Government Incentives and US Competitiveness in Semiconductor Manufacturing

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The Semiconductor Industry Association (SIA) is the voice of the semiconductor industry in the US, one of America's top export industries and a key driver of America's economic strength, national security, and global competitiveness. The semiconductor industry directly employs nearly a quarter of a million workers in the US, and US semiconductor company sales totaled $193 billion in 2019. SIA members account for nearly 95 percent of all US semiconductor industry sales. Through this coalition, SIA seeks to strengthen leadership of semiconductor manufacturing, design, and research by working with policymakers and key industry stakeholders to encourage policies that fuel innovation, propel business, and drive international competition.

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Executive Summary

The semiconductor industry is critical to economic competitiveness and national security in an era of digital transformation, artificial intelligence, and 5G communications. The US semiconductor industry has long been the global semiconductor leader, consistently accounting for 45% to 50% of global revenues. But the US share of semiconductor manufacturing capacity, which was 37% back in 1990, has dropped to 12%. Moreover, only 6% of the new global capacity in development will be located in the US. In contrast, it is projected that during the next decade China will add about 40% of the new capacity and become the largest semiconductor manufacturing location in the world.

This trend could have significant repercussions. With a reduced, shrinking manufacturing footprint, the US semiconductor industry would be challenged to stay at the forefront of further advances in manufacturing-processing technology, architectures, and materials critical for developing the next generations of semiconductors that will make artificial intelligence or quantum computing possible. Furthermore, because 75% of the global capacity is already concentrated in East Asia, maintaining domestic manufacturing capabilities is essential to ensure the US semiconductor industry has a highly resilient, geographically diversified supply chain. This is particularly critical for semiconductors used in US advanced defense systems.

The US ranks high in factors that are key when selecting where to locate front-end fabrication facilities (fabs), such as synergy with existing footprints and ecosystems, access to skilled talent, and protection of intellectual property. But the ten-year total cost of ownership of a new fab located in the US is approximately 30% higher than in Taiwan, South Korea, or Singapore, and 37% to 50% higher than in China—an enormous gap considering that the ten-year cost of a state-of-the-art fab, including both initial investment and annual operating costs, ranges between $10 billion and $40 billion, depending on the type of product. As much as 40% to 70% of that cost differential is directly attributable to government incentives.

Global manufacturing capacity is forecasted to increase by more than 50% from 2020 to 2030, presenting a market opportunity for the US to attract a higher share of the new future fabs. According to our analysis, a $20 billion to $50 billion federal-government program of additional grants and tax incentives for new state-of-the-art fabs built in the next decade would be effective in reversing the last 30 years' declining trend in US semiconductor manufacturing.

Depending on the size of the program, the US could potentially double or triple its participation in the new additional semiconductor manufacturing capacity that still needs to be developed globally to meet the expected growth in market demand, achieving a 14% to 24% share, as opposed to just the status quo's 6%. (See the Exhibit "Potential Impact of New Government Incentives on US Semiconduc-tor Manufacturing Position.")

Exhibit - Potential Impact of New Government Incentives on US Semiconductor Manufacturing Position

Trend vs. 2010–2020: ↓ ≈ ↑	2010–2020 ACTUALS	2020–2030 FORECAST: Status quo	2020–2030 FORECAST: Scenarios of new government incentives[1]: $20B program	$50B program
Share of new addressable capacity[2] captured by the US	**10%**	**6%** ↓	**14%** ↑	**24%** ↑
Excluding China	*12%*	*12%*	*24%*	*41%*
US global ranking by share of new capacity[2] (out of 7 regions)	**#5**	**#5** ≈	**#3** ↑	**#2** ↑
Excluding China	*#4*	*#4*	*#2*	*#1*
No. of new fabs built in the US[3]	**9**	**9** ≈	**14** ↑	**19** ↑

Sources: VLSI Research; Semiconductor Equipment and Materials International (SEMI), second-quarter 2020 update; BCG analysis.

[1] Assumed to apply to new incremental capacity built in the US in the next ten years.

[2] Addressable capacity refers to the new capacity that the industry needs to add to serve the expected growth in demand, and that is not yet in development (remains available).

[3] Normalized to an average fab size of about 75,000 wafers per month (wpm) for comparison purposes, in line with the average fab size used in the 2020–2030 forecasts. The actual number of fabs built in the US in 2010–2020 was 19 (excluding experimental and very small units), with an average size of about 40,000 wpm.

Such government investment would mark an inflection point in establishing the US as a highly attractive location for semiconductor manufacturing. For example, we estimate that a $50 billion incentive program would enable the construction of 19 advanced fabs in the US over the next ten years, doubling the number expected if no action is taken and increasing the capacity located in the US by 57%. These new fabs would be commercially viable and have sufficient capacity to cover the demand from the US defense and aerospace industry. In addition, they could create about 70,000 direct jobs, significantly expanding the US talent pool of highly skilled semiconductor manufacturing technicians; foster the development of local high-tech clusters; and contribute to improving the US trade balance in goods.

Together with continued leadership in R&D, strengthening its capabilities in manufacturing would position the US semiconductor industry to lead the way in the new innovation frontiers of materials, architectures, and fabrication processes that will power the critical advancements in computing and electronics for the next decades.

Introduction

Semiconductors are critical for economic competitiveness and national security. Innovation in semiconductors is foundational in developing advances to drive the global economy into the era of digital transformation, artificial intelligence (AI), and 5G communications. Revolutionary applications—such as augmented- or virtual-reality experiences, the Internet of Things, Industry 4.0 systems, and self-driving vehicles—are on their way to becoming commercial realities.

Modern defense capabilities also rely on sophisticated electronics systems powered by advanced semiconductor components. The defense modernization priorities laid out in the 2018 US National Defense Strategy include microelectronics, 5G, and quantum science as strategic areas requiring US investment. Other priority areas such as cybersecurity, AI, autonomous systems, and advanced imaging equipment also rely heavily on advanced semiconductors. As digitally connected electronic systems become increasingly crucial for managing advanced weapons systems and critical infrastructure, the availability of trusted semiconductor suppliers that can deliver economically viable, reliable, and secure components will become even more pressing for national security.

The semiconductor industry's strategic importance for technology leadership and national security is causing many countries to look at their positions across the semiconductor value chain. The US has been the long-standing global leader in semiconductors, with a 45% to 50% share of worldwide revenues in the last 30 years. However, significant focus is now being placed on the eroding US share in semiconductor manufacturing, which currently stands at 12% of the global installed capacity.[1]

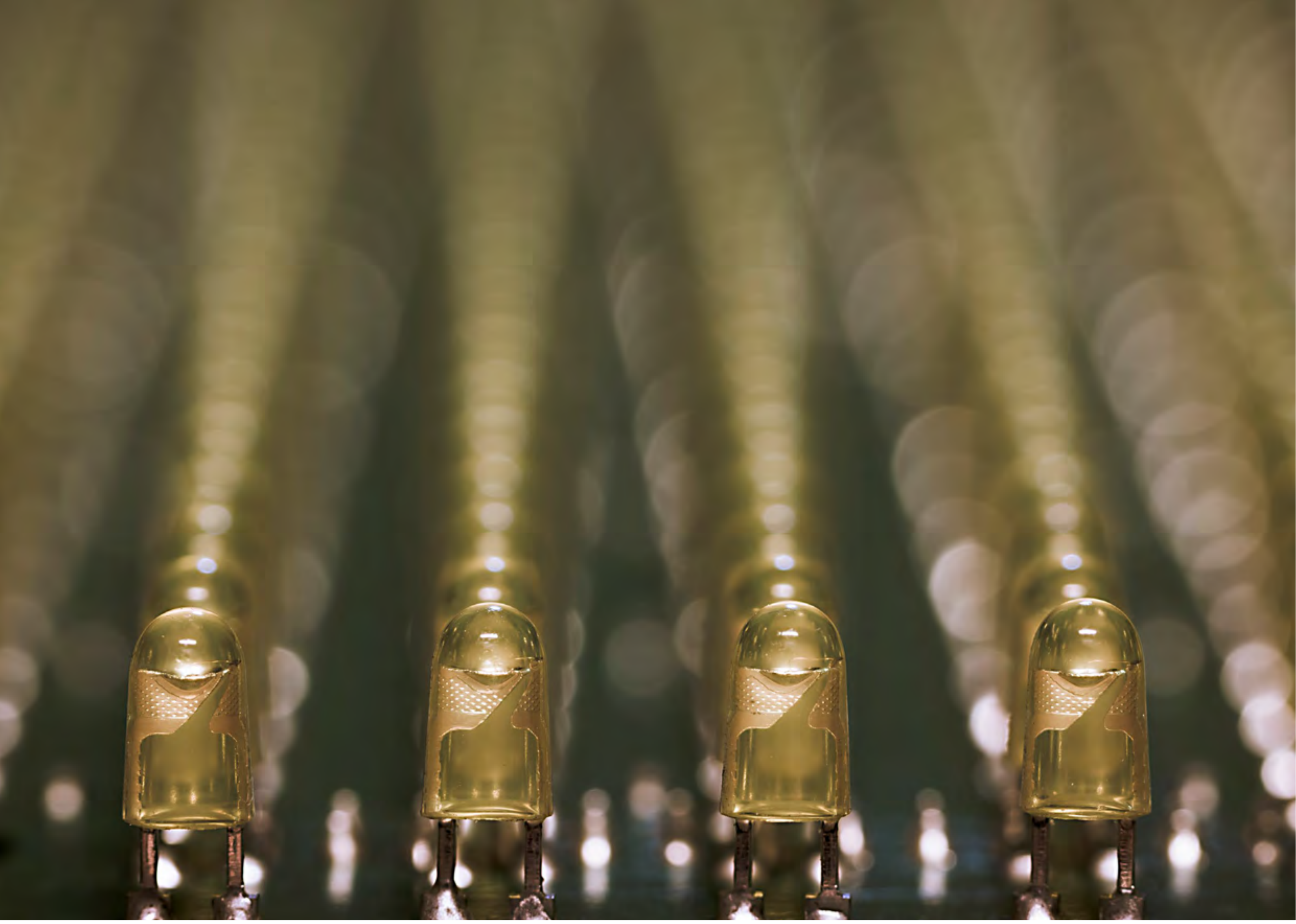
The ongoing geopolitical frictions between the US and China, as well as the disruptions caused by the COVID-19 pandemic, have also raised questions about the potential vulnerabilities in the global supply chain of US semiconductor companies, particularly because a large portion of the manufacturing activity is concentrated in East Asia. In recent years, a number of programs related to the US Department of Defense, such as the Trusted and Assured Microelectronics initiative, have been launched in an attempt to secure the manufacturing layer of the value chain used for domestic supply. The May 2020 announcement by Taiwan Semiconductor Manufacturing Company (TSMC), the largest dedicated semiconductor foundry company in the world, of plans to build an advanced logic fab in Arizona has been portrayed as an initial step toward expanding state-of-the-art semiconductor manufacturing capacity in the US.

