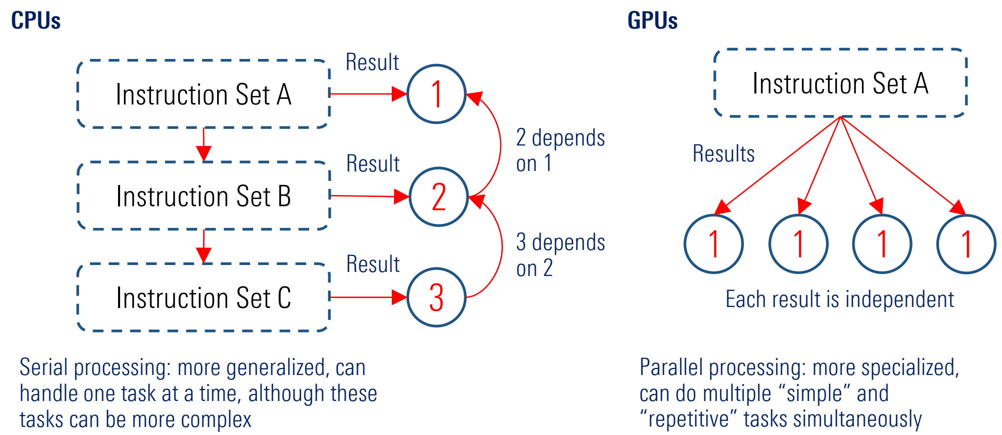
Most of the processors that we use, such as Intel chips in PCs or Apple chips in smartphones, are central processing units. They process data in a linear way, known as serial processing, meaning each step happens in a specific order.

One of Nvidia's main markets is selling graphic processing units, which are traditionally used as graphic cards to render and enhance images in PCs or consoles. This is a type of task where parallel processing excels, meaning tasks can happen simultaneously and independently. For example, graphics are excellent for parallel processing because all the computer needs to know is what color each pixel on the screen needs to be. Each pixel is an independent instance. The color of one pixel is not dependent on a decision being made about another pixel. This means parallel processing because is much more efficient for rendering graphics. There are other tasks where parallel processing is much more efficient, such as running calculations in parallel for training AI large language models like Microsoft's ChatGPT or Google's Gemini.

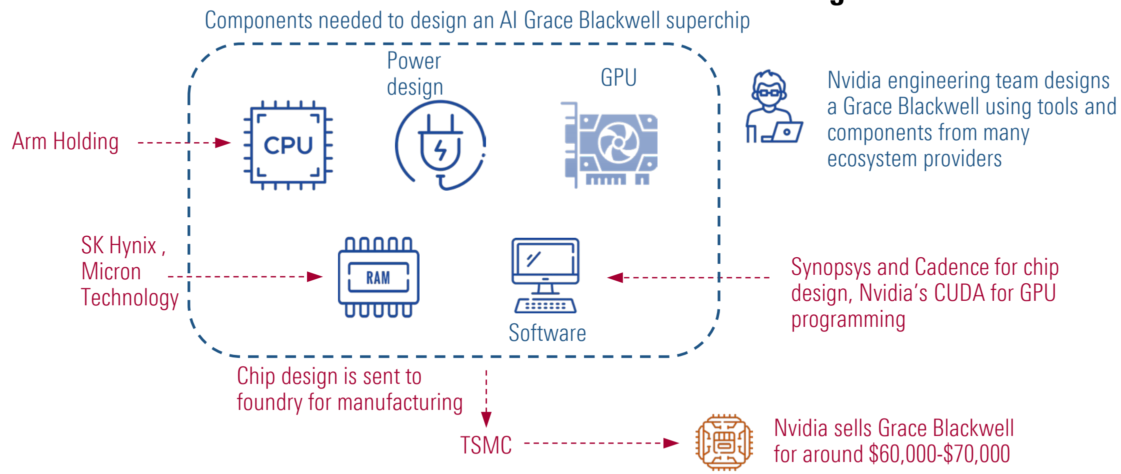
Building AI Systems Involves More Than Just GPUs and Nvidia Excels Everywhere

AI systems deployed in data centers not only consist of graphic processing units. They are a combination of GPUs, CPUs, and other electronic components like high-bandwidth memory, high-speed interconnections, power design choices, and software. Wide-moat Nvidia is highly dominant in the design of AI chips thanks to its comprehensive approach, offering not just GPUs, but full AI solutions that include networking and software. Nvidia's early foresight and decades of R&D investment created these differentiated capabilities.

CPUs Specialize in Serial Processing, While GPUs Specialize in Parallel Processing



