ASSESSMENT OF THE STATUS OF THE MICROELECTRONICS INDUSTRIAL BASE IN THE UNITED STATES

A STUDY CONDUCTED UNDER SECTION 705 OF THE DEFENSE PRODUCTION ACT OF 1950, AS AMENDED

U.S. Department of Commerce
Bureau of Industry and Security
Office of Technology Evaluation

December 2023

1. Executive Summary

This report provides an initial overview of capabilities and challenges of the U.S. microelectronics industry, carried out pursuant to section 9904 of the William M. (Mac) Thornberry National Defense Authorization Act for Fiscal Year 2021. This initial report is based on a survey of organizations that design, manufacture, or distribute microelectronics in the United States, and aims to summarize key industry attributes and experiences and provide broad guidance on what is needed to support a robust domestic semiconductor manufacturing ecosystem.

Key findings of the report include:

- **General Production Capabilities:** The United States is an essential leader in the global microelectronics sector, with companies headquartered in the United States accounting for approximately half of worldwide semiconductor revenue. The semiconductor industry is highly globalized with significant regional concentrations. U.S.-based companies maintain approximately half of their facilities internationally, and several large non-U.S. companies have significant U.S. presences. Estimated share of global activity carried out inside the United States for each stage of the semiconductor industry is:
  - Research and Development: 47 percent
  - Design: 27 percent
  - Front-End Fabrication: 12 percent
  - Assembly, Test, and Packaging: <2 percent, with an additional estimate that 85 percent of chips sold by U.S.-based companies are packaged in Taiwan, China, South Korea, or Malaysia
- **Key Inputs:** Survey respondents expressed significant concern about domestic sources of three categories of materials: bare wafers, gases, and wet chemicals. Within gases, the survey found that helium, nitrogen, hydrogen chloride, neon, nitrogen trifluoride, and hydrogen presented the most frequent acquisition concerns. Concerns for wet chemicals were more dispersed. Survey respondents identified 78 unique chemicals of concern, led by sulfuric acid and isopropyl alcohol. For both chemicals ultra-high purity forms are heavily imported. With minimal Assembly, Test, and Packaging in the United States, there are limited domestic sources for assembly and packaging materials.
- **Workforce:** The semiconductor industry directly employs over 200,000 people in the United States. CHIPS Act investments and industry growth led respondents to expect to add 70,000 additional jobs by 2032. Semiconductor jobs are well paid, with average salaries over 30 percent higher than national averages for related job categories. Respondents identified workforce-related items as both their top business challenges and the most important factors in deciding where to locate a facility.
- **Sales and Growth:** U.S. semiconductor companies are more reliant on sales to China than any other location, including the United States, with an estimated 30-40 percent of sales shipped to China and approximately 25 percent to the United States.[1] Respondents

[1] Sales from U.S. semiconductor companies to the United States are still generally “shipped to” the United States given the extensive level of manufacturing, assembly, and packaging carried out outside the United States.

expected the fastest growth through 2032—exceeding 10 percent per year—in the Aerospace, Defense, and Automotive sectors, which currently combined to represent less than 15 percent of the overall semiconductor market. The Mobile Device and Personal Computer sectors, representing nearly half of all semiconductor revenue, were expected to grow more slowly than the overall industry, though respondents still anticipated growth of more than five percent per year.

- **Capital Expenditures:** U.S.-based companies are narrowing the gap between their capital expenditures made outside the United States and those made domestically, reversing a trend of declining semiconductor capital investments in the United States. Most capital expenditures are attributable to several large companies with major leading-edge investments; six companies, led by TSMC and Intel, account for over 60 percent of the global value of semiconductor property, plant, and equipment. Respondents have existing plans for over $200 billion in expenditures on capital projects in the United States between 2023 and 2032, with respondents expecting that an average of 19 percent of funding would be provided by federal, state, and local governments. Total expenditures will likely significantly exceed this level as CHIPS Act investments become available.
- **Business Challenges:** The United States is seen as quite strong in three of respondents' five most important factors driving investment—Ability to Protect Intellectual Property, Research and Development (R&D) Quality, and Labor Quality—and comparatively weak in the top two factors: Labor Cost and Labor Availability. The three most frequently identified business challenges were Worker/Skills retention, Labor Availability/Costs and Foreign Competition. Respondents were optimistic about the implementation of the CHIPS Act and saw it as crucial to allowing companies to fairly compete.
- **Perspectives on U.S. Government Support:** The cost of manufacturing in the United States is significantly higher than abroad, where manufacturers benefit from subsidies and lower operating costs. Respondents saw incentives as essential to leveling the playing field for doing business in the United States. Longer-term incentives that support continued fab construction can reduce the overall costs of incentives and the cost of production by maintaining the required worker expertise and supply chains. Companies generally saw education and workforce development as a necessary long-term pillar of support for the U.S. microelectronics industry but also have an immediate need for experienced workers. Drawing in talented workers from around the world further concentrates the skilled workforce in the United States and enhances the competitiveness of U.S. businesses.

The report also contains four categories of recommendations, intended to overlap with and supplement the recommendations provided by the Department in the Semiconductors 100-Day Report carried out in response to Executive Order 14017 (America's Supply Chains), many of which have already seen significant progress. These recommendations are:

1. **Level the Playing Field for Semiconductor Manufacturing in the United States**

Companies in the United States for decades have faced higher costs than competitors around the globe. BIS survey respondents identified foreign competition as their third greatest organizational challenge, behind only labor availability/costs and worker/skills retention, with the highest share of respondents listing foreign competition as their single greatest organizational challenge. Low-cost production and foreign subsidies were most frequently mentioned in comments on foreign competition.

There is intense global competition to attract semiconductor fabrication facilities, which serve as a foundation for the entire microelectronics ecosystem, attracting both upstream and downstream investments. Survey responses and existing research indicate that between lower operating and construction costs, direct government funding, tax incentives, and additional funding initiatives in other countries, the cost of manufacturing semiconductors in the United States may be some 30 to 45 percent higher than the rest of the world.

For the United States to manufacture its fair share of semiconductors domestically, companies operating in the United States must be able to compete on a level playing field. Recommendations for allowing semiconductor fabrication to thrive in the United States include:

A. Long-Term Support for Domestic Fabrication Capabilities

The process of constructing fabrication facilities is a valuable resource in its own right. The consistent construction of fabs in the United States will not only serve to decrease the risks of limited domestic production but also will lead to knowledge gains, process improvements, and lower construction and operating cost differentials.

The U.S. government should enact permanent provisions that incentivize steady construction and modernization of semiconductor fabrication facilities, such as the investment tax credit scheduled to end in 2027.

The importance of products relying on mature processes must also be recognized. While these products produce less revenue than leading-edge processes, they are essential for national security uses and significant R&D continues to be performed on products using mature processes. Many of these chips are produced using older, and in some cases obsolete, equipment on smaller wafer sizes. Additionally, forecast PRC overcapacity threatens to make these products financially nonviable in the United States and allied economies. *Incentives to support domestic production should include mature technologies and consider ways to support upgrades to ensure long term commercial viability.*

In addition, survey respondents indicated the variety of overlapping incentives and requirements at the federal, state, and local level presented challenges, especially for smaller companies. *The U.S. government should develop a program to help organize and streamline interactions across the federal government, with local authorities, and* *with economic development organizations and to promote best practices in support of semiconductor facility investments.*

B. Long-Term Support for Domestic Assembly, Test, and Package (AT&P) Capabilities

The production of semiconductors requires assembly and packaging as well as front-end fabrication, and the United States currently has minimal assembly and packaging capabilities. The assembly and packaging capabilities of U.S.-based companies—both in-house and outsourced—are highly dependent on operations in Taiwan, China, South Korea, and Malaysia, with nearly half of all chips provided by U.S.-based companies packaged in Taiwan or China.

The U.S. government should provide sufficient incentives to allow for competitive domestic assembly and packaging capabilities. This should include incentives focused on increased automation. The labor-intensive AT&P segment is heavily concentrated in low-wage areas of the world, but automation can bridge the cost gap of providing AT&P in the United States as well as increase well-paying jobs in equipment manufacturing and servicing.

C. Continue to Protect U.S. Technology

Companies and researchers in the United States lead the world in semiconductor R&D, design, and development of semiconductor manufacturing equipment. Survey respondents indicated that the protection of their intellectual property was a leading factor in deciding where to make investments and that the United States led the world in the ability to protect intellectual property.

The U.S. government should continue to focus on these strengths by aggressively protecting intellectual property and through the targeted use of export controls to ensure that technology developed in the United States is not used in ways that harm U.S. economic or national security. This includes increasing resources for law enforcement and U.S. Government agencies to prevent and prosecute semiconductor intellectual property theft and industrial espionage.

D. Combat Unfair Trade Practices

China has a track record of subsidizing overcapacity in strategic sectors like solar, steel, and batteries that has decimated foreign competitors. The PRC government has provided its domestic semiconductor industry with an estimated $150 billion in subsidies in the last decade, which is likely to drive below market pricing for legacy semiconductors and create an unlevel global playing field for US and other foreign competitors.

The U.S. government should defend domestic semiconductor investments from PRC nonmarket behavior. Respondents most commonly referenced low-cost Chinese production when noting their concerns about the challenge from foreign competition and suggested the U.S. government take action to combat unfair trade practices, including imposition of tariffs or expansion of export controls.

2. Ensure U.S. Leadership in Advanced Research and Development

In addition to protecting technology developed in the United States, the U.S. government should ensure that the United States remains the world's leading place to carry out advanced semiconductor research and development. Governments around the world are targeting U.S. leadership, with the share of semiconductor R&D and design funded by public investment estimated to be 2.3 times higher in the rest of the world than in the United States, including 3.5 times higher in China.

Continued U.S. leadership in semiconductor R&D relies on education and workforce leadership and protection of technology but also requires methods to incubate, protect, and commercialize innovative technologies and support for companies developing sensitive technologies. Recommendations to support continued U.S. leadership in advanced R&D include:

A. Support for "Lab-to-Fab" Transition

Survey respondents highlighted the importance of pre-competitive R&D,[2] broader access to fabrication facilities for research and prototyping, and challenges facing smaller organizations in commercializing research.

The successful implementation of the National Semiconductor Technology Center (NSTC) is a keystone for continued U.S. competitiveness and leadership in semiconductor R&D. As already outlined in the Department's "A Vision and Strategy for the National Semiconductor Technology Center," the NSTC's three high-level goals are (1) Extend America's leadership in semiconductor technology; (2) Reduce the time and cost of moving from design idea to commercialization; and (3) Build and sustain a semiconductor workforce development ecosystem.

Another key feature of the CHIPS Act[3] is the Department of Defense-led Microelectronics Commons program, which has already begun awarding money to regional hubs to drive "lab-to-fab" innovation and accelerate development and commercialization of new semiconductor technologies.

This report's recommendation is not a new feature but rather serves to highlight the importance of the NSTC and the Microelectronics Commons and the broad industry support for their goals.

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[2] Pre-competitive R&D involves research that provides for general and shared technological advancements for the industry

[3] Title XCIX – Creating Helpful Incentives to Produce Semiconductors for America (commonly referred to as the CHIPS Act) of the 2021 National Defense Authorization Act

B. Increased R&D Incentives

Government funding as a share of semiconductor R&D is significantly higher outside of the United States. In addition to working with partners and allies to minimize the impact of non-market actors*, the U.S. government should consider implementing R&D incentives designed to counterbalance the effects of actions required to protect sensitive technologies*. Additionally, export controls, by limiting the size of the addressable market, may reduce revenue opportunities of companies that produce controlled products, in turn reducing funds available for corporate R&D. A supplemental tax credit focused on R&D in areas affected by export controls or related to sensitive technology can help minimize the negative longer-term effects of protecting these technologies.

3. Support the Availability of High-Quality Manufacturing Materials and Inputs

Manufacturing semiconductors requires hundreds of different materials with stringent quality requirements. Maintaining a healthy domestic semiconductor manufacturing base requires a robust material supply chain that is resilient to regional or company-specific shocks. Manufacturing materials are prone to disruption, with concentrated supply and highly volatile prices. The United States is reliant—and increasingly so—on imports of critical materials; the Department of Defense's 2021 100-Day Review of Critical Minerals and Materials (Critical Materials 100-Day Report) noted that China "dominates the processing of strategic and critical materials, giving it de facto control over the flow of material."

The new construction and expansion of semiconductor manufacturing clusters in the United States is already driving expansion of domestic material and input capabilities. Continued investments in U.S. semiconductor manufacturing will help ensure these domestic capabilities are healthy and competitive. Nonetheless, the underlying risks of supply chain concentration and vulnerability remain present. Recommendations to support the availability of high-quality semiconductor manufacturing materials and inputs include:

A. Reform and Strengthen U.S. Stockpiles

As identified in the Critical Materials 100-Day Report, "U.S. stockpile authorities and funding have not kept up with needs." That report provides extensive recommendations on strengthening U.S. supply of critical materials, including methods for strengthening U.S. stockpiles. In addition to the recommendations made in that report, *the U.S. government should explore the value of legislation authorizing the stockpile to function as an economic stockpile* above critical inventory levels to help insulate the economy from large price spikes and supply shocks.

B. Work with Allies and Partners to Decrease Vulnerabilities in Global Supply Chains

Also identified in the Critical Materials 100-Day Report, *the U.S. government should continue and increase coordination with allies and partners to strengthen material supply chain diversity and resilience*. This is of particular importance to the semiconductor industry, which has regional reliance both for raw materials and processed materials, as well as supplier concentration in several key materials. In addition, *the U.S. Government should expand work with allies and partners to establish industry-wide security standards and vendor evaluation processes to address cybersecurity supply chain vulnerabilities.*

C. Explore Incentives for Supply Chain Diversity

Given the concentration of key materials and inputs both geographically and within key companies, both individual companies and the U.S. government should take actions to increase the diversity of supply.