The significant increase in global manufacturing capacity required from 2020 to 2030 to serve the expected growth in semiconductor demand provides a market opportunity for the US to attract more of the new fabs. In this report we study the case for expanding the semiconductor manufacturing footprint in the US. We look first at the current US position and trends to determine how the share of global manufacturing capacity located in the US could evolve if there were no changes to the status quo, and the potential implications for the US semiconductor industry.

To understand the root causes behind the steady decline in US global manufacturing share over the years, we have analyzed the differences in the total cost of building and operating three types of fabs in the US and in other alternative locations. In particular, we have researched the level of government incentives typically offered in each country. Our analysis shows that as much as 40% to 70% of the higher cost for US-based fabs is directly attributable to much lower incentives than those currently provided in China, Taiwan, Singapore, and other countries with a significant semiconductor manufacturing footprint.

We have developed an analytical model to evaluate possible changes to the current trajectory of the US share of global manufacturing capacity. Although this report does not offer policy recommendations, we lay out what additional government incentive programs would be needed if the US were to set a goal of capturing a significant share of the new future capacity and reverse the last 30 years' steady decline in domestic manufacturing. Looking ahead, we see this becomes particularly critical because closer R&D collaboration between design and manufacturing is needed to develop innovations in architecture and materials that could sustain the continuous leaps in performance and cost in future semiconductor generations on which the technology sector and advanced defense systems rely.

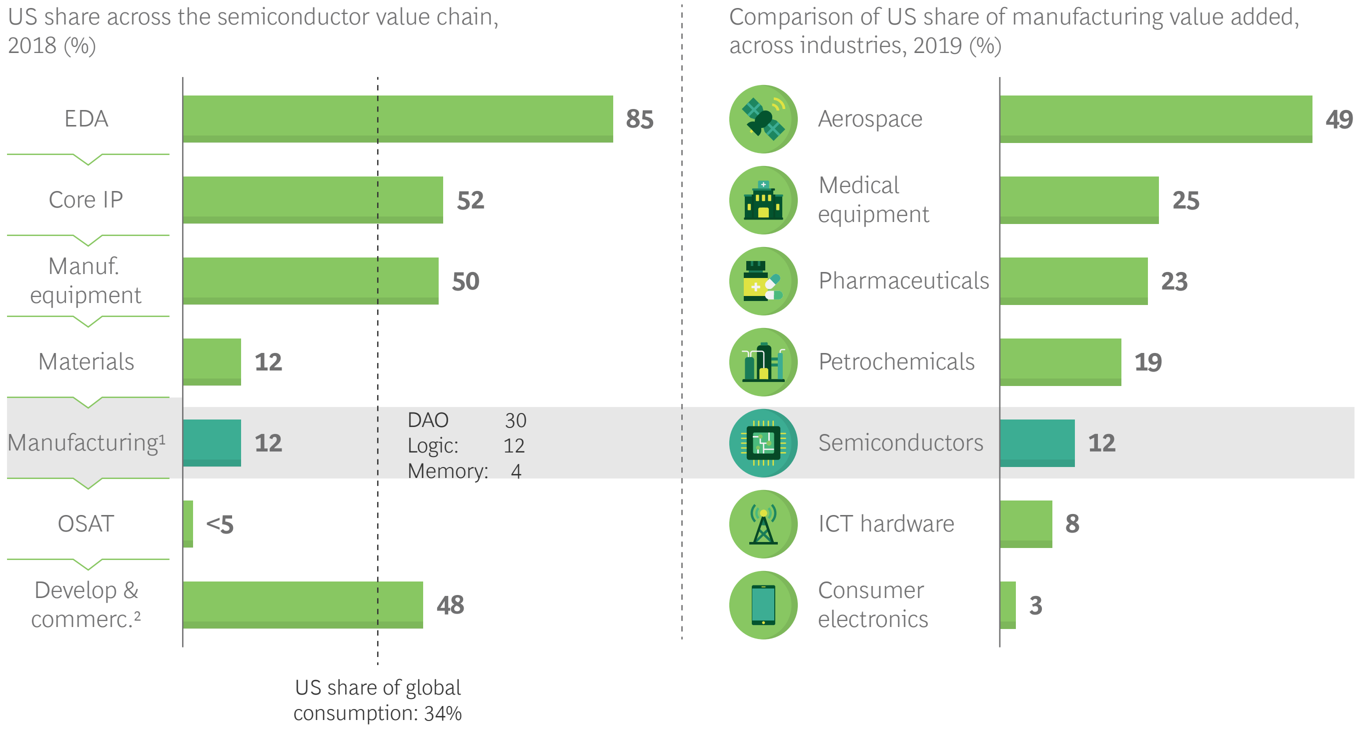
1. This includes all fabs located in US territory, both those owned by firms headquartered in the US and those owned by foreign firms.



Current US Position in Semiconductor Manufacturing

The US invented the integrated circuit and has long been the global leader in semiconductors. US companies consistently account for 45% to 50% of total worldwide sales. A strong position across the value chain has contributed to this standing. US firms command a combined market share above 50% in electronic design automation tools (EDA), intellectual property cores (core IP), integrated circuit design, and manufacturing equipment. In contrast, the US share of semiconductor manufacturing capacity, which was 37% in 1990, now stands at just 12%. (See Exhibit 1.) The US share of manufacturing capacity remains strong in discrete, analog, and optoelectronics products (30%). In fact, the US is still the global manufacturing leader in specific segments such as compound semiconductors and radio frequency and bulk acoustic wave (BAW) filters, although that status too is now being challenged by new investments in Asia. However, the US share is much lower in memory (4%) and logic (12%)—the fastest-growing segments forecasted to drive 90% of the growth in capacity in the next decade.

Exhibit 1 - US Share of Manufacturing Is Low Relative to Rest of Semiconductor Value Chain and Other Strategic Industries



Sources: For semiconductor value chain: BCG analysis based on market data from Gartner, Semiconductor Industry Association (SIA), VLSI Research, SEMI, and company financials. For US share of manufacturing value added: BCG analysis of macroeconomic data from Oxford Economics.

Note: DAO = Discrete, analog, and optoelectronics; EDA = electronic design automation tools; ICT = information and communications technology; OSAT = outsourced semiconductor assembly and test.

[1] Share of global installed capacity located in the US, regardless of company HQ location.

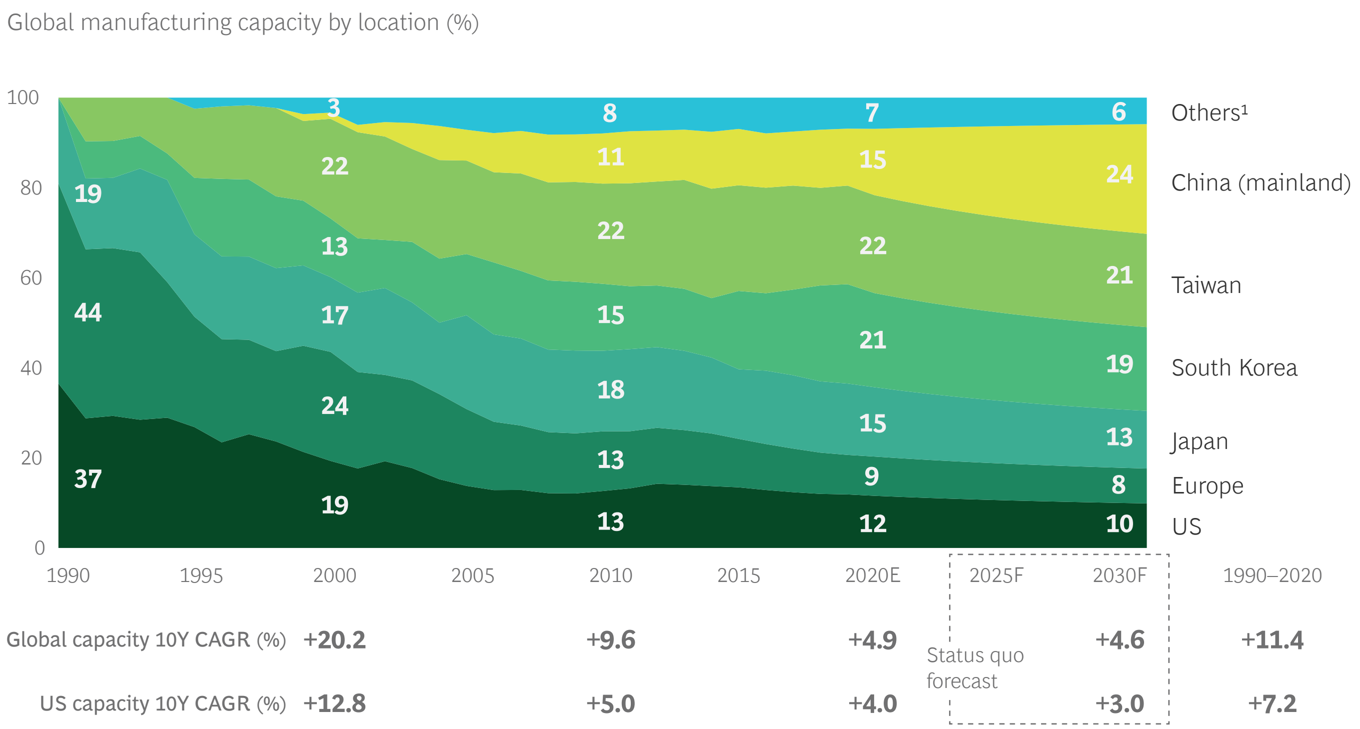
[2] Share of total semiconductor sales (fabless plus integrated device manufacturers).

The decline in the US share of semiconductor manufacturing is consistent with the general trend observed in US manufacturing across industries. The overall US share of global manufacturing value added has decreased from 25% to 30% in the 1990s to 17% in 2018.[2] But the current 12% share in semiconductor manufacturing is well below what the US has in other strategic industries, such as aerospace (49% of global manufacturing performed in the US), medical equipment and pharmaceuticals (about 25%), and petrochemicals (around 20%). Among the industries relying on advanced manufacturing, only in the more labor-intensive sectors—consumer electronics (3%), computers and networking hardware (8%)—is the US share lower than in semiconductor manufacturing.

Unlike several other industries, the US semiconductor industry has not undergone a significant wave of restructuring involving shutdowns and offshoring of US-based manufacturing facilities. On the contrary, during the last 30 years the manufacturing capacity in the US has grown at a 7% cumulative annual rate. Global capacity, however, has increased at 11% annually in the same period. The rise in the US's installed capacity has been outpaced by that of several Asian countries: Taiwan, Korea, and China have been investing heavily to become manufacturing powerhouses. (See Exhibit 2.)

2. Based on data from United Nations National Accounts, cited by Levinson, "U.S. Manufacturing in International Perspective," Congressional Research Service, February 2018.