Nvidia Is the Most Dominant AI Firm Thanks to Its Foresight and Decades of R&D



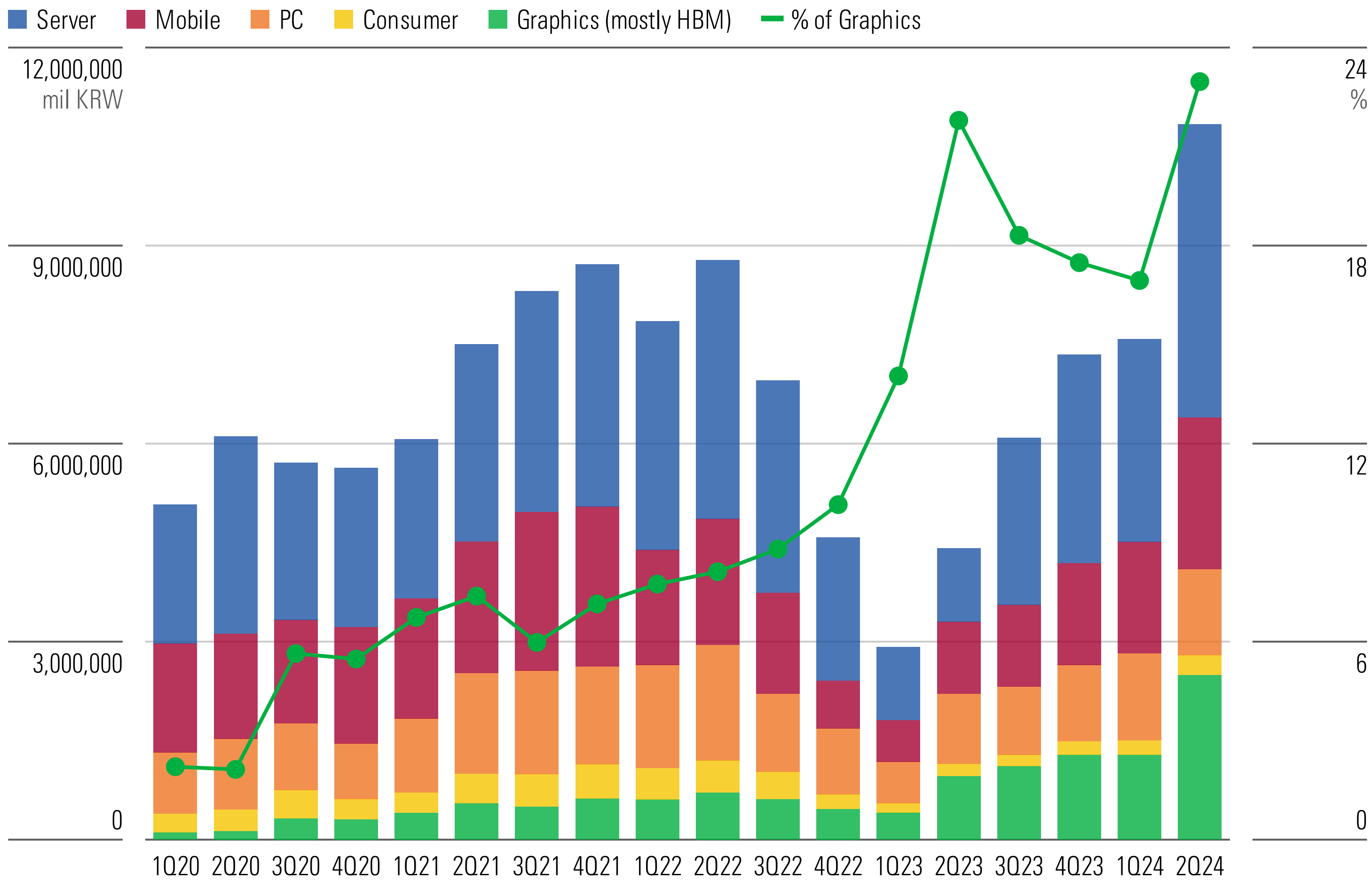
HBM Is the Critical Component for AI Servers and a Bright Spot for DRAM

High-Bandwidth Memory Enables Max Performance
Generative AI servers use high-performance GPUs that process multiple data in parallel. High-performance memory, called high-bandwidth memory, is essential to maximize the performance of the overall system. HBM is the most efficient memory in terms of data transfer speed and power efficiency, with its wide bandwidth achieved by vertically stacking multiple DRAMs.

Demand For AI Servers Will Lead to Demand for HBM
According to TrendForce, HBM accounted for 2% of the DRAM market by volume and 8% by value in 2023, but those numbers will rise to 5% and 21% by 2024, and more than 10% and 30% by 2025. According to SK Hynix, which discloses the breakdown of DRAM sales, HBM sales appear to have reached around 22%-23% of total DRAM sales in the second quarter of 2024.

To meet strong demand for AI servers, memory suppliers are investing heavily in expanding HBM production capacity, which we expect to more than double in 2025.

SK Hynix's HBM Share of DRAM Sales Picked Up in 2023, Contributing to Higher Profitability Than Peers
High-bandwidth memory is just one of many tailwinds being driven by AI demand.



Source: Company filings, TrendForce.

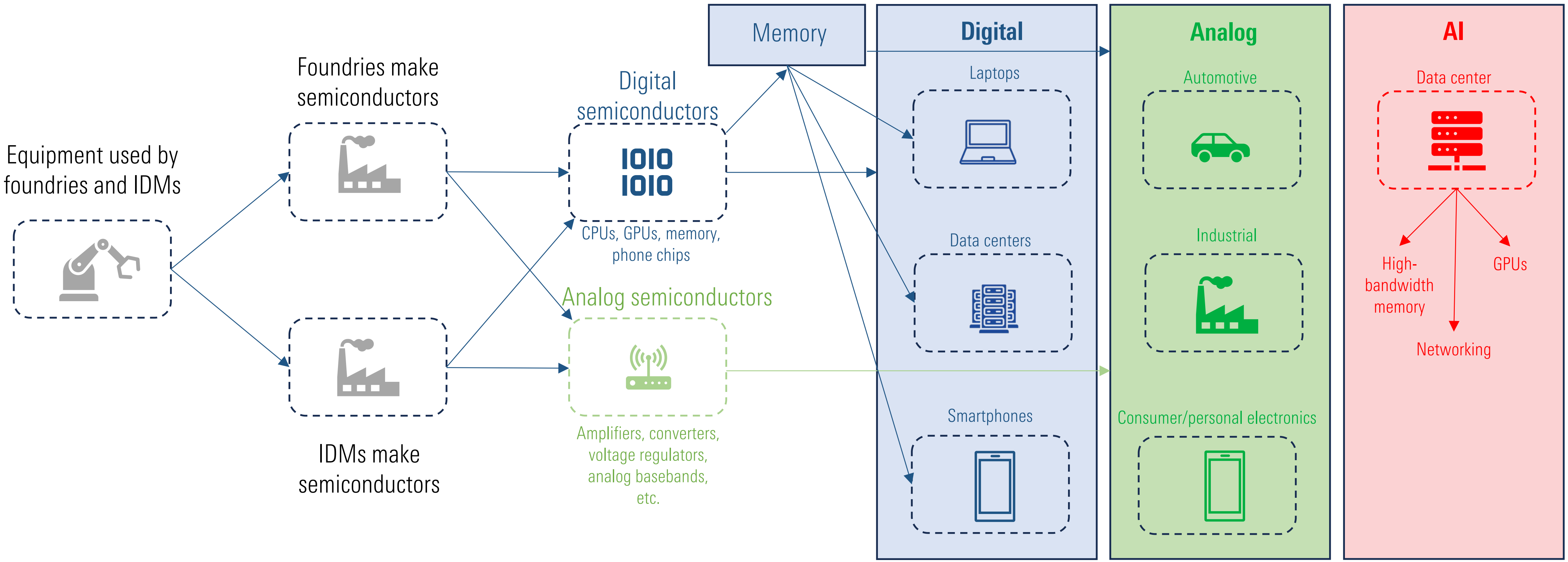
Outlook: Key Product Forecasts

AI is the biggest growth driver today, analog chips are entering a cyclical trough, while memory makers are climbing out of one.