The U.S. government should consider expanding the advanced manufacturing tax credit included in the CHIPS Act to apply to specialized materials needed for the production of semiconductors, as well as for the printed circuit boards that chips connect to.

Additionally, *the U.S. government should explore ways to incentivize companies to diversify their supply chains*, including through tax incentives for geographically diverse sourcing, development and distribution of supply chain best practices and standards, and studies quantifying the cost of concentrated supply chains.

4. Build a Diverse and Accessible Talent Pipeline for Jobs in the Semiconductor Industry

This category is identical to that of the Semiconductors 100-Day Report to highlight that workforce development is vital, the challenges are ongoing, and the solutions require long-term actions. That report highlighted the need for both immediate increases in the ability of companies in the United States to attract and retain talented workers from around the world and for longer term investments in domestic education. Survey responses have made it clear that workforce challenges are at the forefront of semiconductor industry health and competitiveness, requiring an "all of the above" solution.

Recommendations to ensure that U.S. companies have access to the workforce required to thrive include:

A. Increase the Ability of Companies in the U.S. to Hire and Retain Highly Skilled Non-U.S. Citizens

The strength of the U.S. semiconductor industry relies on the strength its workforce. Survey respondents consistently indicated that their ability to find, hire, and retain highly skilled workers was both of key importance in making business decisions and a major challenge to their operations. Limiting the pool of workers available to companies in the United States provides an advantage to foreign competitors. For the U.S. semiconductor industry to continue to lead the world, it needs to be able to hire and retain the greatest talent from around the world.

As identified in the Semiconductors 100-Day Report, *the U.S. government should increase the number of visas available, eliminate country-specific employment-based visas, and exempt highly skilled workers from employment-based visa caps.*

B. Enhance Pathways for Workers in America to Become American Workers

In addition to expanding the ability of U.S. companies to attract talented workers from around the world, the U.S. semiconductor industry will benefit from ensuring these workers are able to stay in the country and continue to drive U.S. innovation and competitiveness. *The U.S. government should expand and enhance the ways in which workers who are not currently citizens or permanent residents can stay in the United States in perpetuity*. By providing broader avenues to permanent residency and citizenship, the United States can ensure it not only can attract the world's most talented workforce, but that it can retain it and allow it to participate in and drive the American dream.

C. Increase Support for U.S.-based Microelectronics Education

Beyond the immediate increase in the availability and talent of the semiconductor workforce enabled by visa and immigration reform, the United States needs to expand the size and skill of the domestic workforce through investments in U.S. education. Survey respondents noted that interest in and ability to support the U.S. microelectronics industry starts in elementary school.

The U.S. government should invest in hands-on STEM training in elementary, middle, and high school. At higher levels, the U.S. government can help contribute to smooth transitions from school to the workforce by collaborating with educational institutions and industry on curriculum building and standardized credentialing, and by increasing scholarships and grants for higher education in electrical engineering and other crucial microelectronics paths.

D. Build More Fabs

The presence of semiconductor fabrication facilities of all sizes serves a key role that not only enables the production of microelectronics, but also provides the foundation that allows the entire microelectronics ecosystem to flourish. In addition to driving investments in the supply chain and knowledge gains through construction and operation of facilities, fabs are crucial for microelectronics education. Survey respondents noted the value of hands-on experience in education and training as well as in sparking initial interest in microelectronics. *The U.S. government should continue to provide the U.S. semiconductor industry with the appropriate incentives and support to ensure that companies and research institutions build and modernize fabs of all types and sizes* to support the future of the U.S. microelectronics industry.

2. Introduction

2.1 Study Origins

Why Microelectronics?

Microelectronics[4] are essential to the global economy, used in every major industry in the world and needed for the production or use of virtually every product in the world. Microelectronics have been called the "DNA" of technology and equated in geopolitical importance to oil.

The importance of microelectronics to everyday life and to U.S. economic and national security was underscored by the global semiconductor shortage of 2020-2021 that had impacts in the hundreds of billions of dollars, and has been a focus of intense reporting, including the Department's June 2021 100-Day Report on Semiconductor Manufacturing and Advanced Packaging[5] (Semiconductors 100-Day Report) issued in response to Executive Order 14017 ("America's Supply Chains"),[6] and September 2021 Request for Information (RFI) and resulting analysis on Risks in the Semiconductor Supply Chain.[7]

The importance of microelectronics to U.S. economic and national security was further highlighted by the inclusion of Title XCIX – Creating Helpful Incentives to Produce Semiconductors for America (commonly referred to as the CHIPS Act) in the 2021 National Defense Authorization Act and the subsequent passage of the 2022 CHIPS and Science Act, which allocated $52 billion to support the domestic production of semiconductors.

The criticality of microelectronics to U.S. economic and national security and the implementation of the CHIPS Act provisions make it essential that the U.S. government have a firm understanding of the capabilities of the existing U.S. semiconductor ecosystem, the risks facing it, and the challenges experienced by the companies that drive it. This initial report on suppliers of microelectronics aims to summarize the key industry attributes and experiences and provide broad guidance on what is needed to support a robust domestic semiconductor manufacturing ecosystem.

Report Requirement

Section 9904 of the William M. (Mac) Thornberry National Defense Authorization Act for Fiscal Year 2021 (FY 2021 NDAA, Public Law 116-283) directs the Secretary of Commerce to assess the capabilities of the United States microelectronics industrial base to support national defense. This provision, contained in the United States Code at 15 U.S.C. §4654, required that the assessment include a survey using authorities in section 705 of the Defense Production Act (DPA) of 1950 (50 U.S.C. §4555). Section 9904 further identified 12 topics for the survey to

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[4] The definition of microelectronics is nebulous but broadly includes electronic devices manufactured using semiconducting materials. This report uses generally uses the terms microelectronics, semiconductor devices, semiconductors, and chips interchangeably to cover integrated circuits as well as non-integrated active semiconductor devices including discrete microelectronic components, optoelectronics, and semiconductor-based sensors.

[5] https://www.whitehouse.gov/wp-content/uploads/2021/06/100-day-supply-chain-review-report.pdf

[6] https://www.federalregister.gov/documents/2021/03/01/2021-04280/americas-supply-chains

[7] https://www.federalregister.gov/documents/2021/09/24/2021-20348/notice-of-request-for-public-comments-on-risks-in-the-semiconductor-supply-chain

cover. These 12 topics broadly cover the location, capabilities, costs, supply chains, and financial performance of companies in the U.S. microelectronics industrial base, as well as information on joint ventures, subsidies, and interactions with the government of the People's Republic of China.

This initial report addresses the Section 9904 requirement to provide—as regards organizations that design, manufacture, or distribute semiconductor products in the United States—a report that includes an assessment of the results of the review and an assessment of gaps and vulnerabilities in the microelectronics supply chain and the national industrial supply base. Given the complexities of the microelectronics ecosystem, a subsequent survey and report will address key features of the microelectronics supply chain that support domestic manufacturing of semiconductors, including semiconductor manufacturing equipment. BIS will also use this report, the subsequent survey and report, and continued analysis to address the list of critical technology areas and impacts on these areas of potential disruptions in production of microelectronics.

Assessment Background

Soon after publication of the FY 2021 NDAA, BIS issued on March 15, 2021, a Request for Public Comment (March 2021 RFI) on Risks in the Semiconductor Manufacturing and Advanced Packaging Supply Chain.[8] The March 2021 RFI sought comments and information from the public to support both the Section 9904 report and Semiconductors 100-Day Report, carried out pursuant to Executive Order 14017, "America's Supply Chains."[9] The March 2021 RFI and subsequent report, contained within Building Resilient Supply Chains, Revitalizing American Manufacturing, and Fostering Broad-Based Economic Growth,[10] were instrumental in providing background for the Section 9904 survey development.

The Semiconductors 100-Day Report identified eight broad risks covering key threats to semiconductor supply chains and provided seven policy recommendations to address identified shortages and risks. The risks were: (1) fragile supply chains; (2) malicious supply chain disruptions; (3) use of obsolete and generations-old semiconductors and related challenges for continued profitability of companies in the supply chain; (4) customer concentration and geopolitical factors; (5) electronics production network effects; (6) human capital gaps; (7) IP theft; and (8) challenges in capturing the benefits of innovation and aligning private and public interests.

Policy recommendations included:

1) Promote Investment, Transparency, and Collaboration, in Partnership with Industry, to Address the Semiconductor Shortage

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[8] 86 FR 14308 (https://www.federalregister.gov/documents/2021/03/15/2021-05353/risks-in-the-semiconductor-manufacturing-and-advanced-packaging-supply-chain)
[9] EO 14017 (https://www.federalregister.gov/documents/2021/03/01/2021-04280/americas-supply-chains)
[10] https://www.whitehouse.gov/wp-content/uploads/2021/06/100-day-supply-chain-review-report.pdf

2) Fund the Creating Helpful Incentives for Production of Semiconductors (CHIPS) for America provisions in the Fiscal Year (FY) 2021 National Defense Authorization Act (NDAA)
3) Strengthen the Domestic Semiconductor Manufacturing Ecosystem
4) Support Manufacturers, Particularly Small and Medium-Size Businesses
5) Build a Diverse and Accessible Talent Pipeline for Jobs in the Semiconductor Industry
6) Engage with Allies and Partners on Semiconductor Supply Chain Resilience
7) Protect U.S. Technological Advantages in Semiconductor Manufacturing and Advanced Packaging

The Department, the broader U.S. government, and the microelectronics industry have made significant progress in implementing these recommendations, though continued focus on the extensive work already underway is essential to sustaining a robust, healthy, and competitive U.S. microelectronics industry.

BIS subsequently issued on September 24, 2021, an additional Request for Public Comment (September 2021 RFI) on Risks in the Semiconductor Supply Chain.[11] The goal of the September 2021 RFI was to build on the knowledge gathered and shared via the March 2021 RFI and Semiconductors 100-Day Report to identify data gaps and bottlenecks in the semiconductor supply chain, supporting transparency and collaboration across the industry.

The Secretary released results of the September 2021 RFI on January 25, 2022, listing key findings and next steps.[12] The September 2021 RFI showed a persistent mismatch in supply and demand for chips, with particular strain for several types of semiconductors—primarily legacy microcontroller, analog, and optoelectronic products—critical for use in medical devices, broadband, defense systems, and autos. The Secretary's comments highlighted the need for increased supply chain transparency and for funding of the semiconductor supply chain incentives identified in Section 9902 of the FY 2021 NDAA.[13]

BIS developed the Section 9904 survey based on industry and survey expertise, information from the March 2021 and September 2021 RFIs, and extensive discussion and testing across federal agencies as well as with members of industry and major industry trade groups. Feedback and suggestions from the Departments of Defense, Energy, and Homeland Security, as well as multiple groups within the Department of Commerce, were critical in developing the survey, as were information, coordination, and comments provided by the Semiconductor Industry Association (SIA), SEMI, and the International Microelectronics Assembly & Packaging Society (IMAPS).

[11] 86 FR 53031 (https://www.federalregister.gov/documents/2021/09/24/2021-20348/notice-of-request-for-public-comments-on-risks-in-the-semiconductor-supply-chain)
[12] https://www.commerce.gov/news/blog/2022/01/results-semiconductor-supply-chain-request-information
[13] These incentives were subsequently funded via the CHIPS and Science Act, on August 9, 2022 (Public Law 117–167; 15 U.S.C. §4652)

The survey was distributed to approximately 200 organizations that design, manufacture, or distribute semiconductor products in the United States on October 21, 2022. BIS completed the data collection in May 2023.

2.2 Process and Survey Discussion

Study Scope

This report is focused on suppliers of semiconductor devices. BIS has aligned product definitions and coverage with existing industry standards,[14] identifying seven categories of semiconductor devices:

- Analog Integrated Circuits
- Micro (Microprocessor (MPU) and Microcontroller (MCU)) Integrated Circuits
- Logic Integrated Circuits
- Memory Integrated Circuits
- Discretes
- Optoelectronics
- Sensors and Actuators

Suppliers of semiconductor devices, for the purpose of this assessment, include organizations that design, manufacture, or distribute semiconductor devices. Accordingly, organizations that design or manufacture semiconductor devices but do not directly sell these products are still considered suppliers.

Throughout this assessment, organizations have been categorized based on their primary microelectronics segment of the above seven categories, as well as their primary process role:

- Fabless – organizations that outsource all or nearly all of their manufacturing processes;
- Integrated Device Manufacturer (IDM) – organizations that carry out most of their own design and manufacturing;
- Foundry – organizations that manufacture exclusively or nearly exclusively for other companies;
- Assembly, Test, and Package (AT&P) or Outsourced Semiconductor Assembly and Test (OSAT) - organizations that assemble, test, and/or package semiconductor devices for other companies;
- Distributor – organizations that do not design or manufacture semiconductors, but sell devices designed and manufactured by other organizations.

Additionally, this report will use the term “semiconductor provider” to refer to organizations that (a) design (fabless) or (b) design and manufacture semiconductors (IDM). This term is intended to cover the original sales of semiconductor devices, but exclude foundries, OSATs, and distributors. This clarification is necessary in some cases to prevent double-counting values based on the extensive use of outsourced manufacturing services in the semiconductor industry; the revenue of semiconductor providers implicitly includes the costs incurred at foundries and

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[14] Categories and definitions are from World Semiconductor Trade Statistics (WSTS), https://www.semiconductors.org/wp-content/uploads/2021/02/Product_Classification_2021.pdf

OSATs. The aggregate revenue of semiconductor providers thus represents the value of all semiconductors sold.