Exhibit 2 - Growth in US Installed Capacity Has Been Outpaced by Asian Countries



Sources: VLSI Research projection; SEMI second-quarter 2020 update; BCG analysis.

Note: All values shown in 8" equivalents; excludes capacity below 5 kwpm or less than 8".

[1] Includes Israel, Singapore, and the rest of the world.

Government policies have been a major factor in this strong growth in Asia. These countries have placed a strategic focus on semiconductors and supported the development of their domestic manufacturing industry with favorable grants, tax credits, and other government incentives that make the economics in their territories more attractive.

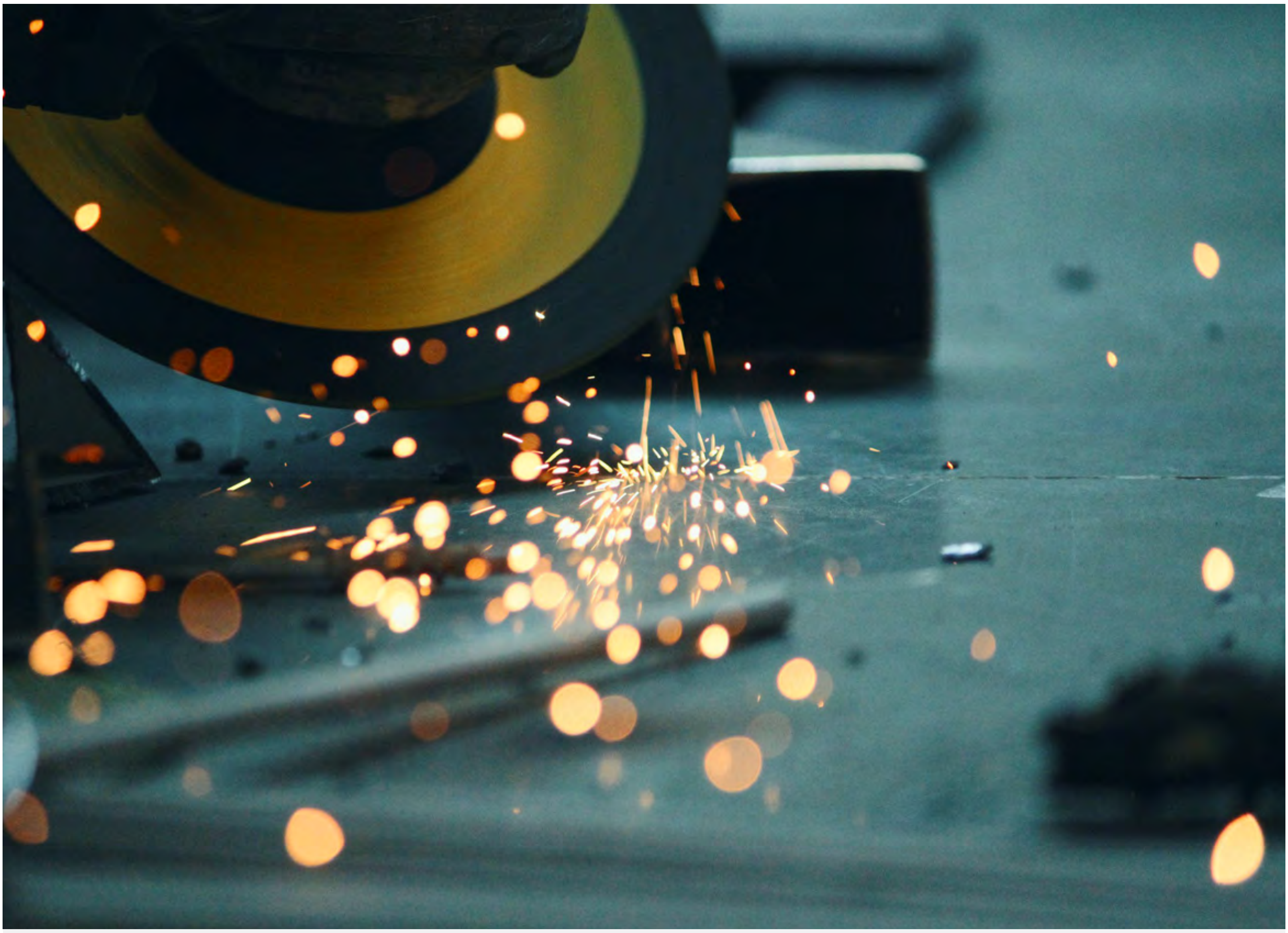
In parallel, the semiconductor industry has seen the rise of the "fabless" model. Many US firms adopted this business model that allowed them to focus on semiconductor design and commercialization while relying on foreign-contract manufacturing partners (otherwise known as dedicated or pure-play "foundries"). These partners have access to lower costs and more attractive government incentives in other countries. They also have the ability to lower the risk on their massive capital investments across a broad pool of global customers. Dedicated foundries account for 38% of global manufacturing capacity, of which only 7% is located in the US. In contrast, the US share of the capacity owned by the world's integrated device manufacturers (IDMs)—which design and manufacture their products in their own fabs, and therefore can realize synergies by locating both activi-ties in the same place—is significantly higher, 14%.

The US share of global manufacturing capacity is expected to decline even further. Current data regarding planned fab construction indicates that only 6% of the new capacity already in development and expected to start operations in the next five years will be located in the US. This is signifi-cantly below the current US share of global installed ca-pacity (12%) as well as the portion of new global capacity that the US added from 2010 to 2020 (10%).

We estimate that, without action, the US share in manufacturing will decrease to 10% by 2030. In contrast, China plans to add about 40% of the global new capacity, and it could emerge as the global leader in installed semiconductor manufacturing capacity, reaching 24% of the world's total capacity in 2030— roughly equivalent to the share of the global demand for semiconductors coming from Chinese device makers. (See the sidebar "China's Efforts in Pursuit of Semiconductor Manufacturing Self-Sufficiency.") Although China may remain a generation or two behind in manufacturing-process technology even in 2030, its ex-panded manufacturing base will likely accelerate its learn-ing curve to close that gap.

Furthermore, there are very significant synergies in building new semiconductor manufacturing capacity within existing clusters. In fact, semiconductor companies regard this as one of the most important factors to consider when selecting the location of a new fab.[3] It creates a self-reinforcing dynamic that will lead to additional declines in the US manufacturing share over time—and further expansion of China's share plus that of other already well-established fab locations in Asia. Ultimately, without significant changes in the current conditions, it will become increasingly difficult for the US to retain any robust domestic capabilities in semiconductor manufacturing.

3. Based on a BCG survey of Semiconductor Industry Association member companies with manufacturing activity, June 2020.



China's Efforts in Pursuit of Semiconductor Manufacturing Self-Sufficiency

China's Ambition

Semiconductor manufacturing has long been a priority, but it gained further urgency in 2014–2015 with the Made in China 2025 plan and the goal of increasing self-sufficiency in semiconductors.

Government Policies

A broad set of policy levers exists both centrally and locally:

1. Investment incentives (land, grants, tax credits…)

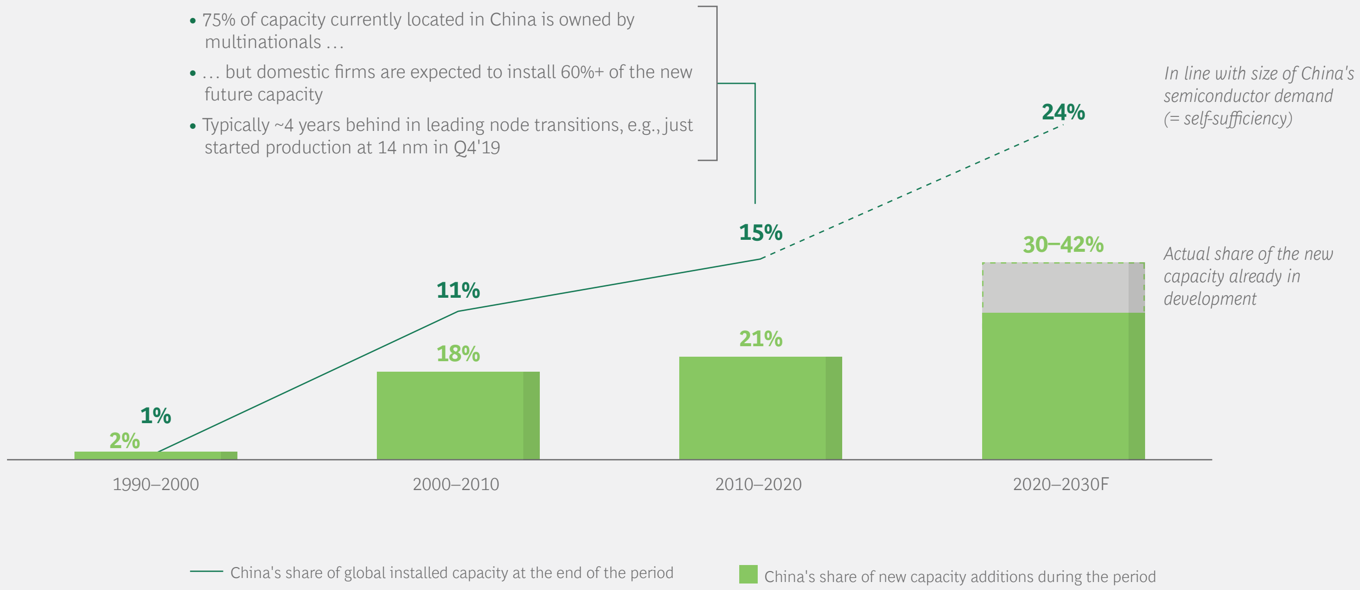
- In China, incentives can make up 30%-40% of a new fab's total cost of ownership, well above that in other countries.
- They are available for both domestic and multinational firms, but the best terms often require some technology transfer.

2. Additional support not typically found in other countries

- Equipment is leased at preferential rates.
- Firms have access to credit and loans at below-market rates.
- The state directly invests equity in domestic companies (which historically have delivered below-market returns).

The OECD estimates that the total amount of government support to the top four Chinese semiconductor manufacturing companies in 2014–2018 exceeded 20%–30% of their revenues. (See the exhibit "Rapid Growth in China's Share of the Global Semiconductor Manufacturing Capacity.")

Rapid Growth in China's Share of the Global Semiconductor Manufacturing Capacity



Sources: China market data from SEMI, IC Insights, and VLSI Research; OECD; BCG analysis.