Key Forecast Framework

Below we break down the different building blocks of our semiconductor industry forecasts. We have an equipment-specific forecast, along with a foundry-specific forecast, while all production (from foundries and IDMs) gets rolled up into our end market/product-specific forecasts (CPUs in PCs, CPU/GPU in datacenters, phone chips, and so on). Semiconductor products are used across each end market to varying degrees, so the lines are not as clear-cut as they may seem below, but the breakout illustrates the prevalent patterns.

Primary Links Between Our Equipment, Foundry, Memory, and Other Product-Specific Forecasts



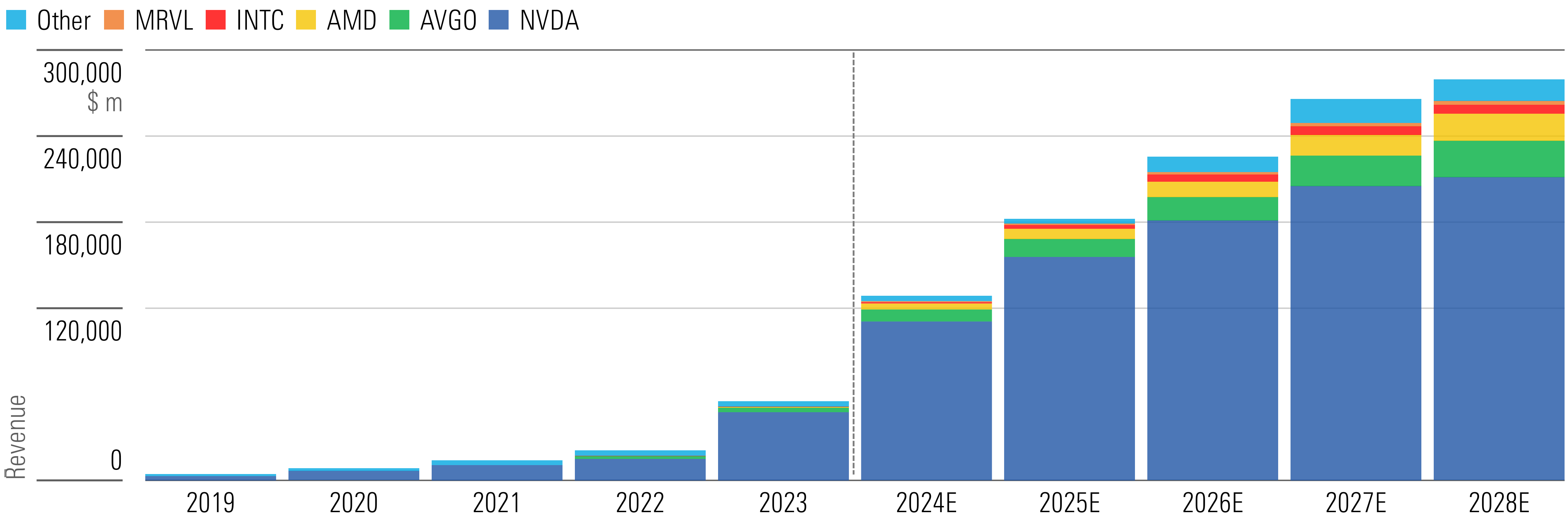
Source: Morningstar.

Artificial Intelligence Is the Biggest Growth Driver for The Industry Over the Next 5 Years

We project nearly 40% compound annual growth for AI accelerator (essentially any chip specifically designed for AI workloads, with GPUs from NVDA being the primary example) revenue through 2028, led by the clear market leader Nvidia. We see Broadcom as a strong second player with its custom accelerators, and AMD in third position (and second to Nvidia in general-purpose AI accelerators). For many of these AI chip leaders, we expect AI accelerators to become a primary growth driver. AI is already Nvidia's primary valuation driver and we expect AI to make up nearly 40%-50% of total company revenue for firms like Broadcom, AMD, and Marvell.

AI Accelerator Sales Will Quadruple by 2028 With AI Demand

Nvidia will receive most of AI demand benefit, but good growth for AMD and Broadcom.



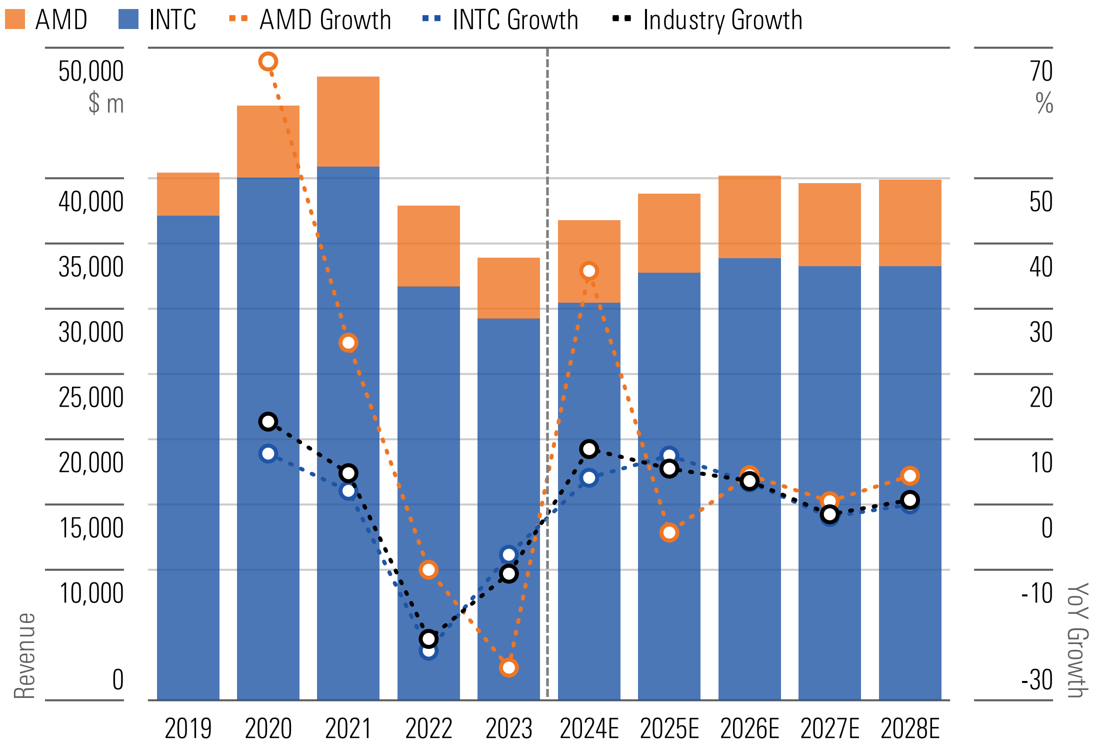
Source: Morningstar estimates, company documents. Data as of Sept. 11, 2024.
Note: Nvidia and Marvell=FY end-January, FY 2025 roughly equal to calendar 2024. Broadcom=FY end-October, FY 2024 roughly equal to calendar 2024.