Survey Topics

As required by 15 U.S.C. §4654, BIS issued a survey to organizations that design, manufacture, or distribute semiconductor products in the United States. The survey was issued on a mandatory basis, using authorities from Section 705 of the DPA and Section 702 of Title 15, Code of Federal Regulations. This survey was designed to cover the 12 topics identified by Congress in the FY 2021 NDAA, as well as other areas necessary to assess the capabilities of the U.S. microelectronics industrial base.

The broad categories of information collected via the survey were:

- **Organization and Facility Information**, including ownership structure, identification of participation in key portions of the microelectronics supply chain, location of facilities, primary operations and capacity
- **Product Capabilities and Outsourcing**, including participation by semiconductor device segment, general device attributes, location of design and production activities, and end uses
- **Input and Manufacturing Equipment Requirements**, including use of U.S.-based suppliers, inventory level, difficulty of acquiring key inputs, and identification of leading suppliers
- **Current and Expected End Uses**
- **Supply Chain Risk Management Practices**
- **U.S. Employment and Workforce Development**
- **Financial Information**, including priorities for R&D and Capital Expenditure and expected impacts of incentives and tax changes
- **Joint Ventures, Partnerships, and Technology Transfer**
- **Competitive Factors and Challenges**, including cost estimates by process stage, assessments of U.S. competitiveness, and past and expected business challenges
- **Long Term Development and Investment**, including burdensome regulations, methods to support U.S. microelectronics, and emerging technologies

Industry Overview

BIS has supplemented survey data with additional publicly available data, compiling information on 500 of the world's largest semiconductor companies. Nearly all major semiconductor companies are publicly traded, providing quarterly and annual reports on their business. These publicly traded companies account for an estimated 95 percent of worldwide semiconductor device revenue, including all of the 30 largest companies.

Based on publicly reported sales and estimates of the revenues of major non-public companies, BIS finds that the global semiconductor market is somewhat larger than most publicly cited estimates, with global semiconductor product revenue of at least $660 billion in 2022, with an additional $190 billion of revenue accounted for by providers of outsourced manufacturing (foundries) and OSAT services. [15]

The below chart lists and categorizes the world's 30 largest semiconductor companies, which account for approximately 75 percent of global semiconductor and semiconductor manufacturing service revenue.

World's Largest Semiconductor Companies				
Company	**Primary Segment**	**Process Role**	**Country of Headquarters**	**2022 Revenue (Billions of USD)**
Samsung*	Memory	IDM	South Korea	$76.2
Taiwan Semiconductor Manufacturing Corp (TSMC)	Foundry	Foundry	Taiwan	$75.9
Intel	Micro	IDM	U.S.	$63.1
Qualcomm	Logic	Fabless	U.S.	$43.0
Apple**	Logic	Fabless	U.S.	$40.0
SK Hynix	Memory	IDM	South Korea	$34.0
Broadcom	Logic	Fabless	U.S.	$33.2
Nvidia	Logic	Fabless	U.S.	$29.6
Micron Technology, Inc.	Memory	IDM	U.S.	$27.2
Advanced Micro Devices, Inc.	Micro	Fabless	U.S.	$23.6
Advanced Semiconductor Engineering (ASE)	AT&P	AT&P	Taiwan	$22.2
Texas Instruments	Analog	IDM	U.S.	$19.6
MediaTek	Logic	Fabless	Taiwan	$18.4
Western Digital	Memory	IDM	U.S.	$16.4
STMicroelectronics	Analog	IDM	Switzerland	$16.1
Infineon	Discretes	IDM	Germany	$15.8
Murata	Sensors	IDM	Japan	$14.0
NXP Semiconductors	Micro	IDM	Netherlands	$13.2
Analog Devices	Analog	IDM	U.S.	$12.0
Kioxia	Memory	IDM	Japan	$11.7
Renesas	Analog	IDM	Japan	$11.3
United Microelectronics Corporation (UMC)	Foundry	Foundry	Taiwan	$9.2
Sony - Imaging and Sensing Solutions***	Optoelectronics	IDM	Japan	$9.1
onsemi	Discretes	IDM	U.S.	$8.3
GlobalFoundries	Foundry	Foundry	U.S.	$8.1
Microchip Technology Incorporated	Micro	IDM	U.S.	$8.1
Semiconductor Manufacturing International Corporation (SMIC)	Foundry	Foundry	China	$7.2
Amkor Technology	AT&P	AT&P	U.S.	$7.1
Marvell Semiconductor, Inc.	Logic	Fabless	U.S.	$5.8
Skyworks Solutions	Analog	IDM	U.S.	$5.3
U.S. Total				**$350.3**
Top 30 Total				**$684.5**

Source: Annual and quarterly financial filings via company websites and U.S. Securites and Exchange Commission.

**Data is for Samsung's Semiconductor (DS) segment.*
***Estimated value of Apple's semiconductor production based on publicly reported share of TSMC's revenue.*
****Data is for Sony's Imaging and Sensing Solutions segment.*

[15] This estimate may exceed those of the Semiconductor Industry Association ($574 billion, via SIA 2023 Factbook) and Gartner ($600 billion, April 26 2023 press release) in part because it is revenue focused, and thus may not have fully accounted for non-semiconductor revenue or integration of semiconductors into other semiconductor devices. Nevertheless, it is the most reliable directly calculated figure available to BIS and will be used throughout this report, in which figures are generally calculated on a revenue basis rather than a unit basis.

The primary segment category reflects a company's majority revenue segment, not the entirety of a company's activities. Companies typically have significant overlap in the segments in which they operate, with many companies providing both micro and logic devices (or devices that might be categorized as either), or both analog and discrete devices. As a result, throughout this report "primary segment" should be seen as BIS's assessment of the segment in which a company generates more revenue than any other segment, not the *only* segment in which the company operates.

The distribution of BIS's estimates of the size of each segment are similar to typical publicly reported estimates, with much of the difference in overall market size attributable to the analog and logic segments. Companies headquartered inside the United States accounted for 53 percent of semiconductor device revenue.

Market Size Estimates (Billions of USD)				
Segment	**Total - Typical Estimates**	**Total - BIS Calculations**	**U.S.-Based Companies**	**Market Share, U.S.-Based Companies**
Analog IC	$90	$133	$74	56%
Micro IC (MCU and MPU)	$100	$119	$84	71%
Logic IC	$155	$180	$132	73%
Memory IC	$130	$130	$32	25%
Optoelectronics, Discretes, and Sensors	$100	$98	$29	30%
Total - Semiconductor Device Providers	**$575**	**$660**	**$352**	**53%**
Foundries	$110	$139	$9	6%
Assembly, Test, and Packaging (OSAT)	$40	$50	$7	14%
Total - Outsourced Manufacturing	**$150**	**$190**	**$16**	**8%**
Sources: SIA, TrendForce/IC Insights, Omdia, Yole, Company financial reports, Aggregated BIS survey data				

The semiconductor industry is highly concentrated, with companies headquartered in eight locales—the United States, Taiwan, South Korea, Japan, China, Germany, Switzerland, and the Netherlands—accounting for nearly all semiconductor revenue. Within each process role, the industry is further concentrated, with companies headquartered in two or three countries controlling most of the market.

Companies based in the United States are particularly strong in design processes, accounting for nearly three-quarters of all fabless revenue, and 42 percent of revenue among companies that do both design and manufacturing. Taiwan-based companies account for the second largest share of the market, due largely to their dominance of the outsourced manufacturing and assembly, test, and packaging roles.

Market Share of Process Roles by Location of Company Headquarters						
	Fabless	IDM	Total Semiconductor Providers	Foundry	AT&P	Total Outsourced Manufacturing
Total (Billions USD)	***$248***	***$412***	***$660***	***$139***	***$50***	***$190***
United States	72%	42%	53%	6%	15%	8%
Taiwan	14%	2%	6%	65%	58%	63%
South Korea	1%	22%	14%	16%	1%	12%
Japan	1%	17%	11%	1%	0%	0%
China (PRC)	12%	2%	6%	9%	20%	12%
Germany	0%	5%	3%	1%	0%	0%
Switzerland	0%	4%	3%	0%	0%	0%
Netherlands	0%	4%	2%	0%	0%	0%

Sources: Company financial reports, Aggregated BIS survey data, BIS estimates

Survey Coverage

BIS collected survey responses from 194 organizations that design, manufacture, or distribute semiconductor devices in the United States. These organizations represent an estimated 95 percent of semiconductor provider revenue for companies headquartered in the United States. Also included in the survey responses are companies with business operations in the United States but headquarters or parent organizations located outside the United States. Responses to the survey cover an estimated 63 percent of global semiconductor sales.

Not explicitly included in this survey are companies that provide the software and equipment necessary to design and manufacture semiconductors, nor are companies that provide materials required for the manufacture of semiconductors. BIS will directly address these topics in subsequent surveys and reports, though this report does include significant information on the use of these tools and inputs from the perspective of organizations that design and manufacture semiconductors.

The 194 survey respondents have primary operations across each of the seven segments (analog, logic, micro, and memory integrated circuits, optoelectronics, sensors and actuators, and discretes – the last three collectively grouped as O-S-D), as well as each of the process roles involved in semiconductor production–fabless (design), IDM (design and manufacture), foundry (outsourced manufacturing), AT&P/OSAT, and distribution.

Survey Respondents - Primary Semiconductor Operations				
Primary Operation			**Primary Process Role**	
Segment	**Respondents**	**Share of Total**	**Fabless**	**IDM**
Analog ICs	38	20%	50%	50%
Logic ICs	22	11%	82%	18%
Microcontroller and Microprocessor ICs	19	10%	89%	11%
Memory ICs	9	5%	22%	78%
Integrated Circuit Subtotal	**88**	**45%**	**64%**	**36%**
Optoelectronics	18	9%	22%	78%
Sensors & Actuators	11	6%	27%	73%
Discretes	14	7%	0%	100%
O-S-D Subtotal	**43**	**22%**	**16%**	**84%**
Foundry	10	5%	---	---
Assembly, Test, and Packaging	14	7%	---	---
Distribution	20	10%	---	---
Other	19	10%	---	---
Total	**194**	**100%**	**48%**	**52%**

Sources: BIS survey data

Approximately half of the respondents had primary operations focused on the design or design and manufacture of integrated circuits (IC); another 22 percent designed or designed and manufactured non-IC semiconductors. The distribution category includes both organizations whose primary overall function is the distribution of electronics and microelectronics as well as organizations engaged in the design and manufacture of semiconductors, but whose U.S. operations (and survey responses) were restricted to sales or distribution. Respondents in the "other" category were generally tangentially involved in the production and distribution of microelectronics, primarily focused on research and development and on the integration of semiconductors into other products.

Respondents—with BIS' survey authorities limited to organizations that operate inside the United States—were largely headquartered in the United States. One hundred sixty of the 194 survey respondents had U.S. headquarters, though 14 of these had majority owners or voting shareholders outside the country. Parent companies were located in 17 countries, with the majority in Japan (12 respondents), Taiwan (10), and China (6).

Semiconductor providers headquartered in the United States reported a total of $320 billion in annual semiconductor sales in the survey, with those headquartered outside the United States accounting for an additional $97 billion. In aggregate, the survey covers $417 billion of the estimated $660 billion (63 percent) in 2022 semiconductor provider revenue. Survey respondents also account for $32 billion in foundry revenue, $8 billion in OSAT revenue, and $50 billion distributor revenue.[16]

[16] Some non-U.S. organizations that are semiconductor providers responded to the survey solely on behalf of their U.S. sales or distribution subsidiaries; these organizations are distributors for the purpose of survey data.

3. U.S. Capabilities, Risks, and Requirements

3.1 Domestic Capabilities and Risks

Companies headquartered in the United States are responsible for half of global semiconductor sales. Much of this strength is due to fabless companies, with U.S.-based companies representing over 70 percent of global fabless revenue, but U.S.-based IDMs are also world-leading, accounting for nearly twice as much revenue as those in the next largest country (South Korea).

The United States is home to far fewer companies engaged solely in semiconductor manufacturing processes, both front-end (foundries) and back-end (OSAT), representing six percent and 15 percent of global revenues, respectively. As a group, companies headquartered in the United States lead the world in the design as well as the combined design and manufacture (IDM) of semiconductors, but the United States has relatively few companies that carry out contract manufacturing services for semiconductor providers.

One reason for the relatively small market share of U.S. foundry and OSAT companies is the sheer size of the market leaders, Taiwan-based TSMC and ASE Group, which each account for approximately half of the total market share for their respective areas. The United States is home to the headquarters of the fourth largest provider of foundry services (GlobalFoundries) and the second largest provider of OSAT services (Amkor), but these companies have significantly less capacity than the two companies that dominate the foundry and OSAT segments and maintain most of their manufacturing capacity outside the United States.