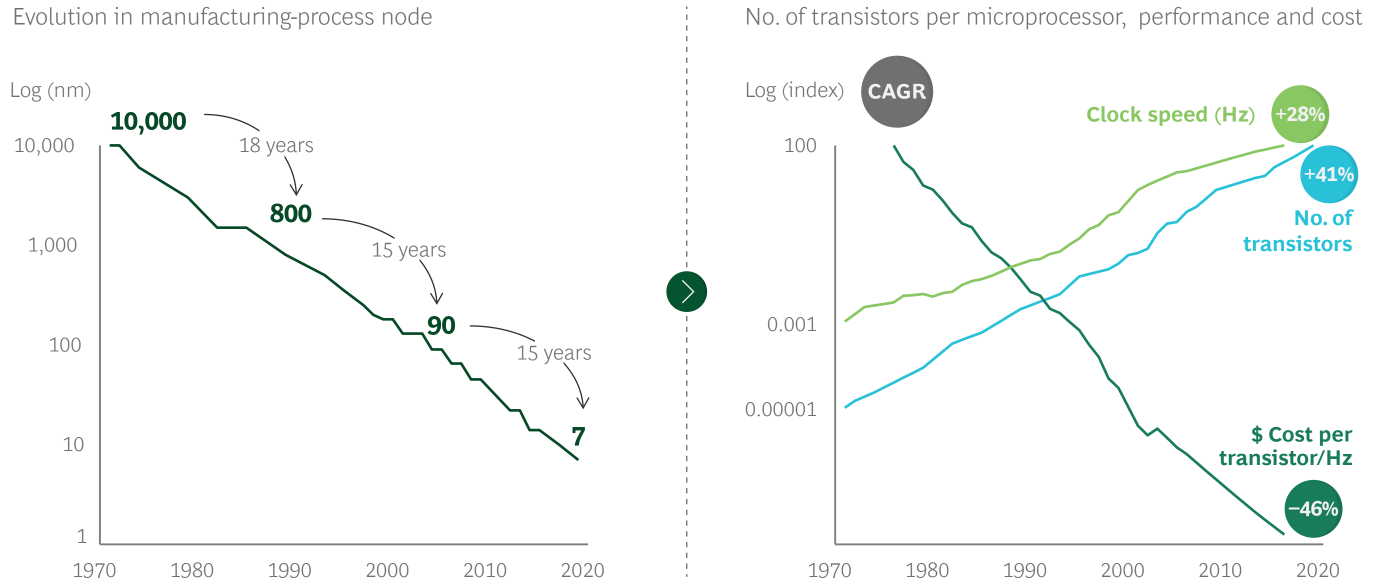
Why It Matters

The sustained decline in the US share of the global manufacturing capacity could have significant repercussions for the US semiconductor industry.

Sustaining Leadership in Semiconductor Innovation for the Long Run

Manufacturing accounts for 45% of the value added and about 20% to 25% of the total R&D investment of the global semiconductor industry. Manufacturing is at the center of the industry's relentless pace of advancement. (See Exhibit 3.) Over the last five decades, the continuous advancement in semiconductor manufacturing through process-node scaling (commonly referred to as Moore's Law) has delivered staggering improvements in semiconductor performance and cost: the number of transistors per wafer has increased by a factor of almost 10 million, yielding a 100,000-fold gain in processor speed and a cost reduction of more than 45% per year for comparable performance. The blazing speed of this technological improvement has enabled the transition from mainframes in the 1980s to smartphones in the 2010s, a driving force of productivity and economic growth.

Exhibit 3 - Advances in Semiconductor Manufacturing Have Driven Dramatic Improvements in Chip Performance and Cost



Sources: Intel; Singularity.com; Wikipedia; BCG analysis.

Established research has documented the negative impact of geographic disaggregation of manufacturing from R&D in industries where product design and manufacturing processes are strongly interlinked.[4] In semiconductors, the success of the fabless business model requires collaboration between the design company and its foundry partners, but geographic proximity has not been a requirement. However, the semiconductor industry is pursuing new breakthroughs in chip architectures and materials to sustain the pace of improvement in performance and the cost required to make new critical technologies, such as AI or quantum computing, possible. Progress in these new frontiers is dependent on increasing R&D collaboration between design and manufacturing.[5] Given the US semiconductor industry's leading position in the basic sciences, integrated circuit design, and production equipment, strengthening its capabilities in manufacturing could position it to lead the way in these areas of innovation that will create the new technology paradigms for the future.

The ability for the US to remain at the forefront of such innovation provides a significant strategic advantage in defining the timing, standards, and business models for semiconductor manufacturing, thereby driving the pace of innovation across the value chain, from manufacturing equipment and tools to design.

Securing Supply-Chain Resiliency

Maintaining robust domestic manufacturing capabilities is also essential to ensure that the US semiconductor industry has a highly resilient supply chain. Approximately 75% of the world's capacity to manufacture semiconductors is concentrated in East Asia, and that number is expected to continue rising, fueled by strong cluster effects. China alone is projected to host roughly 25% of the total global manufacturing capacity by 2030. Taiwan currently accounts for 47% of the global capacity in the leading and advanced nodes (10 nanometers or below) used for advanced logic devices such as high-performance processors that power smartphones or data centers. In memory, which accounts for about 30% of the total semiconductor demand, South Korea has more than 40% of the global capacity. As the COVID-19 crisis has shown, high concentration in one country or region makes a global supply chain vulnerable to disruptions such as natural disasters, pandemics, or geopolitical conflicts. Given the strategic nature of the semiconductor industry for the US economy and national security, bolstering supply-chain resiliency through geographic diversification is imperative.

4. See Fuchs and Kirchain, "Design for Location? The Impact of Manufacturing Offshore on Technology Competitiveness in the Optoelectronics Industry," *Management Science*, December 2010, and Branstetter et al, "Does Offshoring Manufacturing Harm Innovation in the Home Country? Evidence from Taiwan and China," working paper, October 2017.

5. For a recent discussion of these new technology frontiers for the semiconductor industry, see Shalf, "The Future of Computing Beyond Moore's Law," *Philosophical Transactions of the Royal Society A*, January 2020.

Additional Benefits for the US Economy

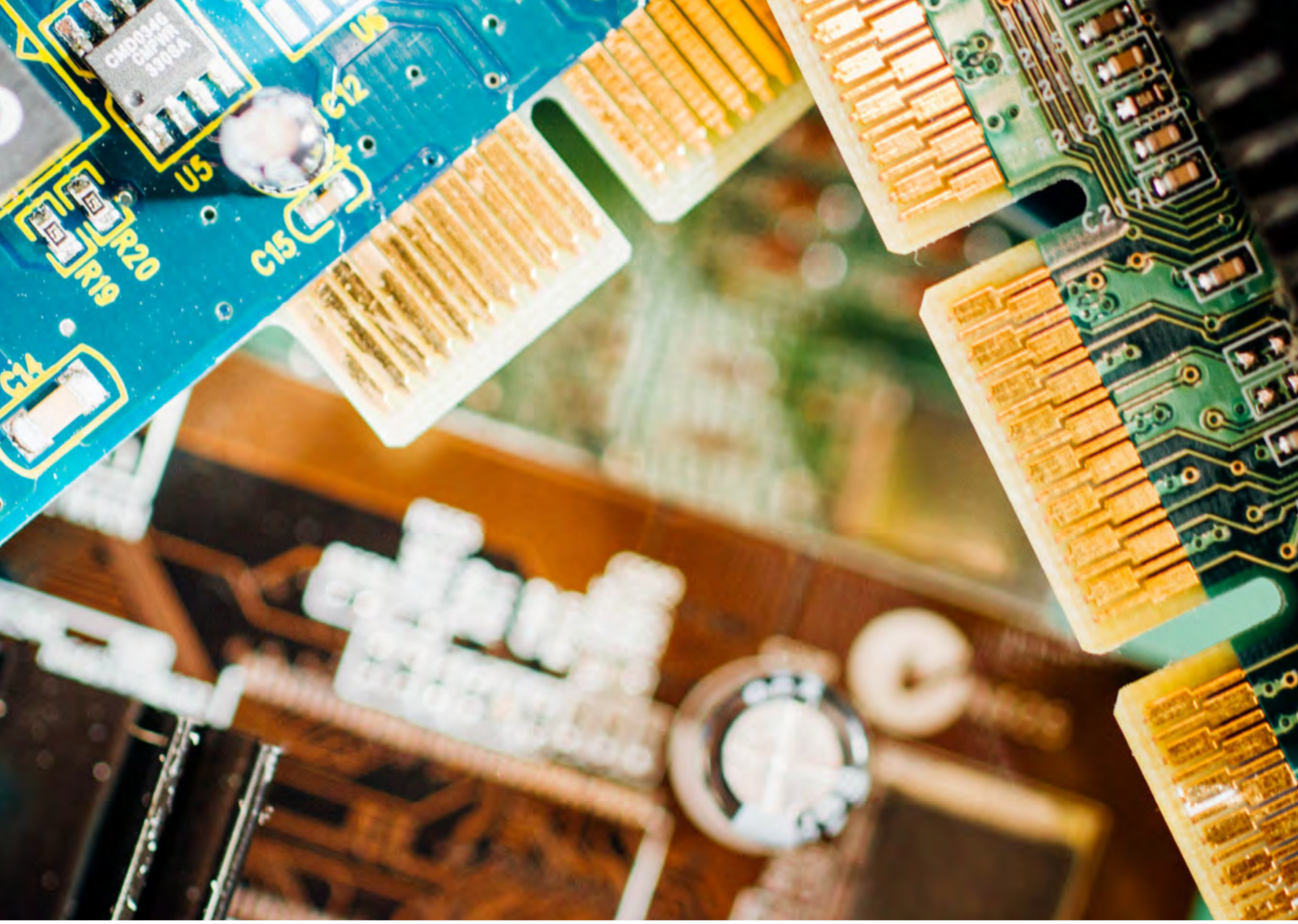
Having a stronger semiconductor manufacturing footprint in the US could also bring additional benefits to the US economy:

- **Development of local high-tech clusters that create high-quality jobs and economic prosperity.** A new fab of standard scale requires 3,000 to 6,000 employees to operate it, depending on the specific product and technology. This direct job creation typically generates a multiplier effect for the local economy, and over time it can also help attract other companies in the value chain that look to benefit from cluster effects such as tight-er collaboration within the semiconductor ecosystem, access to the local talent pool, established supporting infrastructure, and so forth. The US already has a vibrant set of semiconductor manufacturing clusters, such as those around the cities of Dallas and Austin (both in Texas), Portland (Oregon), and Phoenix (Arizona).

- **Improvement of US trade balance in goods.** The US has a very significant trade surplus in semiconductors, over $8 billion in 2019. Having more fabs located in the US could expand this surplus by increasing exports of semiconductor products designed and manufactured in the US—either to end customers or to the overseas facilities of outsourced semiconductor assembly and test (OSAT) vendors to finalize the production process with packaging and testing.