PC and Data Center Processors

We have seen a clear cycle for PC CPU demand, with demand booming during the pandemic, driven by the work-from-home trend. That boom receded and we expect another pickup in demand in 2024-26, driven by the upcoming PC refresh cycle (end of support for Windows 10, AI PCs proliferate in the market).

We See PC CPU Revenue Growth Recovering in 2024 and 2025, Before Flattening

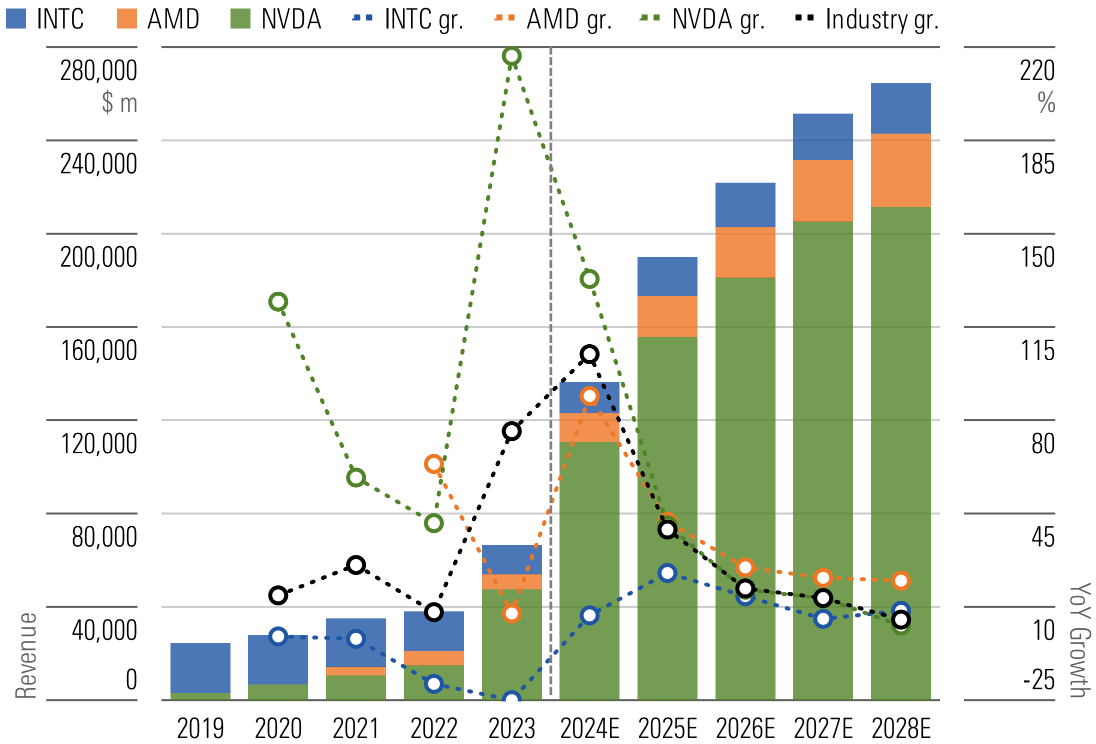
Expect Intel share losses to roughly stabilize after 2024.



Data center processor demand has soared to unprecedented levels, driven by demand for processors in AI-optimized servers. This trend has largely benefited Nvidia. We expect this growth will remain in the double-digit percentage range through 2027, effectively quadrupling the market from 2023-28.

Data Center Processor Sales Will Quadruple by 2028 With AI Demand

Nvidia will receive most of AI demand benefit, but growth percentage not bad for AMD.



Source: Morningstar, company documents. Data as of Aug. 14, 2024.

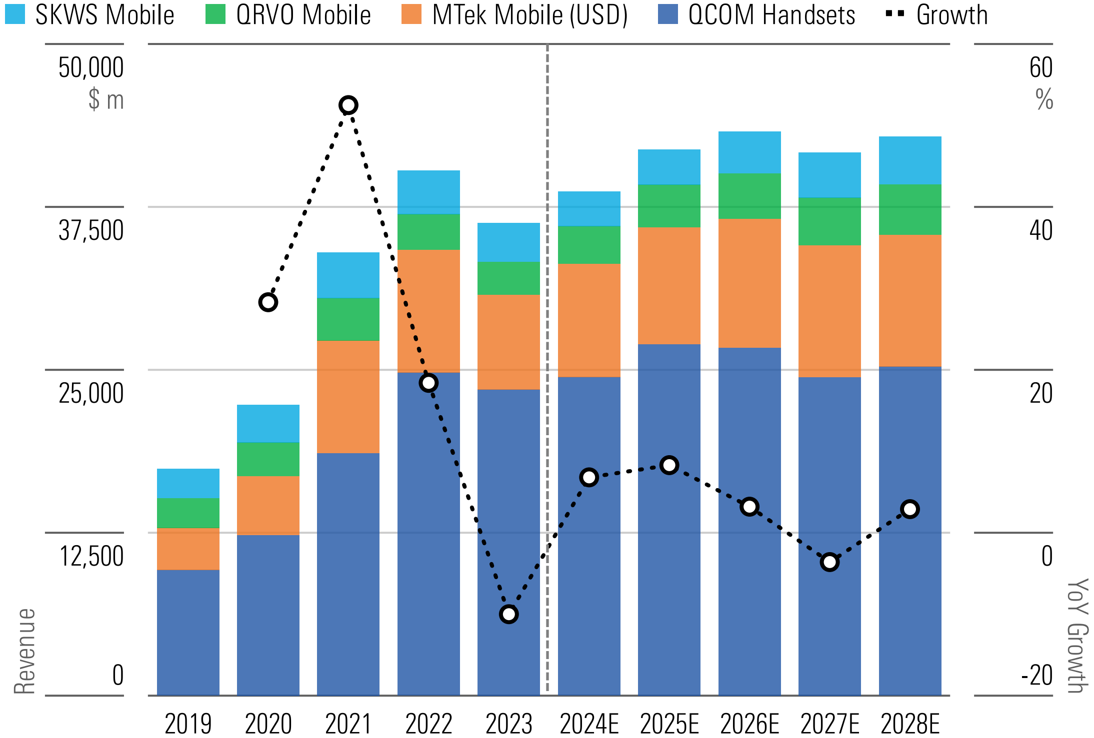
Smartphones and Memory

Smartphone chip growth turned negative in 2023; however, we expect a recovery through 2026. We expect integration of AI into smartphones, like with Apple's iPhone, can drive a recovery. In the longer term, we see smartphones as a flat to low-growth market.