Largest Semiconductor Companies by Process Role			
Fabless			
Company	**Headquarters**	**2022 Revenue (Billions of USD)**	**% of Total**
Qualcomm	U.S.	$43	17%
Apple*	U.S.	$40	16%
Broadcom	U.S.	$33	15%
Nvidia	U.S.	$30	13%
Advanced Micro Devices	U.S.	$24	10%
U.S. Fabless*	***U.S.***	***$178***	***72%***
Total Fabless		***$248***	
IDM (Integrated Device Manufacturer)			
Company	**Headquarters**	**2022 Revenue (Billions of USD)**	**% of Total**
Intel	U.S.	$63	15%
Samsung - Memory	South Korea	$53	13%
SK Hynix	South Korea	$34	8%
Micron Technology	U.S.	$27	7%
Texas Instruments	U.S.	$20	5%
U.S. IDM*	***U.S.***	***$174***	***42%***
Total IDM		***$412***	
Foundry			
Company	**Headquarters**	**2022 Revenue (Billions of USD)**	**% of Total**
Taiwan Semicondutor Manufacturing Company (TSMC)	Taiwan	$76	55%
Samsung - Foundry and LSI	South Korea	$23	16%
United Microelectronics Corporation (UMC)	Taiwan	$9	7%
GlobalFoundries	U.S.	$8	6%
Semiconductor Manufacturing International Corporation (SMIC)	China (PRC)	$7	5%
U.S. Foundry	***U.S.***	***$9***	***6%***
Total Foundry		***$139***	
OSAT (Outsourced Semiconductor Assembly and Test)			
Company	**Headquarters**	**2022 Revenue (Billions of USD)**	**% of Total**
ASE Group	Taiwan	$22	44%
Amkor Technology	U.S.	$7	14%
JCET Group	China (PRC)	$5	10%
TongFu Microelectronics Co (TFME)	China (PRC)	$3	6%
Powertech Technology (PTI)	Taiwan	$3	6%
U.S. OSAT	***U.S.***	***$7***	***15%***
Total OSAT		***$50***	

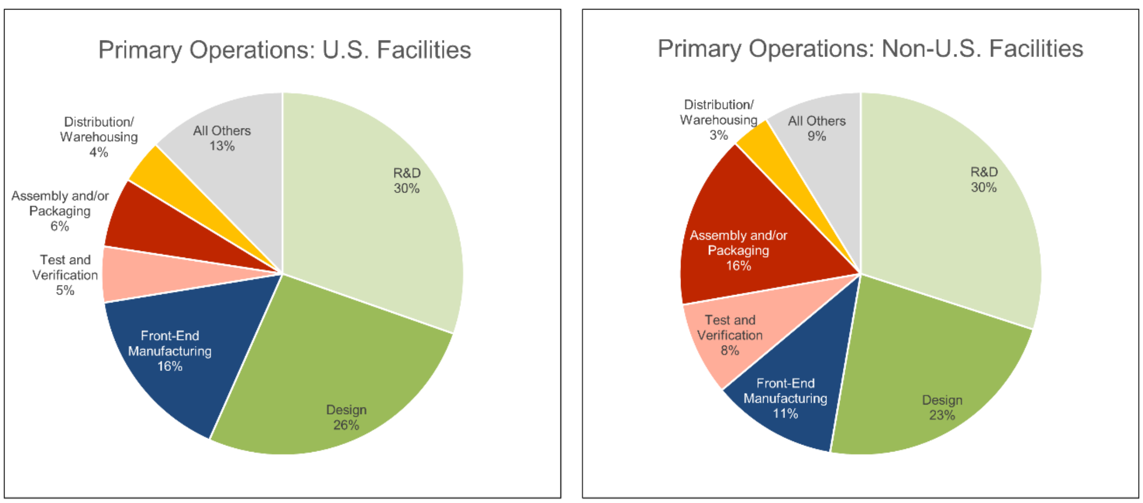
Sources: Company financial reports, Aggregated BIS survey data, BIS estimates

** Revenue figure for Apple is an estimate of the equivalent size of their semiconductor design activity were it a stand-alone business, based on publicly available estimates of Apple's share of TSMC's revenue and on average cost of foundry services for fabless companies. All other companies are publicly traded with a primary focus on semiconductors.*
***Company-specific revenue is based on public reporting, and in some cases includes revenue unrelated to direct production/sale of semiconductors. U.S. and global totals have been adjusted to account for this difference; as a result individual company market shares are overstated in some cases.*

Locations

Semiconductor companies are generally global enterprises, with sales, design, manufacturing, and administrative facilities around the world. Respondents to the BIS survey reported a total of 3,760 facilities in 51 countries, with half located outside the United States. Larger respondents are more global; the ten largest U.S.-based survey respondents reported an average of 74 facilities each—accounting for 20 percent of the total—with 63 percent of their facilities located outside of the United States.

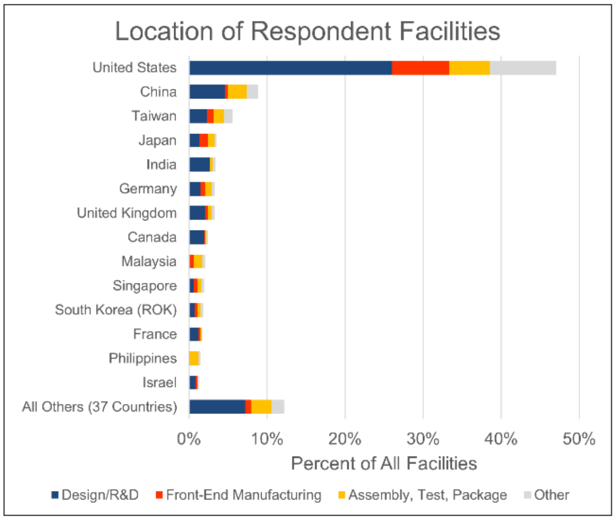
Most respondents' facilities are devoted to design or research and development (R&D). Overall, 30 percent of respondents' facilities were focused on R&D, and 24 percent on semiconductor design. There was little difference in the share of facilities focused on R&D or design inside the United States compared to outside the country. Design and R&D facilities were globally distributed, reported in 39 countries and most heavily focused in the United States, China, and India. Survey respondents tended to have a higher share of fabrication facilities located in the United States, and significantly lower share of back-end facilities in the United States.

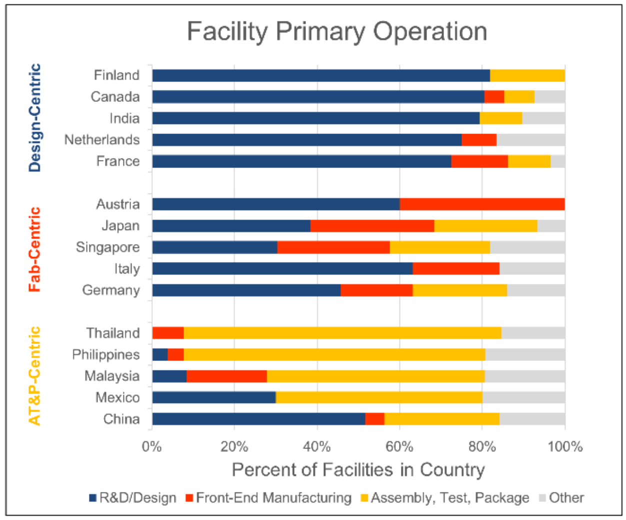


Source: BIS survey data

Outside of the United States, survey respondents most frequently had facilities in China, Taiwan, Japan, and India, with China and Taiwan accounting for over one-quarter of all identified facilities outside the United States. Many countries show clustering or specialization of facilities carrying out a given process step; this is particularly true outside the four major semiconductor powers (the U.S., Taiwan, South Korea, and Japan that, as noted above, host the headquarters of companies accounting for over 80 percent of global semiconductor revenue).

In Finland, Canada, and India, for instance, 80 percent of respondent facilities are focused on R&D or design; on the other end, Southeast Asia is home to a cluster of Assembly, Test, and Packaging facilities, with over 70 percent of respondent facilities in Thailand and the Philippines being focused on AT&P, along with 53 percent of facilities in Malaysia.





Source: BIS survey data

Design and R&D facilities are generally less costly and time intensive to set up (and to shut down). Countries that are host to higher concentrations of design and R&D facilities tend to have newer facilities, yet even accounting for this, India is a significant location of new facilities, with half of its identified facilities commencing operations since 2017, raising India to fifth most facilities among survey respondents. In the United States, 29 percent of facilities among survey respondents were opened since 2017; comparative figures in other major semiconductor-producing locations were 33 percent for Taiwan, 22 percent for China, 16 percent for South Korea, and 15 percent for Japan.

Respondents indicated that the United States was the location for most of their newly opened or planned fabrication facilities, with 13 opened since 2017, and another 14 planned to open in the next five years. These recently opened or planned fabrication facilities account for one-quarter of all reported fabrication facilities in the United States.

Front-end manufacturing (fabrication) was the process with the highest share of facilities located in the United States, with 55 percent of reported front-end facilities located in the United States, a figure that rises to 65 percent for respondents with U.S. headquarters.

In general, survey respondents reported having approximately half of their facilities located inside the United States across all processes except the back-end manufacturing processes of test and verification and assembly and packaging. Facilities dedicated to these processes represented both low shares of overall reported facilities (6 percent and 10 percent, respectively), and lower shares of facilities located in the United States (34 percent and 26 percent, respectively).

Production Processes

While companies headquartered in the United States are responsible for half of global chip sales, semiconductor companies have locations around the world and engage in significant outsourcing of manufacturing. BIS estimates that just over one-quarter of all chips (by revenue) are designed within the United States, 12 percent are fabricated inside the United States, and less than two percent are assembled, tested, and packaged in the United States.

Estimated Share of Global Chip Production Activities Carried Out Inside the United States			
Company	**Design**	**Fabrication**	**AT&P**
Analog	32%	27%	1%
MCU/MPU	20%	7%	<1%
Logic	48%	14%	<1%
Memory	11%	3%	<1%
O-S-D	12%	10%	3%
Total	***27%***	***12%***	***2%***
Source: BIS Survey and Industry Data			

Design

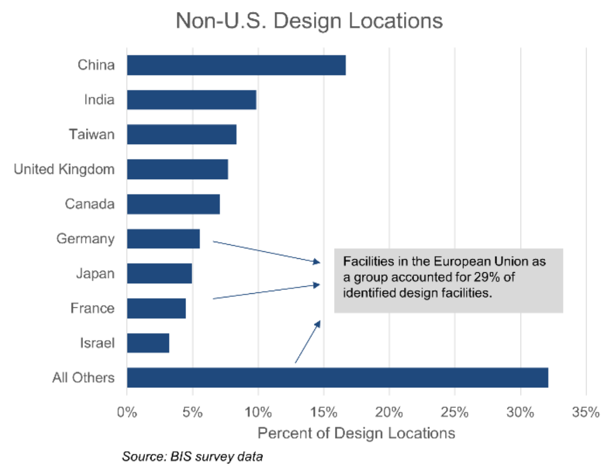
The United States is home to eight of the world's ten largest semiconductor providers and accounted for an estimated 53 percent of the world's original semiconductor device sales in 2022. Much of this commanding market share is driven by the concentration of fabless companies that are headquartered in the United States, which account for nearly three-quarters of global fabless revenue. Only two other locations—Taiwan and China—host the headquarters for companies accounting for more than one percent of global fabless revenue, and revenue of U.S.-based fabless companies exceeds that of each Taiwan and China by more than five times.

The market share of U.S.-based companies among IDMs is lower than that of U.S.-based fabless companies, but still dominant at 43 percent—nearly twice that of next-highest South Korea. Additionally, the aggregate revenue of IDMs is higher than that of fabless companies, so approximately half of the estimated $350 billion in original semiconductor sales by U.S.-headquartered companies are attributable to each group.

The BIS survey included questions covering not just where semiconductor companies are located, but also the proportion of design, front-end fabrication, and back-end manufacturing (AT&P) carried out inside the United States. As noted above, large semiconductor companies are global enterprises, and design activities can be moved around the world with significant more ease than manufacturing.

On the whole, respondents indicated that they carried out slightly less than half of their design activities inside the United States. Somewhat higher shares of logic and analog chips were designed inside the United States, and significantly lower shares of optoelectronic and memory. The memory segment is concentrated in several large IDMs with most operations in Asia; South Korea-based Samsung and SK hynix alone account for over half of the memory market share. The largest U.S.-based memory producer—Micron—reported in its annual report that 21 percent of its workforce was located in the United States, with 77 of the remaining 79 percent in Asia.

Among BIS survey respondents, design facilities outside the United States were broadly distributed, with facilities focused on design reported in 39 countries. China was the single most frequently identified non-U.S. design location, accounting for 17 percent of non-U.S. design facilities, though European Union locations as a group nearly doubled this level.



Respondents focused on logic chips more frequently reported having non-U.S. design facilities in China and Taiwan, while facilities in Canada and the United Kingdom were disproportionately from companies focused on analog chips. A significant portion of optoelectronic, sensor, and discrete design activity is focused in Japan, which is home to several of the world's largest optoelectronics and sensor companies.

Leading-edge[17] and current generation (under 28 nanometers) logic and micro chips relied more on U.S.-based design than chips with larger feature sizes. Survey respondents indicated that 64 percent of the design activities for leading-edge and current generation logic and micro chips took place inside the United States, compared to 39 percent for those 28 nanometers or greater.