Realizing cluster effects along the value chain and reinforcing the resiliency of its global supply chain are of great importance for the sustained competitiveness of the US semiconductor industry. This is not to say that the US should aggressively re-shore semiconductor manufacturing capacity in pursuit of a broad "self-sufficiency" objective. The semiconductor industry is inherently global, because countries and regions have distinct comparative advantages for different activities across the value chain. This characteristic gives US and foreign firms access to the best capabilities at the lowest economic cost so they can fuel the "virtuous cycle" of innovation behind the industry's technology breakthroughs.[6] Furthermore, just as a high concentration of manufacturing in East Asia creates supply-chain vulnerabilities, so would locating within US borders all the capacity needed to serve the US market.

6. See "The Virtuous Circle Enabling US Semiconductor Leadership" in the BCG report *How Restrictions to Trade with China Could End US Leadership in Semiconductors*, 2020.



Understanding US Competitiveness vs. Global Alternative Locations

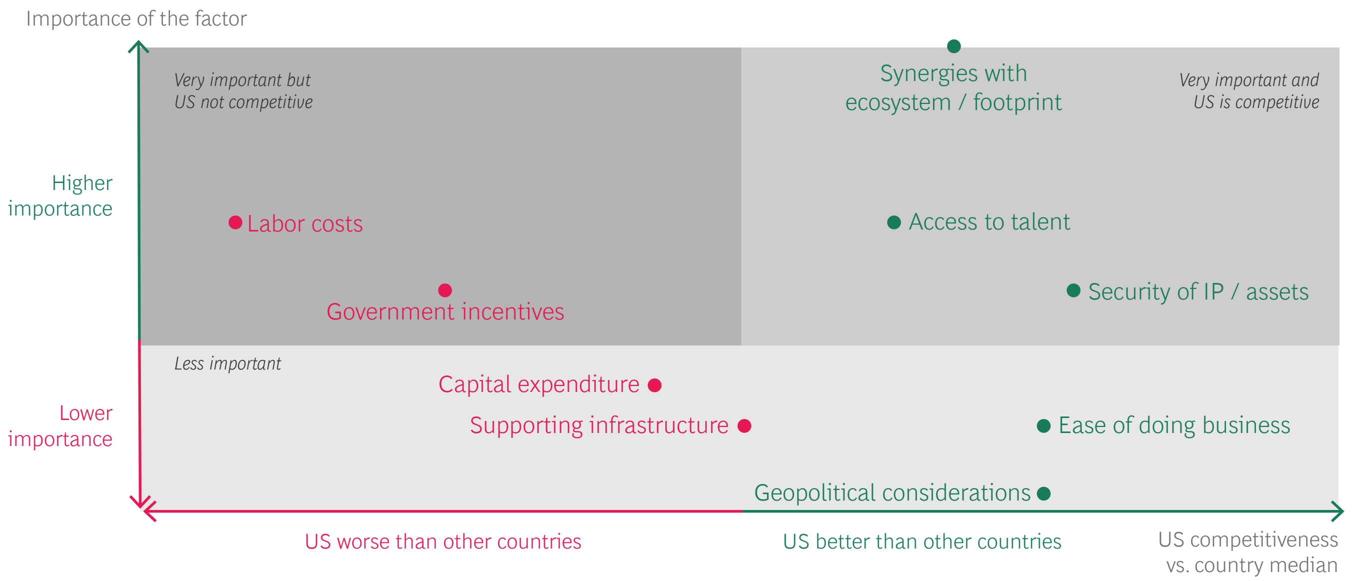
The decline of the US share of global semiconductor manufacturing capacity is not a matter of lacking technical capabilities. In fact, the US has a 28% share of the global capacity in leading and advanced nodes (10 nanometers or below), significantly above its overall 12% share across all manufacturing-process nodes. US companies are global leaders in R&D for manufacturing-process technology across all segments (logic, memory, and analog), along with fab software, equipment, and process-control tools. Eight of the top 20 global companies involved in semiconductor manufacturing (including both IDMs and foundries), which together account for more than 80% of the current global capacity, already have manufacturing operations in the US. Semiconductor manufacturers employ approximately 180,000 workers in the US and operate fabs in 18 US states.

Then why do companies choose to build fabs outside the US? We have leveraged our experience in the semiconductor industry, discussions with industry leaders, and a survey of US semiconductor companies involved in manufacturing to identify the key criteria companies apply to decide where to build new capacity, as well as the relative position of the US versus other alternative locations. (See Exhibit 4.)

The US ranks very favorably in three of the five most important factors: synergies with an existing footprint, access to talent, and protection for intellectual property and assets. However, the US is perceived to be significantly behind alternative locations in the two other key factors identified—labor costs and government incentives.

Exhibit 4 - Though Rated High in Three Fab Location Criteria, US not Competitive in Fab Economics

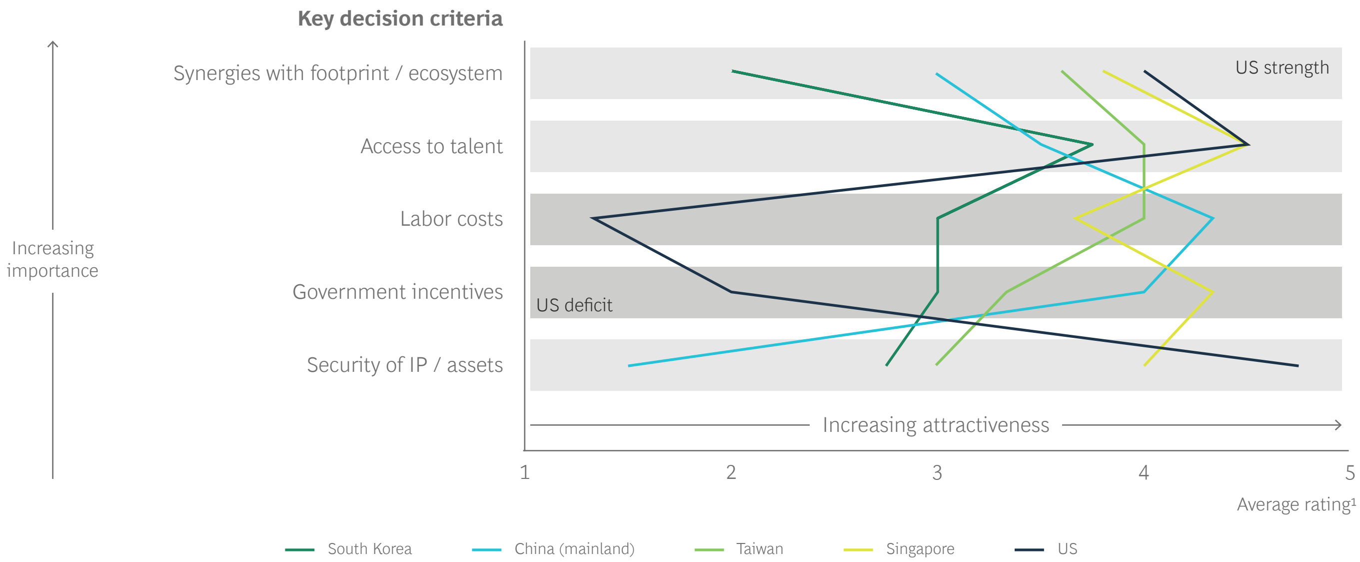
FACTORS CRITICAL FOR SELECTING FAB LOCATION



Source: BCG survey of SIA members, question C2: What are your most important decision criteria for choosing a fab location?

Note: Exhibit does not show other factors that were not selected as important by survey respondents.

COMPARISON OF INDIVIDUAL RATINGS IN TOP FIVE CRITERIA FOR FAB LOCATION SELECTION



Source: SIA member survey data, question G1: Please rate the following countries for each of your key decision factors for locating a fab (*N* = 6).

[1] Scale of 1–5: 5 = Highly attractive, 1 = Not at all attractive.

Indeed, the US is not currently a cost-competitive location for semiconductor manufacturing. Semiconductor fabs require enormous investments. In fact, with a higher-than-20% ratio of capital expenditure over revenues for the overall industry in 2019, the semiconductor industry is at par with power and utilities as the most capital-intensive sector in the entire economy.[7]

To quantify the cost differential between the US and other regions, we have benchmarked the total cost of ownership (TCO)[8] over a ten-year period for three representative types of fabs illustrative of the new capacity that will be built in from 2020 to 2030.[9] (See Exhibit 5.)

Exhibit 5 - Three Representative Types of Fabs to Benchmark Total Cost of Ownership Across Locations

	ADVANCED LOGIC	ADVANCED MEMORY	ADVANCED ANALOG
Type of semiconductor products	Processors for mobile phones, AI systems, and supercomputers	Advanced flash storage for mobile phones, PCs, and data centers	Power electronics for electric vehicles, aircraft, and renewable energy
Manufacturing technology	• 12-inch wafer size • 5 nm node	• 3D NAND, 128 layers • 12-inch wafer size • 20 nm node	• 12-inch wafer size • 65 nm node
Capacity (wafers per month)	35,000	100,000	40,000
No. of employees	~3,000	~6,000	~3,000
Capital investment ($ billion)	~20	~20	~5

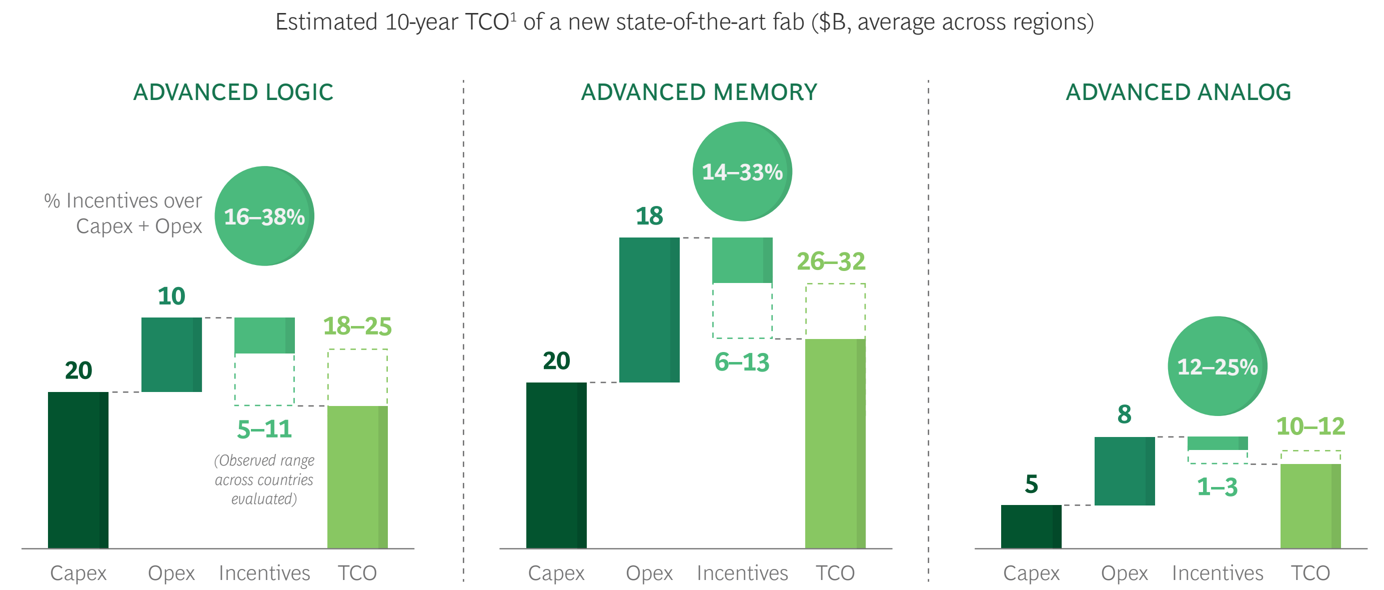
Sources: SIA; BCG analysis.