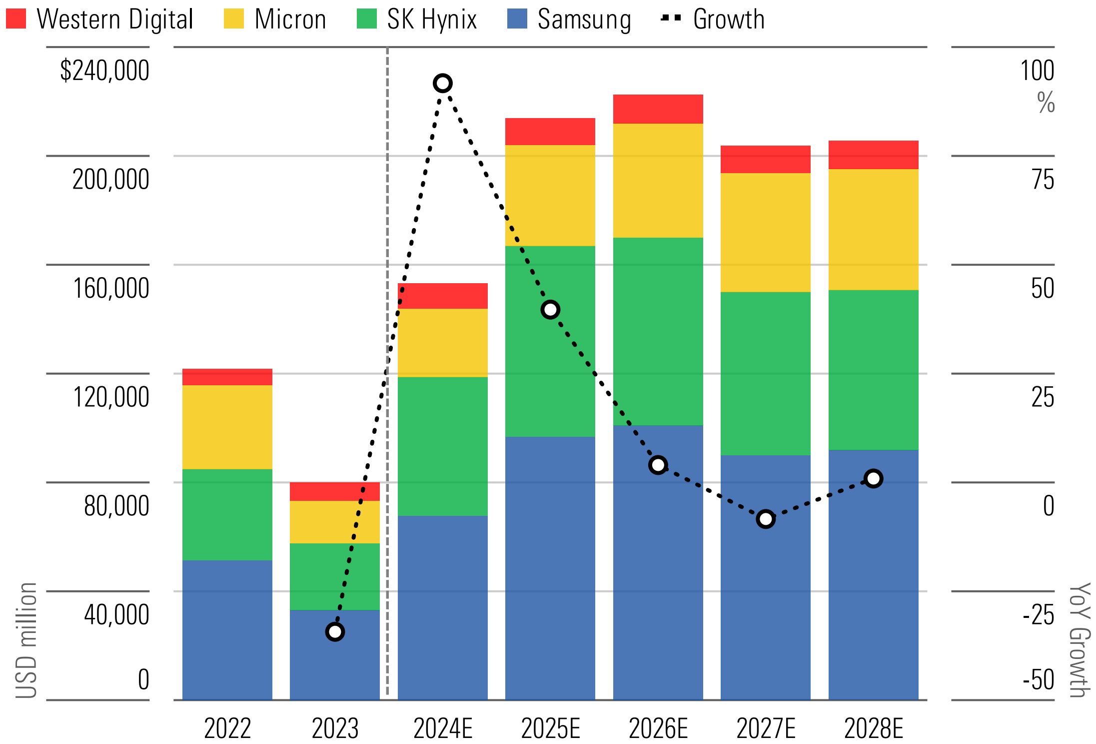
Memory revenue saw a precipitous downturn in 2023. We expect a strong, three-year cyclical recovery to follow, helped by AI investment. Over the long term, we continue to expect cyclicality, but midcycle growth in the midsingle digits.

Smartphone Chip Sales Should Start to Recover After a Tough 2023

Once refresh cycle ends in 2025, flatter sales expected.



We Expect Growth Across Cycles for Memory Chipmakers



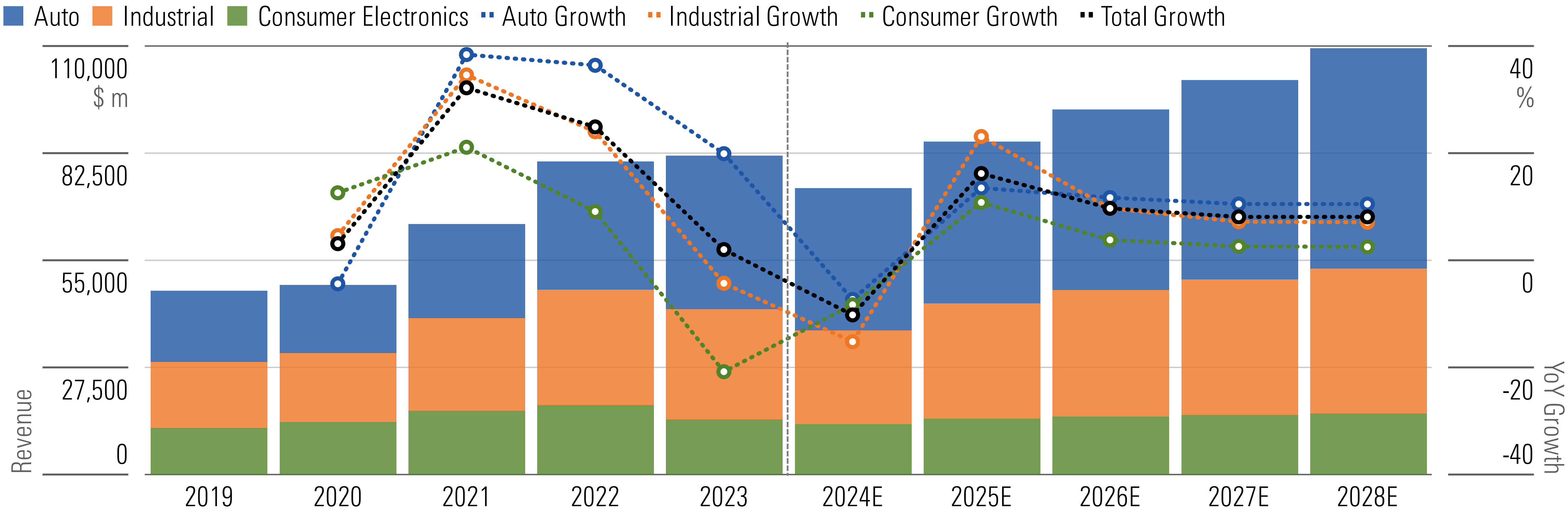
Source: Morningstar estimates, company documents. Data as of Aug. 14, 2024.
Note: Western Digital NAND revenue only. Samsung memory revenue only. SK Hynix and Samsung adjusted to USD (KRW/USD FX rate of 0.00075). Micron=end-October FY. Western Digital=end-June FY.