Front-End Fabrication

The chips that are among the most frequently designed inside the United States—leading-edge and current generation logic and micro chips—are among the least frequently fabricated in the United States. Only TSMC, Samsung, and Intel have fabrication capabilities below 7 nanometers in volume production, with TSMC and Samsung alone operating at the leading-edge in 2022.[18] Leading-edge logic chips—largely provided by U.S.-based fabless companies—are thus dependent on TSMC and Samsung for wafer fabrication. Current plans from Intel would add another leading-edge fabrication option in 2024, and newly formed Japan-based Rapidus announced in December 2022 a partnership with U.S.-based IBM, with a goal to develop production of 2 nanometer chips by "the second half of the decade."[19]

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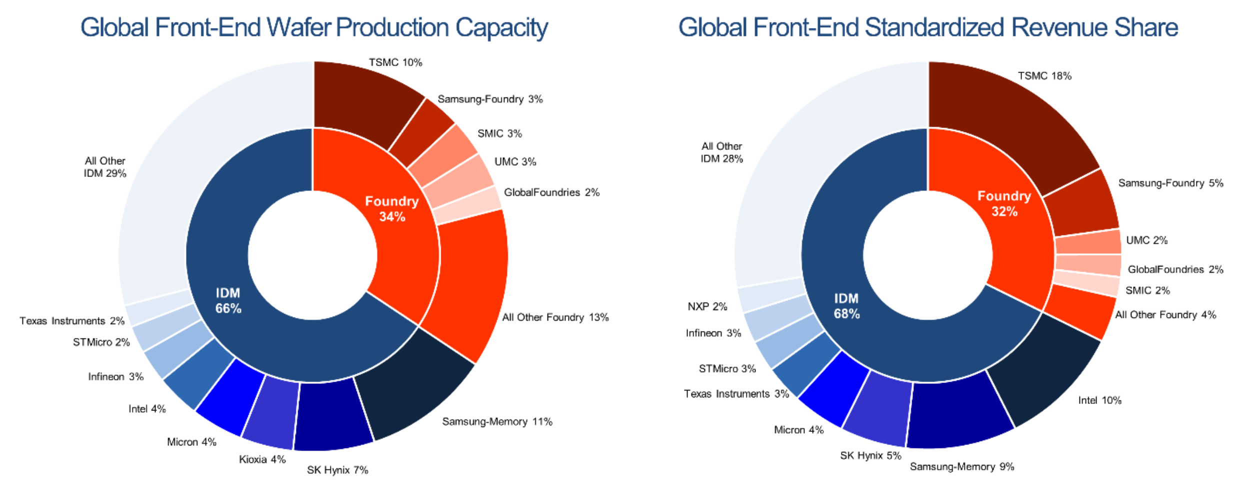
[17] This generally refers to chips identified as "5nm" or smaller, but is more precisely defined for the purposes of the CHIPS Notice of Funding Opportunity as logic chips produced in high volume using extreme ultraviolet (EUV) lithography tools, 3D NAND chips with 200 layers or above, or DRAM chips with a half-pitch of 13 nm or below.

[18] Samsung announced it began initial production at 3nm in June 2022 (https://news.samsung.com/global/samsung-begins-chip-production-using-3nm-process-technology-with-gaa-architecture); TSMC announced volume production at 3nm in December 2022 (https://pr.tsmc.com/english/news/2986); Intel announced in April 2023 that its Intel 7 process was in high-volume production and its Intel 4 process was underway with product launch expected in the second half of 2023, with plans to introduce a 2nm process (20A) in 2024 (https://www.intc.com/news-events/press-releases/detail/1615/intel-reports-first-quarter-2023-financial-results, https://www.intc.com/news-events/press-releases/detail/1623/powervia-test-shows-industry-leading-performance

[19] https://research.ibm.com/blog/rapidus-ibm-2nm-chips

These companies accounted for an estimated 17 percent of global wafer production capacity in 2022 and—given their focus on high-value leading-edge chips—33 percent of wafer fabrication value (rising to 28 percent and 42 percent, respectively, when including Samsung's memory business).



Source: Company financial reports and public reporting, SEMI World Fab Forecast aggregate BIS data and calculations
"Standardized Revenue Share" based on the estimated value of chip front-end fabrication

Approximately one-third of wafer fabrication is carried out by foundries, with the remaining two-thirds performed by IDMs. Of the IDM-based production, 40 percent is from memory providers, which rely almost exclusively on the IDM model. A majority of logic and micro chips are produced via the fabless-foundry model; these chips make up 45 percent of global semiconductor market share, but IDM-based logic and micro chip production accounts for approximately 10 percent of global chip capacity.

In general, newer and smaller technology nodes are produced using the fabless-foundry model, while chips with larger feature sizes are more frequently produced by IDMs. Three-quarters of all logic/micro chips under 28 nanometers were fabricated in foundries, compared to 36 percent of logic/micro chips over 90 nanometers.[20] Similarly, nearly all analog chips under 90 nanometers were fabricated in foundries, compared to less than half of those over 90 nanometers. The memory segment is the exception for integrated circuit production, as virtually all chips are produced by IDMs.

[20] Based on BIS survey data

Percent of Chips Fabricated at Foundries					
Primary Node	**Logic/Micro**	**Analog**	**Memory**	**Optoelectronics, Sensors & Actuators**	**Discretes**
Under 28 nm	75%	---	<5%	---	---
28 nm - <90 nm	70%	>90%	30%	53%	---
90 nm - <350 nm	36%	44%	58%	39%	18%
350nm or greater	---	44%	99%	32%	20%
Total	***72%***	***53%***	***<5%***	***44%***	***19%***

Source: BIS survey data

Foundries

The importance of TSMC and Samsung foundry services to the U.S. and global microelectronics ecosystem is difficult to overstate. The two companies' foundries account for approximately 13 percent of global chip capacity but nearly 40 percent of foundry capacity, over 70 percent of foundry revenue, and nearly all volume production under 7 nanometers.[21]

Intel aims to also become a major leading-edge foundry, announcing in 2021 the creation of a foundry division and setting a goal of being the world's second largest foundry by 2030.[22] Much of the growth of Intel's foundry division (which in 2022 reported revenue under one billion dollars, compared to Samsung's $20 billion and TSMC's $76 billion), would come from leading-edge feature sizes, driven by the planned introduction of Intel 3 in late 2023 and Intel 18A in late 2024.[23]

Outside of TSMC, Samsung, and Intel, foundries tend to focus on more mature feature sizes. The world's third, fourth, and fifth largest foundries— U.S.-based GlobalFoundries , , Taiwan-based United Microelectronics Corporation (UMC), and China-based Semiconductor Manufacturing International Corp (SMIC), all derive most of their revenue or capacity from semiconductors above 40 nanometers.[24] By comparison, TSMC reported that in the first quarter of 2023 half of its revenue was from processes at or under 7 nanometers, and 77 percent from those at or below 28 nanometers.[25]

Foundry capabilities inside the United States are limited, but several companies are planning significant expansions in domestic foundry capacity. Of the few U.S.-headquartered foundries, only GlobalFoundries recorded over $1 billion in revenue in 2022, and just one-quarter of

[21] Leading-edge node definitions are imprecise, making direct comparisons challenging. Production under 7 nanometers is based on company's announced nodes. Intel rebranded their previously-named "7nm" process as "Intel 4" in 2021; this process entered volume production in late 2022. Leading-edge process nodes do not correspond precisely to feature size, but some industry sources suggest that the Intel 4 process is similar in performance to TSMC's 3nm process.

[22] https://asia.nikkei.com/Business/Business-Spotlight/How-Intel-plans-to-rival-TSMC-and-Samsung-as-a-chip-supplier

[23] https://www.intel.com/content/dam/www/central-libraries/us/en/documents/2022-intel-investor-meeting-ifs.pdf

[24] Based on annual reports and investor presentations

[25] https://investor.tsmc.com/english/quarterly-results/2023/q1

GlobalFoundries' production capacity is located in the United States, at facilities in New York and Vermont.[26] Facilities in Singapore and Germany make up the bulk of GlobalFoundries' production capacity. The company announced in 2021 plans to invest $1 billion in expanding the capabilities of its Malta, New York facility, as well as the adjacent construction of a new multi-billion facility.[27]

Intel Foundry Services (IFS)—an Intel division first announced in 2021—reported revenue of $900 million in 2022 but expects rapid growth. Intel announced plans in early 2022 to acquire Israel-based Tower Semiconductor, with $1.5 billion revenue. This acquisition attempt was terminated in August 2023 following refusal by China's State Administration for Market Regulation to approve the deal.[28] Intel has announced plans to spend more than $40 billion, split between facilities in Arizona and Ohio, that will serve foundry customers; the addition of Tower would have added facilities in California and Texas, as well as two sites in Israel, two in Japan, and one in Italy.[29] The two companies instead reached an agreement for Tower to use their own equipment at Intel's facility in New Mexico to expand capacity in cooperation with Intel Foundry Services.[30]

Smaller U.S.-headquartered foundries include LA Semiconductor, which incorporated in 2021 and operates an Idaho facility it purchased from onsemi, capable of producing above 180 nanometers;[31] SkyWater Technology operates fabrication facilities in Minnesota and Florida, and announced in 2022 a new facility to be located in Indiana; and Polar Semiconductor, located in Minnesota but majority-owned by Japan-based Sanken Electric, who also serves as Polar's primary customer.[32]

Beyond U.S.-headquartered companies, Samsung operates a fabrication facility in Austin, Texas and announced in 2021 plans to invest $17 billion in a new facility in Taylor, Texas, with plans to open in 2024.[33] TSMC is in the process of building two fabrication facilities in Arizona, expected to open in 2025 and 2026 with a total investment of $40 billion.[34] Significantly smaller, with $740 million in global revenue, Belgium-based X-Fab operates a foundry focused on larger feature size analog and mixed signal chips in Lubbock, Texas that accounts for approximately 15

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[26] GlobalFoundries Annual Report

[27] https://www.wamc.org/new-york-news/2021-07-19/globalfoundries-to-build-second-fab-in-malta

[28] https://www.intel.com/content/www/us/en/newsroom/news/intel-news-aug-2023.html; https://www.forbes.com/sites/johannacostigan/2023/08/17/china-blocks-intel-deal-spotlighting-us-chip-strategy-and-the-national-anxieties-driving-it/

[29] https://www.intel.com/content/www/us/en/newsroom/news/intel-breaks-ground-two-new-leading-edge-chip-factories-arizona.html; https://www.intel.com/content/www/us/en/corporate-responsibility/intel-in-ohio.html; https://ir.towersemi.com/static-files/bc0e72ce-2002-4c84-b382-21e646451925

[30] https://www.intc.com/news-events/press-releases/detail/1643/intel-foundry-services-and-tower-semiconductor-announce-new

[31] https://finance.yahoo.com/news/la-semiconductor-purchases-fabrication-plant-171300416.html

[32] https://polarsemi.com/news/sanken-notice-of-change-of-consolidated-subsidiary/

[33] https://news.samsung.com/global/samsung-electronics-announces-new-advanced-semiconductor-fab-site-in-taylor-texas

[34] https://pr.tsmc.com/english/news/2977

percent of the company's capacity.[35] X-Fab announced in 2023 plans to invest $200 million in an expansion of the facility.[36]

Altogether, foundry operators have plans underway to spend more than $100 billion on new foundry capacity located in the United States, vastly increasing domestic foundry capabilities. Capital expenditures in the United States by companies operating or building foundries nearly tripled from 2017 to 2022,[37] with the bulk of the already-announced $100 billion in foundry-building expenditures still to come.[38]

IDMs

Most chips are fabricated outside of foundries. IDMs account for two-thirds of original chip sales, and 80 percent of chips outside of the micro and logic segments.[39] The most significant portion of chips manufactured by IDMs are memory chips, which are almost exclusively produced by a small group of IDMs. Though accounting for a significantly smaller revenue share, discrete semiconductors are also nearly universally a product of IDMs. Analog integrated circuits, optoelectronics, and sensors and actuators are heavily, though not exclusively, provided by IDMs.

Memory

The memory segment accounts for approximately 30 percent of global wafer production capacity, and over 40 percent of IDM capacity. Nearly all of this memory production capacity is held by four companies: Samsung (South Korea), SK hynix (South Korea), Kioxia/Western Digital Flash Ventures (Japan-based joint venture), and Micron (United States).

Memory fabrication takes place almost entirely outside of the United States. SK hynix and Flash Ventures have minimal presence in the United States, largely devoted to sales and distribution. Samsung has significant fabrication facilities in Texas but identifies their major memory production sites as located in South Korea and China.[40] Micron is headquartered in the United States—with production facilities in Virginia, under construction in Idaho, and planned in New York—but maintains just 13 percent of its property, plant, and equipment (PP&E) in the country; it has a larger presence in Taiwan (33 percent of PP&E), Singapore (31 percent), and Japan (18 percent).[41]

Outside of these four major producers, effectively all of the next tier of suppliers (each with significantly less than five percent of the memory market) are headquartered in China or Taiwan, with manufacturing concentrated in those locations. Key producers in this group—all with estimated revenue between one and three billion dollars— include China-based Yangtze

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[35] https://www.xfab.com/manufacturing/our-fabs
[36] https://lubbockeda.org/x-fab-texas-announces-expansion-in-lubbock-tx/
[37] Based on BIS survey data
[38] For a regularly updated picture of U.S. semiconductor facilities and recent investments, the Semiconductor Industry Association maintains an interactive U.S. Semiconductor Ecosystem Map. (https://www.semiconductors.org/u-s-semiconductor-ecosystem-map/).
[39] Based on BIS survey data
[40] https://images.samsung.com/is/content/samsung/assets/global/ir/docs/2022-4q-Business-Report.pdf
[41] Micron 2022 10-K

Memory Technologies Co (YMTC) and Changxin Memory Technologies (CXMT), and Taiwan-based Nanya, Winbond, and Macronix.

Given this concentration of manufacturing capability in South Korea, Japan, China, and Taiwan, BIS estimates that just three percent of memory manufacturing takes place inside the United States. This level is expected to increase by 2030, with Micron announcing plans in 2022 to spend $15 billion building a new fabrication facility in Boise, Idaho,[42] and intentions to spend up to $100 billion by 2042 building a "megafab" in Clay, New York.[43] The company indicated these investments would raise its U.S.-based production to 40 percent of its total output by 2032.[44]

Analog

Outside of memory, the largest segment (by revenue) attributable to IDMs is analog. The segment is split, with survey respondents whose primary analog nodes are below 90 nanometers indicating they almost exclusively use foundries for production, while most revenue from chips above 90 nanometers comes from IDM-produced chips.