7. Semiconductor capital intensity was calculated as aggregated capital expenditure, reported in 2019 by 68 of the largest semiconductor companies across design, IDMs, foundries, and OSAT over 2019's total global semiconductor market size, based on Gartner data. Data from other industries has been taken from the *Damodaran Online* database (New York University's Stern School of Business), as of January 2020.
8. TCO is calculated as capital expenditures plus cash operational expenses over a ten-year period, minus incentives.
9. These three specific types of advanced fabs selected for the analysis are representative examples, but they do not account for all the new capacity to be built in the next decade. Many other semiconductor product lines, such as DRAM memory, insulated-gate bipolar transistors, image sensors or radio frequency filters, are forecasted to experience significant demand growth between 2020 and 2030, and will also require additional manufacturing capacity.

As Exhibit 6 shows, a state-of-the-art semiconductor fab of standard capacity requires roughly between $5 billion (for an advanced analog fab) and $20 billion (for advanced logic and memory fabs) of capital expenditure (including land, building, and equipment). This is significantly higher than, for example, the estimated cost of a next-generation aircraft carrier ($13 billion) or a new nuclear power plant ($4 billion to $8 billion). In addition to the up-front capital expenditure, we calculate that the ongoing cash operating expenses (labor, utilities, and so on) amount to approximately $0.6 billion to $2.0 billion per year. Therefore, the total gross TCO of a new fab—without considering government incentives—over a ten-year period can reach a staggering $11 billion to $15 billion (for advanced analog) and $30 billion to $40 billion (for advanced logic or memory).

Given the size of these numbers, incentives provided by governments are fundamental to supporting the investments required and have become a regular part of the business case for new fab investments. Government incentives typically reduce up-front capital expenditure on land, construction, and equipment, but they can also extend to recurrent operating expenses such as labor costs. In total, we estimate that government incentives can offset between 15% and 40% of the gross TCO (before incentives) of a new fab, depending on the country.

Exhibit 6 - Government Incentives Have Material Impact on Fab Economics

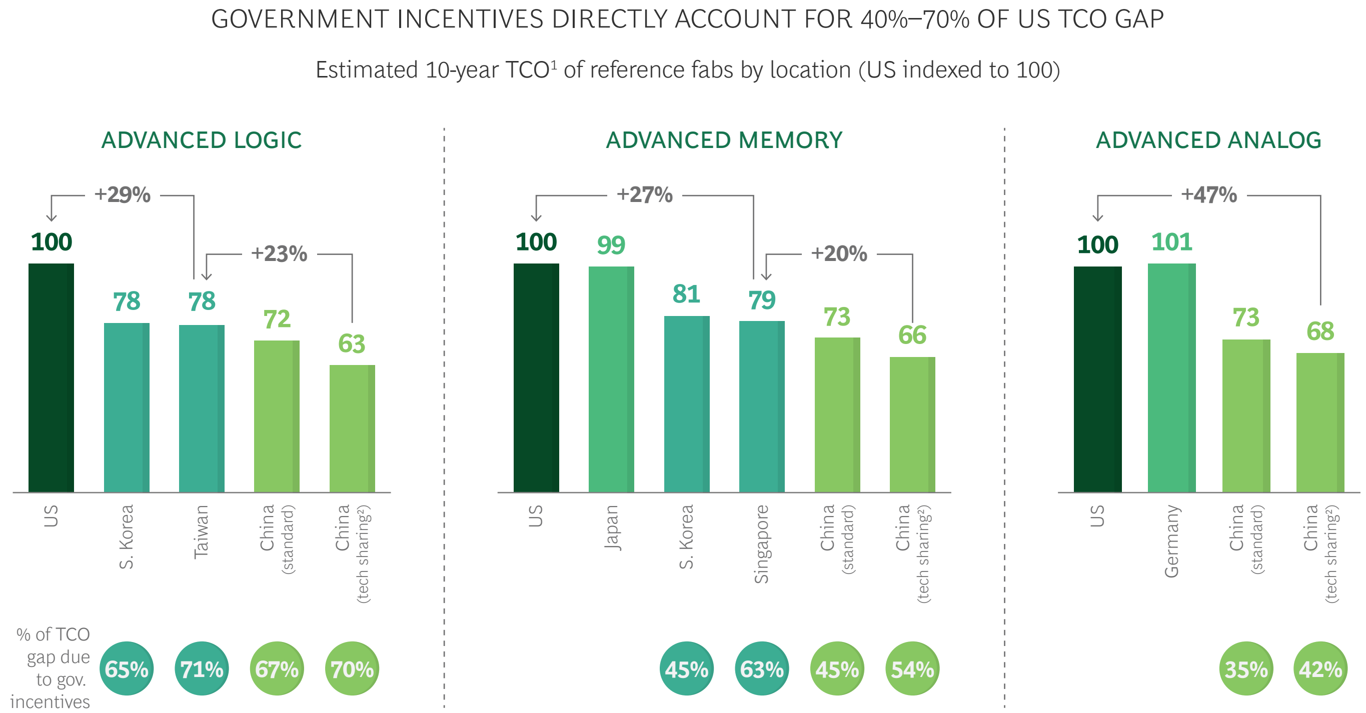


Source: BCG analysis.

[1]TCO includes capital expenditure (upfront land, construction, and equipment) plus ten years of operating expenses (labor, utilities, materials, taxes). The average is of estimated values across analyzed countries (US, Japan, South Korea, Taiwan, China, Singapore, and Germany).

For each type of fab considered, we have analyzed the up-front capital expenditure, annual operating costs, and government incentives in different countries. According to our analysis, across all three types of fabs the TCO for a US-based fab is approximately 25% to 30% higher than the equivalent fab located in Taiwan or Singapore. (See Exhibit 7.) China, which provides very high government incentives on top of its structurally lower wages, appears to be even more cost competitive. In the US, the TCO is roughly 50% higher than in China, even not counting additional advantages in financing costs provided by China through access to credit and equity below the cost of capital, which a recent study by the Organization for Economic Co-operation and Development (OECD) found to be very substantial.[10]

Exhibit 7 - TCO of US-Based Fabs Is 25%–50% Higher than in Other Locations



Source: BCG analysis.

[1] TCO includes capital expenditure (upfront land, construction, and equipment) plus ten years of operating expenses (labor, utilities, materials, taxes).

[2] A wider range of incentives, including equipment leaseback with advantageous terms, is available to multinational firms that choose to enter into technology-sharing arrangements in China.

10. See "Measuring Distortions in International Markets: The Semiconductor Value Chain," Organization for Economic Co-operation and Development (OECD), 2019.

Several factors explain this significant gap in TCO:

- **Government incentives, a major factor.** US incentives are on the lower end of the range, significantly below those available in Asian countries with an existing large semiconductor manufacturing footprint. (See Exhibit 8.) Depending on the type of fab and the country in question, these incentives make up 40% to 70% of the cost advantage other countries have over the US. In some cases, the incentives are prioritized for national semiconductor manufacturing champions and so serve to support the domestic semiconductor industry. But in many cases they are also available to multinational companies. The US can be competitive on taxation in some cases because of an effective tax rate that is significantly lower than the nominal corporate tax rate, as well as substantial reductions in state and local taxes in some locations. However, these state and local government incentives fall significantly short of the grants and direct cash incentives provided by other national governments.

Exhibit 8 - Comparison of Government Incentives Across Locations

	US[1] (%)	Japan (%)	S. Korea (%)	Taiwan (%)	Singapore (%)	Asia avg.[2] (%)	China[3] (%)	Germany (%)	Israel (%)
Capex reductions									
Land	50	75	100	50	100	85	100	100	75
Construction and facilities	10	10	45	45	25	33	65	35	45
Equipment	6	10	20	25	30	20	35	5	30
Opex reductions									
Labor and benefits	5	5	5	5	15	7	33	7	5
Tax reductions[2]									
Corporate tax	–	–	60	–	35	30	75	–	74
State tax	100	–	–	–	–	–	–	–	–
Property tax	100	100	100	–	–	60	–	–	–
Overall	**10–15**	**~15**	**25–30**	**25–30**	**25–30**	**~25**	**30–40**	**10–15**	**~30**

Source: BCG analysis.

Note: Incentives are on the first ten years of operation. All countries also include a 100% reduction on equipment-import costs and a 5% R&D write-off and deferral; not exhaustive.

[1] Based on a best-case scenario with current incentives and recent agreements.

[2] Excluding China.

[3] Mainland China.