Analog/Mixed-Signal Overall Outlook

***Analog/Mixed-Signal semiconductors demand fell in 2023, and we expect it to fall even further in 2024 driven by further weakening in auto and industrial demand. After 2024 we expect a recovery for each key end market. We think secular tailwinds toward higher chip content in cars and industrial devices remain intact, which leads us to believe the overall analog market will continue to grow at a more than 8% rate persistently, even while 2024 has been rough.

The Analog/Mixed-Signal Cycle Should Trough in 2024; We Expect a Sustainable Rebound Starting in 2025 Culminating in 8% Growth in 2027 and 2028

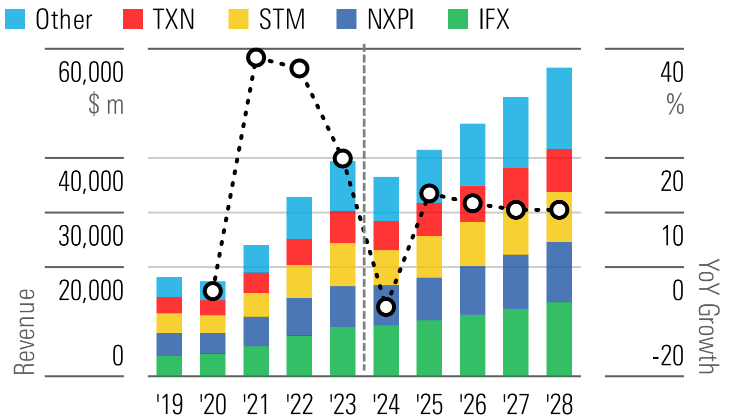
Consumer demand will lag industrial and auto demand.



Source: Morningstar, PitchBook, company documents. Data as of Aug. 14, 2024.
Note: Includes revenue from TXN, ADI, MCHP, NXPI, STM, IFX, ON, and MPWR.

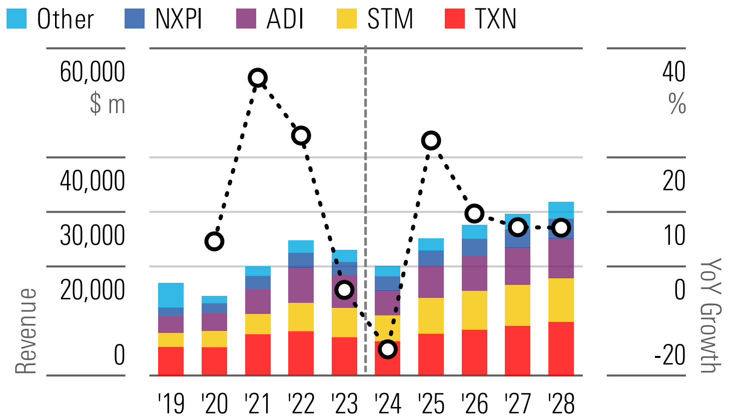
Analog/Mixed-Signal Buildup—Auto, Industrial, and Consumer

Autos Analog Demand to Recover in 2025



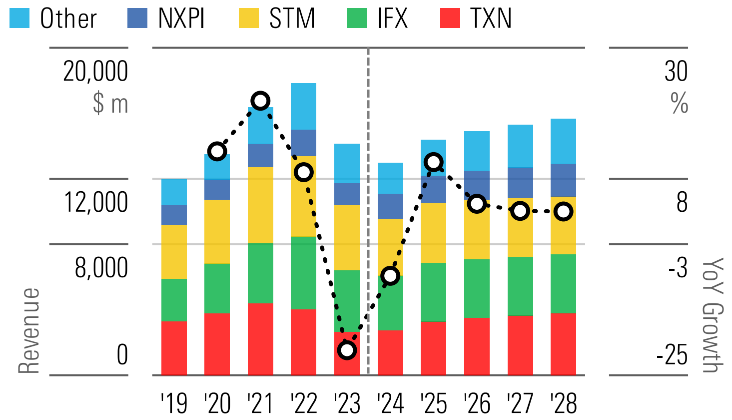
Automotive chip demand will face a difficult year in 2024 due to inventory adjustments and lower electric vehicle production than previously expected. Still, we're bullish on the long-term opportunities here. Cars are incorporating more and more sensors and processors. EVs also provide analog chipmakers with terrific opportunities for content gains within battery management systems, or BMS. As analog chipmakers are experts in voltage regulation, these BMS systems ensure that battery cells are charging properly and draining electricity, thus extending the battery's useful life.

Industrial Analog Demand Will Also Recover in 2025



Industrial chip demand fell off a cliff in 2024 as customers had built up inventory levels in reaction to the previous global chip shortage, but demand is now aligning with true production levels. While macroeconomic conditions will dictate the pace of any cyclical bounceback in the near term, over the longer term we anticipate healthy growth as all types of electronic devices become smarter with more sensors, processors, connectivity, and voltage regulation. Internet of Things gadgets are one area of future growth, but at the other end of the spectrum, large industrial equipment used in factory automation, for example, should deploy more and more chip content over time.

Consumer Analog Demand Will Not Fully Recover



The consumer electronics end market saw a sharp rise during the shift to remote working as people upgraded their computing devices and peripherals (webcams, headsets, headphones, and so on). We think that revenue during this time will represent a peak over the next few years. More recently, demand suffered an inevitable pause thereafter. We're less fond of market opportunities in consumer electronics as these products have shorter useful lives, tend to be more price competitive, and might be subject to rising competition from Chinese chipmakers over time.