The analog segment has the highest share of chips manufactured inside the United States, with an estimated 27 percent of global analog chip manufacturing carried out in the country. IDMs from the United States and Europe are dominant in the analog market, with the nine largest analog suppliers based in these two regions, and U.S.-based companies accounting for over half of the global analog market share. U.S.-headquartered companies as a group fabricated 40 percent of their analog chips inside the United States in 2022.[45]

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[42] https://investors.micron.com/news-releases/news-release-details/micron-invest-15-billion-new-idaho-fab-bringing-leading-edge

[43] https://investors.micron.com/news-releases/news-release-details/micron-announces-historic-investment-100-billion-build-megafab

[44] https://investors.micron.com/news-releases/news-release-details/micron-announces-historic-investment-100-billion-build-megafab

[45] Based on BIS survey data

Leading Analog IC Suppliers			
Company	**Headquarters**	**2021 Revenue (Billions of USD)**	**Analog Market Share**
Texas Instruments	U.S.	$14.1	19%
Analog Devices	U.S.	$9.4	13%
Skyworks Solutions	U.S.	$5.9	8%
Infineon	Germany	$4.8	6%
STMicroelectronics	Switzerland	$3.9	5%
Qorvo	U.S.	$3.9	5%
NXP	Netherlands	$3.5	5%
onsemi	U.S.	$2.1	3%
Microchip	U.S.	$1.8	2%
Renesas	Japan	$1.1	1%
All Others	---	$23.5	32%
Total	**---**	$73.9	***100%***
Source: IC Insights			

[46]

U.S.-based Texas Instruments is the global market leader, with nearly $20 billion in total sales in 2022 (three-quarters of which is analog),[47] more than 50 percent higher than next-largest U.S.-based Analog Devices (whose analog segment is estimated to itself be more than 50 percent higher than next-largest U.S.-based Skyworks Solutions).[48]

Texas Instruments alone accounts for more than one-quarter of analog fabrication capabilities inside the United States.[49] The company also has announced major expansion plans in the United States, including an $11 billion facility adjacent to the Lehi, Utah facility the company purchased from Micron in 2021,[50] the $6 billion expansion of its Richardson, Texas facility (completed in 2022),[51] and plans to spend up to $30 billion constructing four fabrication facilities in Sherman, Texas, with initial construction having started in 2022.[52] The new facilities would increase Texas Instruments' U.S.-based square footage by over 30 percent.

Several other major analog providers have announced expansion plans in the United States, though none are close to the scale of Texas Instruments' efforts. Second-largest analog provider Analog Devices is in the midst of spending $1 billion to double the capacity of its Oregon

[46] https://www.planetanalog.com/analog-rankings-top-10-suppliers-own-68-market-share/
[47] Texas Instruments 2022 10-K
[48] ICInsights via https://electronics360.globalspec.com/article/18216/ti-remains-top-supplier-of-analog-ics-in-2021
[49] The company reported in 2022 that 61% of its square footage and 75% of its PP&E was located in the United States, providing a reasonable range for estimating its U.S.-based fabrication. At 61%, it would account for $9.15B of the estimated $36B (25%) in U.S.-fabricated analog chips; at 75% this would rise to $11.3B (31%)
[50] https://news.ti.com/texas-instruments-selects-lehi-utah-for-its-next-300-millimeter-semiconductor-wafer-fab
[51] https://news.ti.com/blog/2022/09/29/tis-new-300-millimeter-wafer-fab-in-richardson-texas-begins-initial-production
[52] https://www.kxii.com/2022/05/18/texas-instruments-breaks-ground-new-30-billion-manufacturing-plant/

facility,[53] while Microchip Technologies is spending $800 million to triple production at its own Oregon facility.[54] Among non-U.S. companies, Netherlands-based NXP Semiconductors is reportedly exploring a $2.6 billion expansion of its presence in Austin, Texas,[55] Germany-based Infineon is reported to be considering a $700 million expansion of its own Austin, Texas facility,[56] and Germany-based Robert Bosch announced in 2023 plans to buy TSI Semiconductors' Roseville, California foundry and spend $1.5 billion updating it to produce their own chips.[57]

Discretes

Discrete semiconductors—largely consisting of power transistors, signal and switching transistors, and diodes—are largely produced by IDMs. U.S.-based companies account for approximately one-quarter of the discrete market share,[58] led by Alpha and Omega, Diodes Incorporated, Littelfuse, onsemi, Vishay Technologies, and Wolfspeed. Much of the remaining market share is provided by European companies—notably Infineon and STMicroelectronics—and Japanese companies—Fuji Electric, Mitsubishi Electric, Renesas, ROHM, and Toshiba among the most prominent.

Several of these companies have significant operations in the United States. Germany-based Infineon, the market share leader in power discretes,[59] reported that the United States was the primary location of its property, plant, and equipment[60] and, as noted above, is exploring significant expansions of their U.S. facilities. Onsemi in 2022 acquired GlobalFoundries' East Fishkill, New York facility, which it notes is the company's "largest U.S. manufacturing location as well as the only 300mm power discrete and image sensor fab in the country."[61] U.S.-based Wolfspeed has also announced major expansion plans in the United States, including a $5 billion investment focused on silicon carbide production in Siler City, North Carolina that will increase the company's materials capacity by over 10 times, and an expansion of what the company describes as "the world's first, largest, and only 200mm Silicon Carbide fabrication facility" in Marcy, New York.[62]

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[53] https://www.bendbulletin.com/business/analog-devices-is-spending-1-billion-to-upgrade-oregon-chip-factory/article_2653afbc-969e-11ed-a1ad-ab110d25a2d8.html

[54] https://www.microchip.com/en-us/about/news-releases/corporate/microchip-reaches-milestone-in-800-million-multi-year-initiative

[55] https://www.statesman.com/story/business/2022/05/10/chipmaker-nxp-considers-austin-2-6-b-expansion-up-800-new-jobs/9725633002/

[56] https://www.statesman.com/story/business/2022/02/17/chipmaker-infineon-considers-700-million-expansion-austin-site/6814491001/

[57] https://www.reuters.com/technology/bosch-buys-us-semiconductor-foundry-expand-ev-chip-output-2023-04-26/

[58] Based on BIS survey data and market estimates

[59] https://www.infineon.com/dgdl/2023-05-04+Q2+FY23+Investor+Presentation.pdf?fileId=8ac78c8b8779121b0187e2f1daad0043

[60] Based on company annual reports

[61] https://investor.onsemi.com/static-files/583d10c2-a0c9-41fb-8b7b-1bbd5f2347dc

[62] https://www.wolfspeed.com/company/news-events/news/wolfspeed-announces-plan-to-construct-worlds-largest-most-advanced-silicon-carbide-device-manufacturing-facility-in-saarland-germany/; https://www.wolfspeed.com/company/about/mohawk-valley-fab/

Beyond the U.S. and European companies with major U.S. presences, most of the remaining discrete market share is based in Japan or China. Nearly all of these companies maintain their fabrication facilities within the country of their headquarters. Notable exceptions include Chinese-owned but Netherlands-based Nexperia (owned by Wingtech), which has fabrication facilities in Germany and the United Kingdom, and Ampleon (owned by Jianguang Asset Management), which has a production site in the Philippines.[63]

Optoelectronics and Sensors & Actuators

Optoelectronic and sensor & actuator semiconductors, like discrete semiconductors, generally use larger feature size technologies, and are generally produced by IDMs. Image sensors and light sensors, used heavily in mobile devices and automobiles, account for the bulk of the segments' revenue. Much of the market share is held by companies based outside the United States, with Japan-based Sony and South Korea-based Samsung reported to account for over half of the image sensor market share.[64] U.S.-based but Chinese-owned Omnivision (purchased in 2018 by Will Semiconductor) also holds a significant share of the image sensor market, but operates on a fabless model, with TSMC a notable fabrication provider.[65]

U.S.-based companies have a stronger market position in semiconductor lasers, with Coherent Corporation, Lumentum, and IPG Photonics operating as major providers of semiconductor lasers. Lumentum and Coherent alone account for over three-quarters of the vertical cavity surface-emitting lasers (VCSEL) market, with uses in mobile devices, data centers, and automobiles.[66] Semiconductor lasers also have broader industrial usage, with IPG Photonics reporting that 90 percent of their revenues came from materials processing customers, including the production of semiconductors themselves.[67]

Overall, BIS estimates the U.S.-based companies account for approximately 20 percent of the optoelectronics and sensors & actuators segments market share, and with less than 10 percent of global fabrication of these devices occurring inside the United States.

Logic and Micro

The remaining segments—Logic and Microprocessors (MPUs) and Microcontrollers (MCUs)—are produced largely using the fabless model, as identified above, with some notable exceptions. Intel, while adding a foundry services division, remains an IDM, and is a significant manufacturer for the logic and MPU/MCU segment. By revenue, it is the world's second largest semiconductor provider (behind Samsung), is 50 percent larger than the next largest non-memory chip provider (Qualcomm), is three times larger than the next largest non-memory IDM (Texas Instruments), and eight times larger than the next largest logic/micro IDM (Microchip Technology). While most of the logic and micro segment is fabless, most of its IDM portion is Intel.

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[63] https://www.nexperia.com/about/worldwide-locations/; https://www.ampleon.com/contact.html
[64] https://www.eenewseurope.com/en/cmos-image-sensor-market-growth-to-soften/
[65] https://www.ovt.com/press-releases/omnivision-leads-pixel-shrink-race-with-the-development-of-worlds-smallest-0-56-micron-pixel/
[66] https://optics.org/news/13/9/30
[67] IPG, Coherent, and Lumentum annual reports

The other notable logic/micro area provided by IDMs is in chips with larger feature sizes, particularly over 90 nanometers. BIS estimates that nearly two-thirds of logic and micro chips over 90 nanometers are produced by IDMs. These chips are largely produced on 200mm (8 inch) or smaller wafers, with survey respondents identifying 8-, 16-, and 32-bit MCUs most frequently. These chips constitute (by revenue) a relatively small portion of the overall segment value; logic/micro chips over 90 nanometers account for an estimated six percent of the total value of logic/micro chips produced.

IDMs Use Foundries Too

Though generally associated with fabless production, IDMs also use foundries. Intel notes that it is one of TSMC's "top customers," with up to 20 percent of its production using external foundries.[68] Analog market leaders similarly supplement internal manufacturing with foundry production; Texas Instruments reported externally sourcing 20 percent of its production in 2022, while this figure for Analog Devices was over 50 percent.[69] Infineon describes their foundry rationale:

> *We manufacture products in-house when doing so means that our customers benefit from lower cost, higher performance or improved availability. … However, where in-house manufacturing offers no additional customer benefit or opportunity to differentiate ourselves from the competition, we work together with contract manufacturers.*[70]

Based on BIS survey data, these practices are widespread. Over 80 percent of IDMs reported using external production for some portion of their front-end fabrication, with an average of 19.6 percent of their product revenue flowing through foundries.

Assembly, Test, and Packaging

A very small share of global assembly, test, and packaging (AT&P) takes place inside the United States. Once chips are designed and fabricated on wafers, they need to be tested and put inside a package that protects the chip and supports interfacing with other electronic components. Most assembly and packaging activity is outsourced, and nearly all of the OSAT market is based in Taiwan or China, with Taiwan-based companies alone receiving half of the market share.

Based on survey data, BIS estimates that approximately 60 percent of all AT&P is outsourced, with under two percent of global AT&P carried out within the United States. Even among the chips fabricated inside the United States, less than ten percent are packaged in the country.

The only U.S.-based company with significant global OSAT market share is Amkor, which is headquartered in Tempe, Arizona and has no AT&P capacity inside the United States. The company's $7 billion 2022 revenue make it the world's second largest OSAT, with 14 percent of the market. Amkor operates largely in Asia, with 97 percent of its workforce and PP&E in that region.[71] Its largest concentration of facilities is in South Korea, which accounts for 60 percent of

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[68] https://www.intel.com/content/www/us/en/newsroom/opinion/expanding-foundry-partnerships-critical-piece.html

[69] Texas Instruments and Analog Devices 2022 annual reports

[70] Infineon 2022 annual report

[71] Amkor 2022 annual report

its PP&E and 40 percent of its square footage. The bulk of the company's remaining facilities are in Japan, China, Philippines, and Taiwan, each of which account for between 10 and 17 percent of the company's square footage. An under-construction facility in Vietnam is expected to open in late 2023 and will make Vietnam the location of Amkor's second biggest footprint.

The OSAT market led by Taiwan-based ASE Group, which held a commanding market share lead in 2022 with revenue three times that of second-place Amkor. ASE operates primarily out of Taiwan (57 percent of its square footage) and China (24 percent), with other Asian locations accounting for an additional nine percent of its footprint.[72]

The world's third and fourth largest OSATs are China-based JCET and TongFu Microelectronics (TFME), with 10 percent and six percent market share, respectively. These companies operate largely within China, with JCET reporting 77 percent of its footprint is in China (most of the remainder is in South Korea), and TFME having just one of its seven facilities outside China.[73] TFME is a major supplier to AMD, having formed a joint venture with the company to purchase in 2016 AMD's AT&P facilities in Suzhou, China and Penang, Malaysia. AMD retains a 15 percent stake in the joint ventures.[74]

These four companies account for approximately three-quarters of the OSAT market share. With the next four largest OSAT providers—Powertech (PTI), Huatian, Chipbond, and ChipMOS—based in Taiwan or China, much of the remaining market share is also concentrated in these locations.