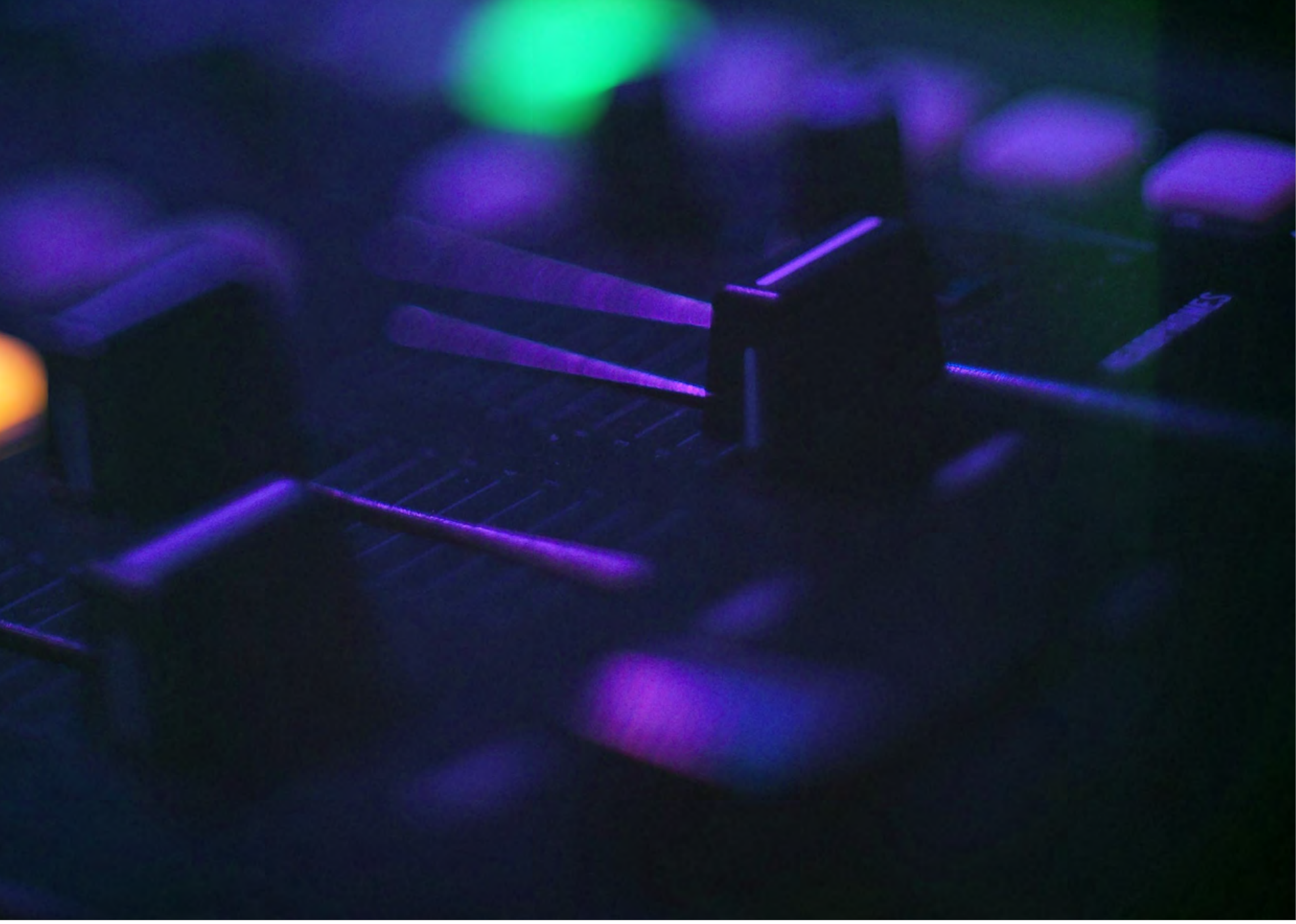
[4] The effective tax rate is considered separately from generally available incentives and is based on current statutes.

- **Natural disadvantages in factor costs.** Approximately 15% to 40% of the difference in TCO between the US and alternative locations is due to structural disadvantages in the cost of two factors: labor and utilities. Median wages in manufacturing are higher in the US than in other countries, and the US labor costs for fab construction and for operation are 40% above those in Singapore and Taiwan, and up to twice as high as in China. Differences in utility costs between the US and other countries are less significant but can still be nearly 25% higher in the US than in China.

- **Capital expenditures.** These account for 15% to 20% of the US disadvantage in TCO. About half of the capital expenditure in a new fab goes to manufacturing equipment provided by a small set of highly specialized global suppliers, and therefore is expected to be similar across regions. Construction cost, which accounts for 20% to 40% of the capital expenditures, varies more significantly.

In addition, some countries further promote their domestic semiconductor-industry ecosystems by building the supporting infrastructure around fab locations at no cost to the semiconductor producer. China bestows particularly comprehensive benefits in this regard, typically including housing, telecommunications, and the infrastructure for utilities and logistics.[11] Similarly, other Asian countries—such as Taiwan, Singapore, and South Korea—also provide infrastructure support, often by way of special economic zones and science parks. In Taiwan, for instance, in addition to providing access to land, electricity, and water, science parks also allot space for other supply-chain companies to integrate into a larger manufacturing ecosystem. Likewise, South Korea's government cooperates beyond utilities and infrastructure to identify and provide convenient locations, simplified or expedited procedures, and eased regulations.

11. See "China's Innovation Prowess Lies Not in One Valley but in Many Hubs," *South China Morning Post*, August 12, 2017, and "Measuring Distortions in International Markets: The Semiconductor Value Chain," OECD, 2019.

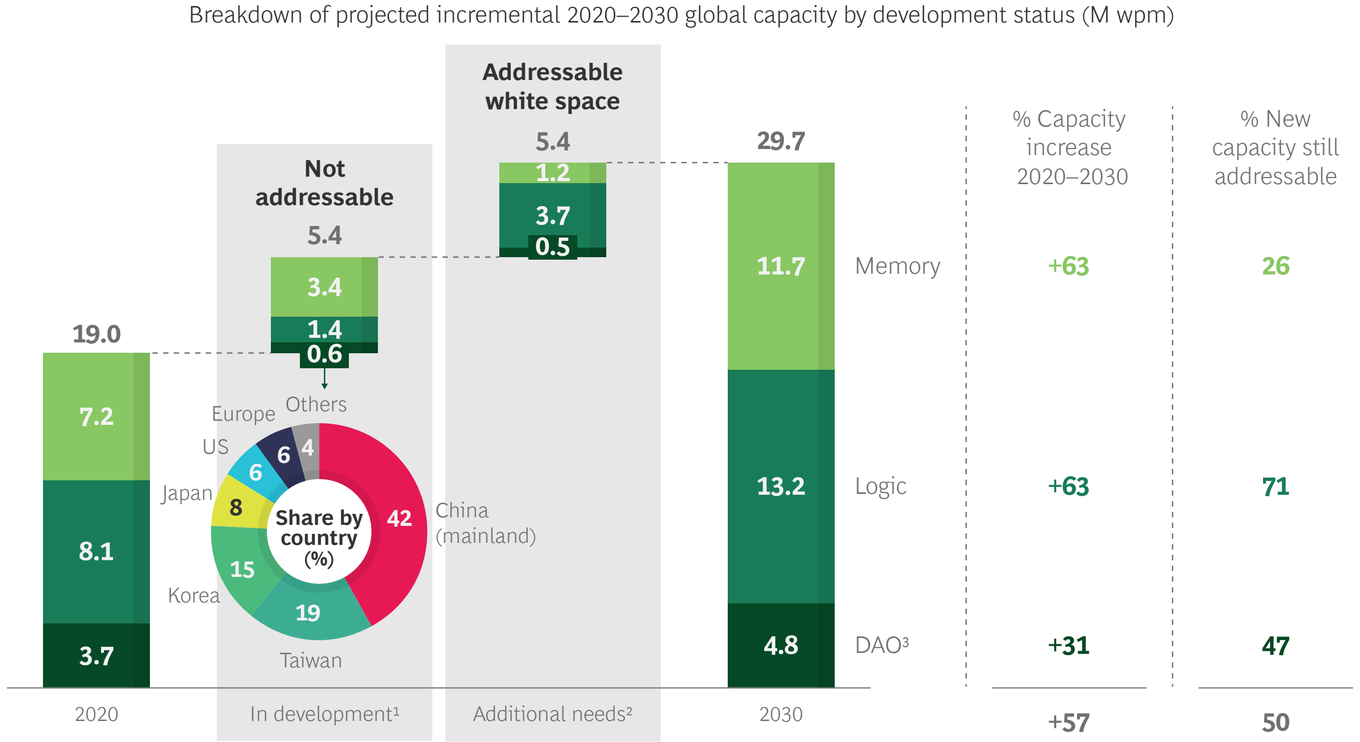


The Opportunity to Change the Trajectory in the Next Decade

Expanding the domestic manufacturing footprint is extremely important for the US semiconductor industry and, given the strategic nature of semiconductors as enablers of technology advancements, is essential to promote overall US economic competitiveness and national security.

Global demand for semiconductors is forecasted to grow at a cumulative average annual rate of 5% over the next decade, driven by large-scale adoption of new technologies, including AI, Internet of Things, edge computing, 5G, and electric and increasingly autonomous vehicles. Manufacturing capacity is expected to increase correspondingly by 56% from the current installed base, or approximately an addition of 10 million wpm by 2030. As of June 2020, about 50% of that new capacity to be added worldwide from 2020 to 2030 was not yet in development or planned. (See Exhibit 9.) This "white space," or addressable portion of the incremental capacity needs, presents an opportunity for the US to attract a higher share of the new future builds, above the 6% that it has achieved in the new capacity already in development or planning stages.

Exhibit 9 - Strong Expected Increase in Global Capacity Presents Growth Opportunity for US



Sources: BCG analysis based on market forecasts from SEMI, VLSI, and Gartner; input from SIA members; BCG project experience.

[1]"In development" includes any status between "groundbreaking" and "production" plus "planned or announced" (verbal or public confirmation of intentions to build).

[2] Estimated additional incremental capacity needed to meet projected 2030 demand, but without concrete announcement from any company or country.

[3] Discrete, analog, and optoelectronics.

Realizing this market opportunity requires making the US a more attractive location for semiconductor manufacturing by bringing the TCO of a fab in the US closer to that of alternative locations. Because the US presents clear strengths in other criteria that are important for fab location—such as synergy with the existing footprint and the rest of the ecosystem, access to a skilled talent pool, and protection of intellectual property—full cost parity may not be required to entice semiconductor companies to build a larger portion of their new capacity in the US. In addition, the evolving geopolitical context also makes broader geographic diversification of the manufacturing footprint more appealing to both US and foreign semiconductor companies.

Making the economics of new US-based fabs more compelling involves closing the gap in government incentives, which are directly responsible for 40% to 70% of the higher TCO in the US, according to our analysis. New government incentives may also help offset all or part of the observed structural US disadvantage in construction and operational costs.

To evaluate potential changes to the current trajectory of the US share of global manufacturing capacity, we have developed an analytical model that breaks down the forecasted total new global capacity by product type and country. We have then used our estimates of the economics of different fabs across countries to create a "merit order" based on TCO. Given the US strength in other key selection criteria for fab location, we assume that the TCO of a US-based fab would need to come down from its current level of 25% to 30% above Taiwan, Singapore, or South Korea to just 5% to 10% above—rather than full cost parity—to make the US an attractive location for a new fab.

For that to happen, a new US government incentive program will have to be put in place. We define this new incentive program as a fund (for example, a grant, a tax credit program, or both) with a fixed total amount, available for incremental new capacity built in the US from 2021 to 2030.[12] We assume that existing US state and local incentives remain in place and apply to any incremental new capacity built in the US (that is, they are set on a "per fab" basis and not capped at a given total amount).

How much of the still-addressable new global capacity the US may be able to attract depends on the size of the new US incentive program considered. We have modeled both the status quo and two possible scenarios for additional US incentives. Exhibit 10 shows the expected outcomes for each scenario.