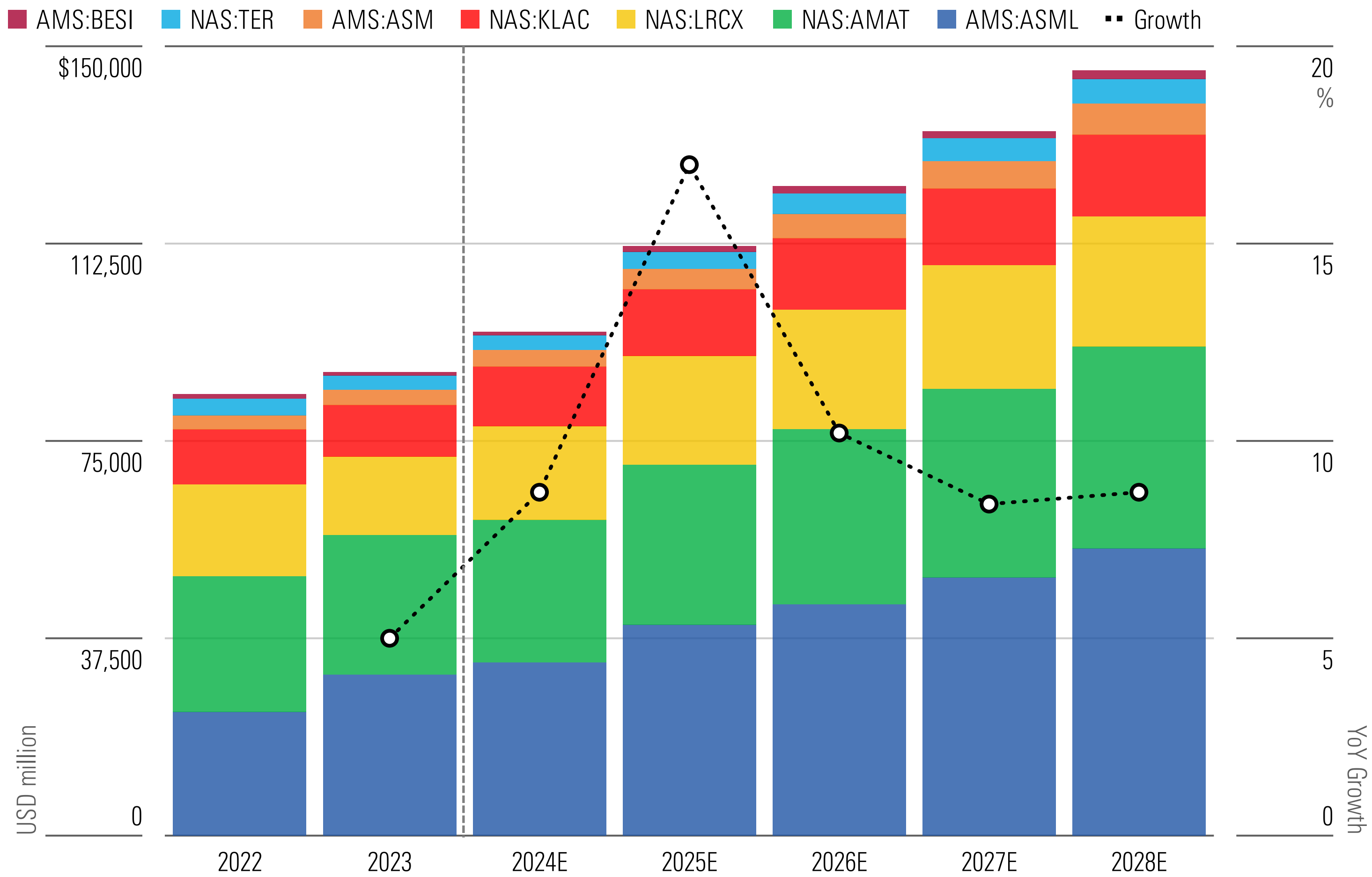
Source: Morningstar, PitchBook, company documents. Data as of Aug. 14, 2024.

Semiconductor Equipment Growth Is Driven by Chip Supply and Complexity

Equipment Revenue Grows as Industry Grows
We expect strong, double-digit growth for chip equipment revenue under our coverage over the next five years. We see chip equipment growth as a derivative of broader semiconductor revenue growth, but with upside from rising equipment intensity for more complex chips. Specifically, AI processors and high-bandwidth memory require more advanced packaging and cutting-edge equipment. In our view, this should drive medium-term equipment growth above our longer-term views of semiconductor growth in the high single digits.

Capacity, Complexity Enable Above-Industry Growth
Chip equipment's growth drivers are semiconductor supply and semiconductor complexity. Greater manufacturing capacity requires more equipment, which raises system orders for equipment suppliers. Increasingly complexi chips require more equipment to produce and more advanced equipment that commands higher pricing. Put together, we model rising supply and rising complexity to drive strong growth for equipment suppliers under our coverage.

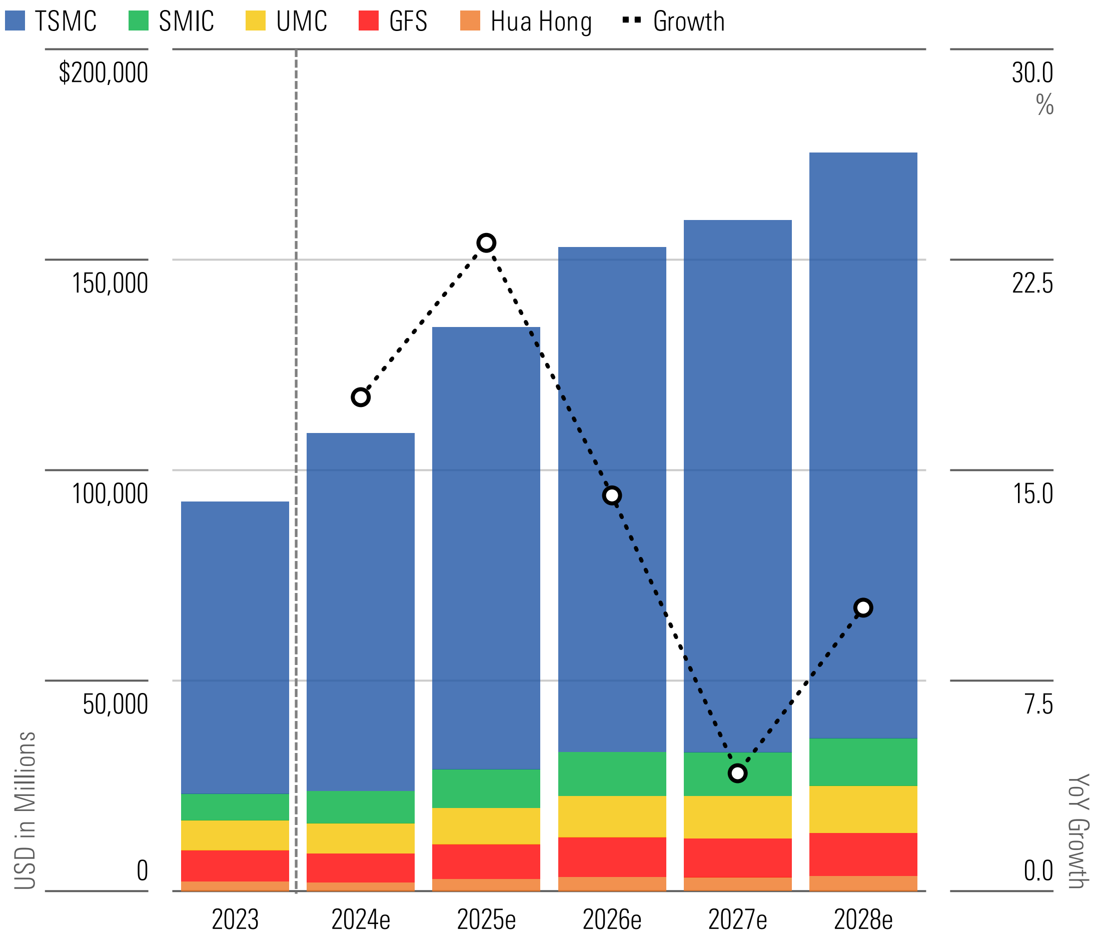
We Forecast 11% Growth for Chip Equipment Through 2028



Source: Company documents, Morningstar estimates. Data as of Aug.19, 2024.
Note: ASML, ASM, and BESI reported in EUR, adjusted based on EUR/USD exchange rate of 1.11. AMAT=FY end-October. LRCX and KLAC FY=end-June.