In addition to stand-alone OSATs, leading-edge foundries TSMC and Samsung also carry out significant levels of packaging for their customers led by the expansion of their advanced packaging business. TSMC, for instance, noted in its 2023 first quarter earnings call that approximately seven percent of its revenue for 2022 was from packaging; this would place TSMC's packaging revenue roughly on par with the third-largest OSAT, and up over 40 percent since 2020.[75] In its 2023 second quarter earnings call, the company indicated that demand for its advanced packaging exceeded its capacity, and that it was working to approximately double its advanced chip-on-wafer-on-substrate (CoWoS) packaging capacity. A similar packaging revenue share to TSMC would place Samsung's foundry packaging revenues in the range of the sixth or seventh largest OSAT, with its larger memory business also having significant in-house packaging.

Intel, as both a growing foundry and a large IDM, carries out significant AT&P. Though its foundry services in 2023 are a fraction of the size of TSMC's, the company reported that its

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[72] ASE 2022 annual report
[73] JCET and TFME company websites
[74] AMD 2022 annual report
[75] https://investor.tsmc.com/english/encrypt/files/encrypt_file/reports/2023-04/882aa7c981570fe00c0bba76648983b02b54cbf4/TSMC%201Q23%20Transcript.pdf; https://www.globenewswire.com/en/news-release/2022/02/15/2385153/0/en/Advanced-Packaging-Market-Worth-55-Bn-Globally-by-2028-at-8-CAGR-Exclusive-Report-by-The-Insight-Partners.html

packaging revenue grew 67 percent in the first quarter of the year.[76] Intel has also announced plans to spend $4.6 billion building an assembly and test facility in Poland,[77] and $3.5 billion expanding and updating its Rio Rancho, New Mexico operations to support advanced packaging growth.[78] The company operates additional AT&P facilities in Vietnam, Malaysia, China, and Costa Rica.

Other large IDMs also maintain significant AT&P capabilities. Based on survey responses, 61 percent of chips produced by IDMs (by value) are packaged in-house, though these facilities are generally located outside of the United States. BIS survey data shows that 80 percent of the IDM-owned facilities focused on AT&P are located outside of the United States, a figure that rises to 90 percent for the ten largest IDMs. China, Philippines, and Malaysia accounted for over half of the non-U.S. facilities.

Overall, BIS estimates that 85 percent of chips sold by U.S.-based companies are packaged—either in-house or by OSATs—in four locations: Taiwan, China, South Korea, and Malaysia.

3.2 Availability of Inputs

The manufacture of microelectronics requires hundreds of different types of materials, driving a segment of the microelectronics ecosystem that produces over $60 billion per year in sales.[79] While this assessment does not include direct survey data from providers of semiconductor materials, BIS did collect data from semiconductor providers on their use of and challenges in acquiring materials.

BIS collected data on 16 categories of materials and inputs to front-end and back-end fabrication, asking respondents about their key suppliers, use of U.S.-based suppliers and alternate suppliers, lead times, inventory levels, and difficulty acquiring each material or input. In general, respondents more frequently used U.S.-based suppliers for their U.S. facilities and non-U.S. suppliers for facilities outside of the United States. However, significant variation was noted across material types.

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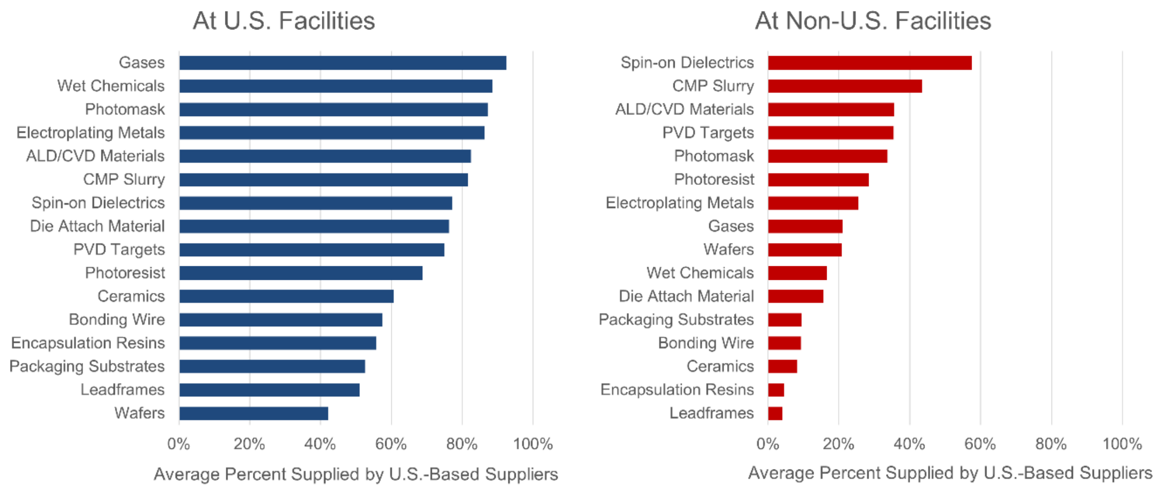
[76] https://d1io3yog0oux5.cloudfront.net/_9d396b15745336f7503a1c0f97d5782b/intel/db/887/8943/prepared_remarks/CXinvestorreport23.jtb.pdf
[77] https://www.intel.com/content/www/us/en/newsroom/news/intel-plans-assembly-test-facility-poland.html
[78] https://www.intel.com/content/www/us/en/newsroom/news/new-mexico-manufacturing.html
[79] Semiconductor Industry Association Comments on CHIPS Program Office Request for Information (87 Fed. Reg. 61570), November 14, 2022 (https://www.regulations.gov/comment/DOC-2022-0001-0096)

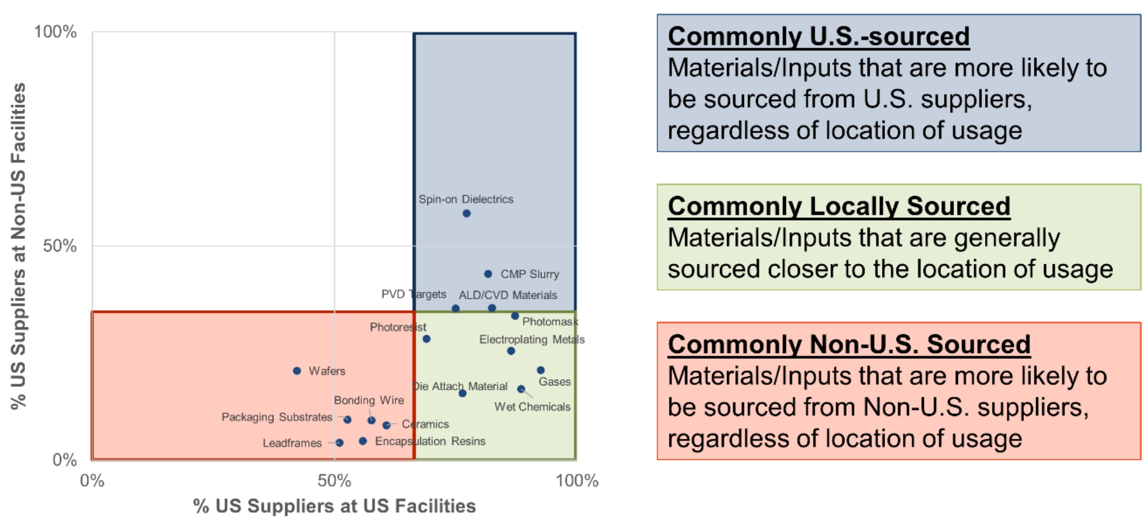
Use of U.S.-Based Material Suppliers



Source: BIS survey data

Respondents indicated that on average, they acquired 69 percent of their material used at facilities located inside the United States from U.S.-based suppliers, compared to 20 percent of material used at non-U.S. facilities.[80] Materials used for AT&P—bonding wire, ceramics, packaging substrates, encapsulation resins, and leadframes—were significantly more likely to be of non-U.S. origin, regardless of location of the facility. Conversely, U.S.-based suppliers were relatively more prevalent in materials for deposition and etch—spin-on dielectrics, CMP slurry, ALD/CVD materials, and PVD targets. The remaining materials, most notably wet chemicals and gases, tended to be sourced from U.S.-based suppliers for locations inside the country, and from non-U.S.-based suppliers at non-U.S. facilities.

Inputs/Materials Sourcing Practices



Source: BIS survey data

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[80] Companies may not have full visibility into original sourcing of materials. The survey data addresses respondents' understanding of where their inputs are acquired, but does not fully represent the location of their suppliers' activities and sourcing.

Wafers

Bare wafers were a notable standout, as the only material for which the majority was sourced from non-U.S. suppliers both inside and outside the country. Wafers were most frequently identified by respondents as a material or input they were concerned about their ability to acquire between 2022 and 2027, with 80 percent of those respondents indicating their level of concern was extreme, great, or moderate.

The silicon wafer market is concentrated in several large suppliers, largely based in East Asia. Japan-based Shin-Etsu Chemical and SUMCO account for over half of the overall wafer market, with Taiwan-based GlobalWafers, South Korea-based SK Siltron, and Germany-based Siltronic accounting for all but 10 percent of the remaining market share.[81]

Each of these wafer providers have a production presence in the United States, with several having planned to expand their U.S. production capacity based on CHIPS Act investments. SK Siltron announced in 2021 plans for a $300 million investment in Bay City, Michigan, focused on silicon carbide wafers.[82] Shin-Etsu operates a facility in Vancouver, Washington and began permitting plans in 2022 for a 300,000 square foot expansion.[83] GlobalWafers has carried out a $300 million expansion of its O'Fallon, Missouri facility and is constructing a $5 billion for a new 3.2 million square foot "state-of-the-art" facility in Sherman, Texas, with the $1 billion first phase expected to be complete in 2025.[84] The company's CEO commented that these expansions would not "be possible without the passage of the CHIPS Act."[85]

Gases

Beyond wafers, survey respondents were most concerned about their ability to purchase the gases and wet chemicals required for the production of semiconductors. Gases—with over 100 different electronic specialty gases (ESGs)[86]—presented the most acute concern. Forty-two percent of respondents who identified gases as an item of concern foresaw extreme or great difficulty in acquiring them between 2022 and 2027.

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81 https://www.siltronic.com/fileadmin/investorrelations/2021/Quartal3/20211026_Siltronic_Q3_2021_Investor_Presentation.pdf

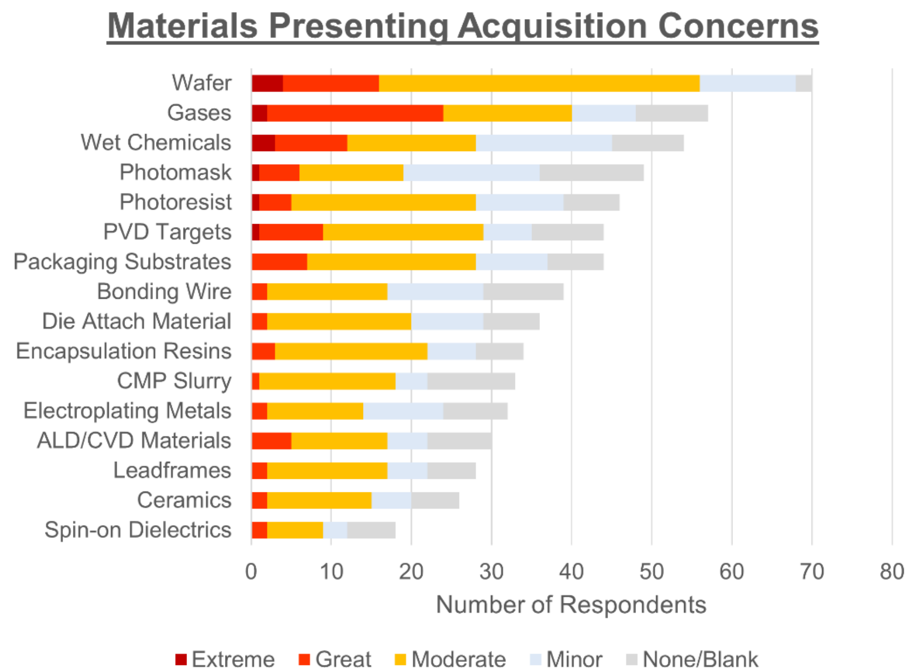
82 https://www.prnewswire.com/news-releases/sk-siltron-css-announces-300-million-michigan-expansion-to-support-electric-vehicle-growth-301333677.html

83 https://www.columbian.com/news/2022/aug/12/seh-america-plans-300000-square-foot-expansion-to-vancouver-campus/

84 https://www.bizjournals.com/dallas/news/2023/08/04/globitech-globalwafers-sherman-texas-instruments.html

85 https://www.reuters.com/technology/taiwans-globalwafers-invest-5-bln-new-silicon-wafer-plant-texas-2022-06-28/; https://www.commerce.gov/news/press-releases/2022/06/globalwafers-selects-sherman-texas-new-semiconductor-silicon-wafer-site; https://www.stltoday.com/news/local/stcharles/st-charles-county-plant-touts-expansion-aims-to-combat-global-semiconductor-shortage/article_b3568ee8-2a6e-11ee-a3ab-f78b87208585.html

86 https://www.linde-gas.com/en/images/Gasworld - Creating a Semiconductor FEB18_tcm17-477345.pdf



Source: BIS survey data

Respondents identified 33 gases of concern with six accounting for half of the total identifications: Helium (15 percent), Nitrogen (13 percent), Hydrogen Chloride (6 percent), Neon and Neon Blends (6 percent), Nitrogen Trifluoride (6 percent), and Hydrogen (4 percent). An additional 13 percent of gas identifications were for general/bulk gases, rather than specifying a particular compound.