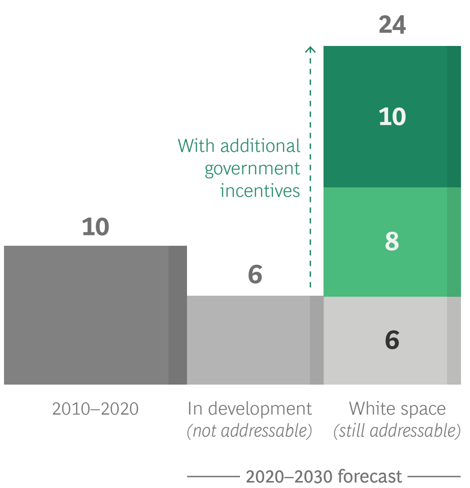
- **Status quo.** We assume that with no changes to the existing incentives, the observed 6% share of the US in the projects already in development is a good indicator of what portion of the additional addressable new capacity the US may be able to attract. This would be below the 10% share of the new global capacity that the US installed in the past decade. As a result, the US share of global manufacturing would further decline from 12% in 2020 to 10% in 2030.

- **Scenario 1—New $20 billion government incentive program.** Based on our modeling, we expect the US to attract a total of 14 new fabs, five more than in the status quo, capturing 14% of the new addressable capacity. The US would become the third-largest location for building new capacity, surpassed only by mainland China and Taiwan. As a result, the US would be able to sustain its current 12% share of the global installed capacity in 2030, averting the loss of two percentage points expected with the status quo.

- **Scenario 2—New $50 billion government incentive program.** According to our model, such a program could make the US the top destination for new semiconductor capacity aside from China. We estimate that the US would be able to attract a total of 19 fabs, ten more than in the status quo. This represents a 24% share of the addressable new capacity entering the market in the next decade—a major lift from the 10% of 2010 to 2020 and the 6% share with the status quo. It would result in an increase in the US share of the global installed capacity from 12% in 2020 to 13% to 14% in 2030—a major improvement over the 10% share predicted in the status quo.

Exhibit 10 - Potential Impact of New Incentive Program on US Manufacturing Position

US share of new additional global semiconductor manufacturing capacity (%)



	Share of white space captured by US (%)	US ranking by white space share	No. of new fabs to build in the US[2]	US share of 2030 capacity (%)
$50B program[1]	**24%** ↑	**2** ↑	**19** ↑	**~13–14%** ↑
$20B program[1]	**14%** ↑	**3** ↑	**14** ↑	**~12%** ≈
Status quo	**6%** ↓	**5** ≈	**9** ≈	**~10%** ↓

Trend vs. 2010–2020: ↓ ≈ ↑

Sources: VLSI Research; SEMI second-quarter 2020 update; BCG analysis.

[1] Assumed to apply to new incremental capacity built in the US in the next ten years.

[2] Normalized to an average fab size of about 75,000 wpm, in line with the average fab size used in the 2020–2030 forecasts, for comparison purposes. According to SEMI data, the actual number of fabs built in the US in 2010–2020 was 19 (excluding experimental and very small units), with an average size of around 40,000 wpm.

12. In our model, we assume that the new additional incentives would apply only to the incremental capacity on top of what would be built in the status quo scenario (that is, "capacity that otherwise would not have been built in the US"). In practice, this means that only certain types of fabs using advanced technology may qualify for the new incentives.

The new government incentives would turn the US into an attractive location for new fabs, with competitive economics. These potential incentives would mark a real inflection point and would reverse the sustained erosion in US share that has been a historical trend over the last 30 years. The US would be reestablished as a competitive location for semiconductor manufacturing, well positioned to continue increasing its participation in the global expansion of capacity over the decades beyond 2030.

Moreover, the expected expansion in US manufacturing capacity that a new government incentive program would enable could bring significant benefits for the competitiveness of US technology, supply-chain resiliency, and national security. The number of fabs built in the US over the next decade could jump from just nine in the status quo to 19 with a $50 billion incentive program. These new US-based fabs would bring state-of-the-art manufacturing technology and sufficient capacity to cover semiconductor demand from the US defense and aerospace industries. In addition, we estimate that these 19 new fabs could create about 70,000 direct jobs, significantly increasing the US talent pool of skilled semiconductor manufacturing technicians and strengthening US capabilities in advanced manufacturing-process technology.

Finally, these government incentives, and the construction of this new capacity in the US, would not introduce distortions into the global semiconductor market. Such incentives are nondiscriminatory and are available for new incremental projects put forward by companies. A program of this nature does not aim to pick winners or direct market outcomes through government ownership of capacity or manufacturing companies. Furthermore, the commercial viability of the potential new fabs is also supported by the fact that the US also already has in place all the key enablers: semiconductor manufacturing know-how, talent, supporting infrastructure, a thriving semiconductor ecosystem across the value chain, and global market access. This minimizes the risk of creating global overcapacity, something clearly not in the interest of the US semiconductor industry.

Turning the Tide for US Semiconductor Manufacturing

The strategic nature of the semiconductor industry for technology leadership and national security raises questions about the steady decline in the share of the global semiconductor manufacturing capacity located in the US over the last 30 years. The ongoing geopolitical frictions between the US and China are intensifying this concern. Already, 75% of the world's semiconductor manufacturing capacity is concentrated in East Asia, and China is investing aggressively to emerge as the largest global manufacturing powerhouse in 2030.

Given the strong increase expected in global capacity to meet the growth in semiconductor demand from 2020 to 2030, the next ten years present a market opportunity for the US to stop the decline and even possibly expand its manufacturing share. The US already has comparative strengths in some key criteria used to select fab locations, such as synergies with its existing footprint and ecosystem, skilled talent, and protection of intellectual property, but it is not competitive in cost. Although the purpose of this report is not to offer policy recommendations, our analysis suggests that expanding the limited state-level government incentives currently in place with a new targeted $20 billion to $50 billion federal program over ten years could bring US incentives in line with those offered by Taiwan, South Korea, or Singapore and reestablish the US as an attractive location for advanced semiconductor manufacturing.

The window to reverse the historical trend and grow the US semiconductor manufacturing footprint is rapidly closing, though. First, 50% of the new capacity required to serve the global demand in the next ten years is already in development and therefore likely no longer addressable. In addition, the current manufacturing powerhouses—particularly Taiwan and South Korea, but increasingly also China and rising lower-scale locations such as Singapore and Israel—benefit from important cluster effects that naturally favor construction of new capacity in the existing manufacturing sites, creating a virtuous circle that makes it increasingly harder for countries like the US with smaller, shrinking footprints to even maintain their global share.

It is important to note that although leveling the playing field in government incentives for US-based fabs is necessary in order to expand the US share in manufacturing, there are also other important structural enablers for a thriving semiconductor manufacturing sector where government support may be beneficial. Fundamental research in materials and manufacturing sciences is essential for the foundations of innovation, and government support has historically proved effective in this area. Similarly, another significant way government can encourage domestic manufacturing may be by supporting training to ensure the US can have a robust talent pool of production engineers, operators capable of working with highly sophisticated computer-controlled equipment, and skilled technicians.

Finally, although the US position in manufacturing is attracting strong interest from policymakers, the strength of the US semiconductor industry also requires a continued commitment to maintaining US R&D leadership and ensuring access to global markets.[13] A strong US semiconductor industry, well integrated into the global technology supply chain, is vital to develop the advances that will make the new era of digital transformation and AI possible. As with the mobile revolution in the past decade, the massive benefits of such breakthroughs will reach consumers and enterprises in all countries, not just in the US.

13. See the Semiconductor Industry Association report *Sparking Innovation*, June 2020.

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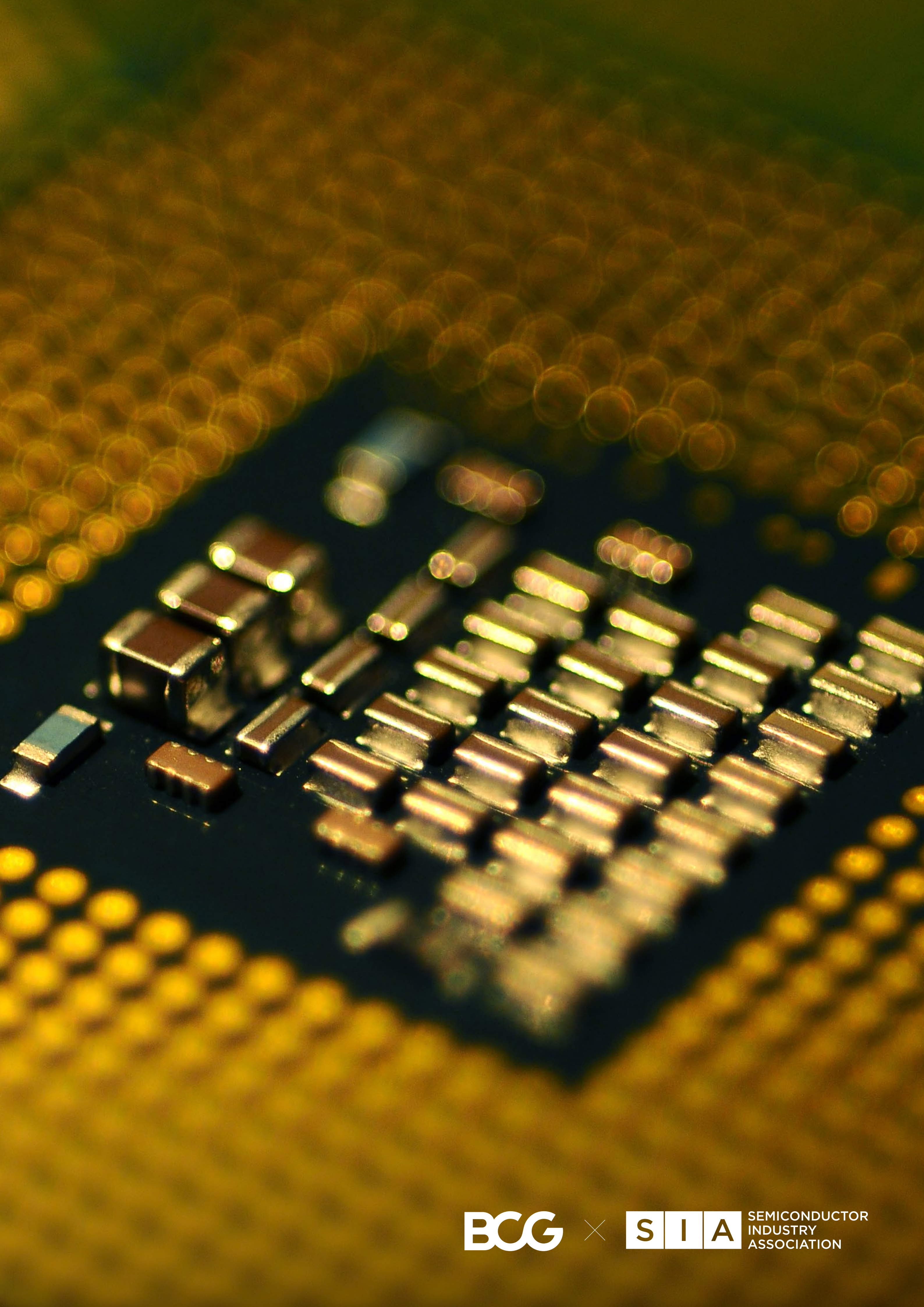
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