Foundries—Primarily Driven by TSMC's Outlook, Beneficiaries of Outsourcing, and AI

We Expect Pure-Play Foundry Revenue to Grow 13.7% Through 2028



Outsourcing and New Technology Drive Above-Average Growth for Foundries
We expect double-digit growth for revenue of pure-play foundries under our coverage over the next five years. Foundry revenue grows faster than that of the broader semiconductor industry owing to IDMs outsourcing more of their capacity and customers willing to pay a premium for technological superiority and geopolitical resilience.

New Technology Drives Increased Complexity, AI Is a Large Growth Driver
Foundry growth drivers are increased volumes and chip complexity. Foundries can sell more wafers by tapping into new device categories that emerge roughly every few years. We see military weapons, PCs, smartphones, and AI data centers playing pivotal roles by structurally increasing semiconductor demand since the 1970s. Advanced robotics, autonomous vehicles, and interconnected factories are some drivers that will propel demand in the next decade or two.

TSMC Is a Prime Grower, but Smaller Foundries Will Grow Too
Chip complexity is more than packing more transistors on a chip. TSMC is the best example of a foundry raising wafer prices for each successive new process node. But smaller foundries can also benefit by making chips that better tiptoe the tradeoffs between power consumption, cost, and reliability under rugged conditions.

Source: Morningstar, company documents. Data as of Aug. 14, 2024.

ESG Risk Snapshot

Summary of Sustainalytics ESG Risk Ratings

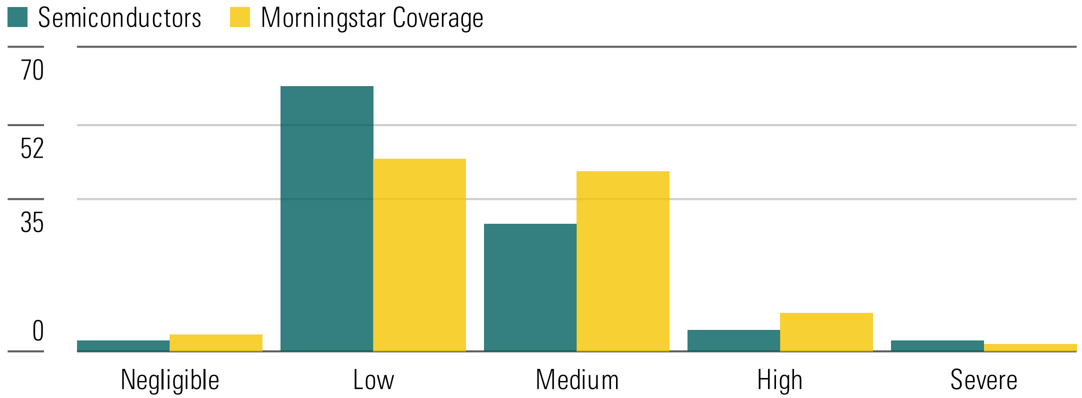
Sustainalytics ESG Risk Ratings assigned to semiconductor stocks under our coverage are concentrated in Low ESG Risk Rating and Medium ESG Risk Rating scores. Sixty-one percent of our semiconductor coverage has a Low ESG Risk Rating, while 29% has a Medium ESG Risk Rating. The key environmental, social, and governance risks for the semiconductor industry are human capital, resource use, and business ethics.

Human Capital: Semiconductor firms have higher human capital risks as the sector relies on highly skilled labor such as engineers, researchers, and technicians for chip development and manufacturing.

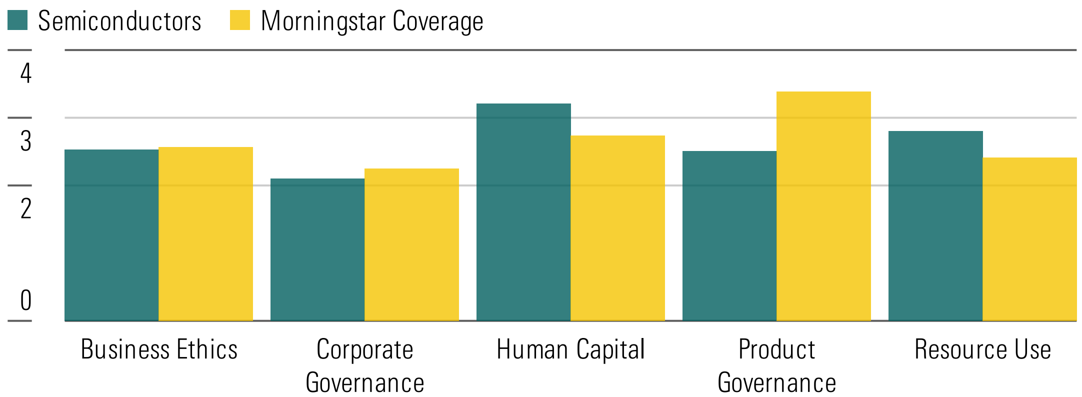
Resource Use: Foundries, memory makers, and IDMs are more exposed to resource use risks than fabless and equipment companies as they require vast quantities of water for chip production and key raw input materials such as specialty gases.

Business Ethics: Semiconductor companies are exposed to risks related to intellectual property and anticompetitive practices. They use litigation to protect their IPs, resulting in legal and settlement costs. They have also faced accusations of price fixing through rebates and subsidies to equipment manufacturers to gain market share.

Distribution of ESG Risk Ratings for Semiconductors and Morningstar Coverage



Top ESG Risk Rating Scores by Material ESG Issue



Source: Morningstar, Sustainalytics.
Note: Higher scores denote higher risk.

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