Three main factors were cited for nearly all concerns in acquiring gases: growing needs due to expanding semiconductor production, geopolitical instability, and limited sources of material. Geopolitical concerns were largely focused on the war in Ukraine, with concerns focused on the impact on the production and supply of Helium, Neon, Xenon, and Krypton gases. For Helium, several respondents also expressed concerns about supply due to the Congressionally-mandated sale of the Federal Helium System assets operated by the U.S. government's Bureau of Land Management.[87] The sale process began July 12, 2023 and is expected to take eight to nine months to complete.

The ESG market is relatively concentrated, with SEMI reporting that six suppliers accounted for half of the market share in 2019.[88] Survey responses suggested that this understates the reliance on key suppliers in the United States. Just three suppliers—Linde, Air Liquide, and Matheson—accounted for 60 percent of all identifications of respondents' primary supplier of gases.

[87] For more detail on the assets sale: https://www.gsa.gov/about-us/regions/region-7-greater-southwest/region-7-newsroom/greater-southwest-feature-stories-and-news-releases/gsa-announces-sale-of-federal-helium-system-assets-06222023

[88] https://semi.org/en/blogs/technology-trends/opportunities-in-electronic-specialty-gases

Respondents generally did not have multiple sources for individual gases, reporting that an average of 83 percent of their identified gases were provided by their primary supplier.

Electronics are generally not the primary focus for suppliers of ESGs; Linde, for example, reported that 74 percent of their sales were in the manufacturing, chemicals and energy, healthcare, and metals and mining markets.[89] Linde and Air Liquide both report that the electronics segment represented nine percent of their sales, while Matheson parent company Nippon Sanso reported electronics revenue of 18 percent of their business.[90]

Wet Chemicals

Wet chemicals were the third most frequent category of inputs about which respondents expressed concern. As with gases, many respondents indicated the expansion of production would require a commensurate increase in consumption of chemicals (and in some cases disproportionate increases, as more advanced nodes require more processes and more chemicals), with concerns about limited supply both in the United States and worldwide. The main additional source of concern was the lack of U.S.-located suppliers able to meet quality or qualification requirements in particular chemicals.

Respondents identified 78 separate chemicals of concern, led by sulfuric acid (H_2SO_4), which was identified twice as frequently as the next most identified wet chemical (isopropyl alcohol (IPA)). Both chemicals are needed in ultra-high purity form, with import dependence in 2020 estimated at 47 percent and 83 percent, respectively.[91]

Supplier concentration is less acute in wet chemical supply than in other semiconductor materials, with no single supplier identified as a respondent's primary supplier more than 15 percent of the time. The most frequently identified supplier of wet chemicals—U.S.-based Entegris—announced plans in 2023 to sell its electronic chemicals business to Japan-based Fujifilm.[92]

Other Materials

Photomask and Photoresist

Concerns related to photomask acquisition tended to focus on the risk for extended lead times due to the relatively small supply base and increased demand for photomasks. The photomask category was the single most concentrated input category, with the top three suppliers—U.S.-based Photronics, Japan-based Toppan, and U.S.-based Compugraphics—accounting for 70 percent of the primary supplier identifications.

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[89] https://investors.linde.com/-/media/linde/investors/documents/events-and-presentations/linde2q23teleconferenceslides.pdf?la=en

[90] https://www.airliquide.com/sites/airliquide.com/files/2023-02/air-liquide-2022-strong-performance-acceleration-investment-decisions-prepare-future-presentation.pdf; https://www.nipponsanso-hd.co.jp/en/ir/library/integrated_report.html

[91] https://techcet.com/wp-content/uploads/2021/08/TECHCET-AdvisoryAlert-Impact-081121LS.pdf

[92] https://investor.entegris.com/news-releases/news-release-details/entegris-sell-electronic-chemicals-business-fujifilm

Respondents indicated their U.S. facilities were heavy users of photomasks sourced from within the United States. Three-quarters of respondents indicated the photomask at their U.S. facilities was entirely U.S.-sourced, and 88 percent of respondents stated that most of their photomask was U.S.-sourced. This notable level of U.S.-sourcing is supported by both the significant market share of U.S.-based companies as well as notable production inside the country by Japan-based Toppan, which further announced in 2023 plans for a $185 million expansion of its Round Rock, Texas facility.[93]

For photoresist, concerns were largely centered on the increased need for photoresist and reliance on companies based in Japan. Four of the five most frequently identified providers of photoresist in the BIS survey were based in Japan: FujiFilm, Tokyo Ohka Kogyo (TOK), Kayaku Advanced Material, and JSR Micro. The fifth, Merck, is based in Germany. Some reports suggest that as much as 90 percent of the world's photoresist may be produced in Japan.[94]

Deposition Materials

Materials used in deposition—physical vapor deposition (PVD) targets, atomic layer deposition/chemical vapor deposition (ALD/CVD) materials, and spin-on dielectrics—were not generally seen as presenting major acquisition concerns for respondents. The most significant identified concerns revolved around obsolescence or discontinuation of products, increased demand, and unreliable sources for the underlying materials.

Many of these materials are provided by U.S.-based companies. In PVD targets, U.S.-based companies accounted for four of the five most frequently identified primary suppliers: Materion, Praxair (owned by UK-based Linde), Honeywell, and Plasmaterials. In the less-frequently cited spin-on dielectrics, U.S.-based DuPont is a key supplier, as is HD MicroSystems, a DuPont-Showa Denko joint venture. In ALD/CVD materials, German-based Merck and its subsidiaries—Versum Materials, EMD Electronics, and Sigma-Aldrich—accounted for the four most frequently identified primary suppliers and represented half of all identified providers of ALD/CVD materials.

Packaging Materials

Given the relatively minimal level of AT&P done in the United States, the associated required materials generally did not have large numbers of respondents expressing concern. There were, however, indications of acute concerns within those companies that do require these materials. Leadframes, ceramics, and packaging substrates were behind only gases and wafers in the share of respondents ranking their level of acquisition concern as "extreme", "great", or "moderate".

These materials have limited sources of supply in the United States, with most sources of supply located in Asia, where nearly all AT&P is performed. For leadframes in particular, respondents indicated having minimal sources inside the United States. Just six percent of respondents

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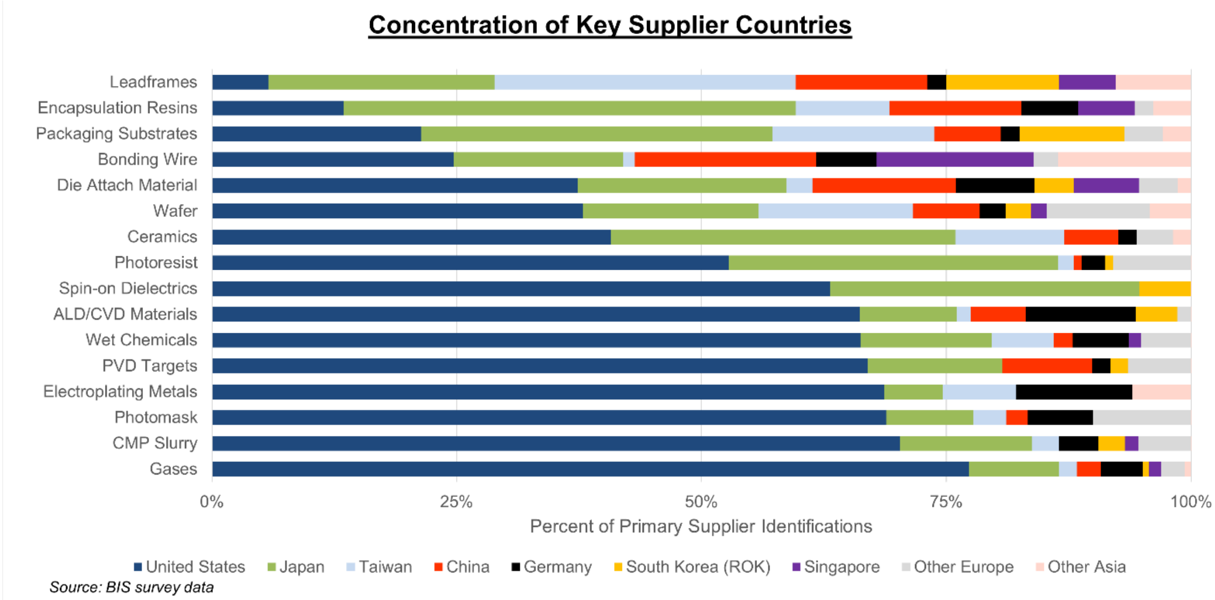
[93] https://roundrockchamber.org/toppan-photomasks-selects-round-rock-location-for-major-185m-expansion/
[94] https://www.reuters.com/article/us-southkorea-japan-laborers-factbox/factbox-the-high-tech-materials-at-the-heart-of-a-japan-south-korea-row-idUSKCN1TX12I

indicated that a U.S.-based supplier was their primary supplier of leadframes, and 79 percent of respondents reporting having only foreign suppliers for leadframes.



Material Summary

Semiconductor fabrication requires a large variety and diverse set of material inputs. Companies manufacturing semiconductors tend to source these materials relatively locally. Survey respondents indicated that the United States lacks sufficient bare wafer production capabilities and has a minimal supply chain supporting AT&P. The industry as a whole is highly reliant on companies based in Japan for photoresist, and many respondents expressed concern about the global supply of key gases, with significant reliance on a few large suppliers.

There are some indications that the large investments in new fabrication clusters in the United States is pulling in significant investment in the supporting ecosystem. With Intel and TSMC collectively investing $60 billion in new leading-edge fabrication facilities in Arizona, many suppliers have also announced plans to build new facilities in the state. As of July 2023, ten material suppliers planned to invest over $1.6 billion in new facilities in Arizona.[95] More broadly, 13 additional material input providers have plans to invest over $8.5 billion in new or expanded U.S. capacity, including—as indicated above—investments by several bare wafer suppliers, with GlobalWafers alone investing more than $5 billion.[96]

3.3 Availability of Equipment

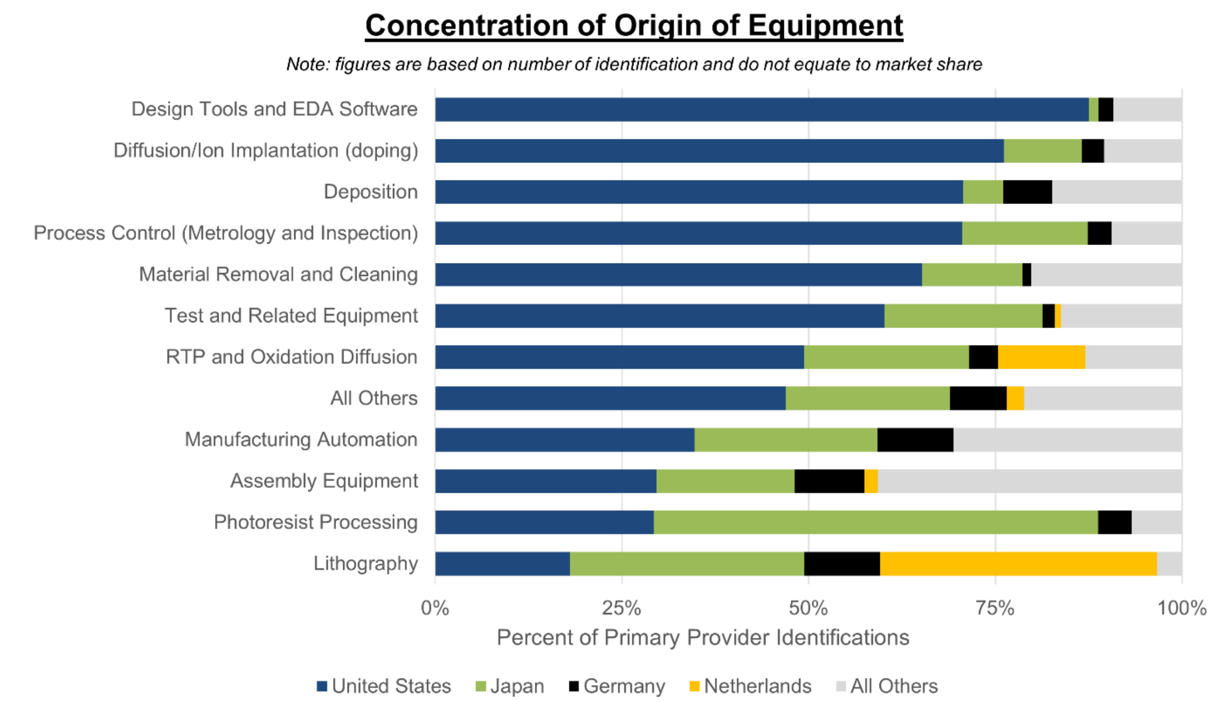
Semiconductor companies purchased in excess of $100 billion of semiconductor manufacturing equipment (SME) in 2022,[97] with equipment accounting for an estimated half of the cost of a

[95] https://www.semiconductors.org/the-chips-act-has-already-sparked-200-billion-in-private-investments-for-u-s-semiconductor-production/
[96] https://www.semiconductors.org/the-chips-act-has-already-sparked-200-billion-in-private-investments-for-u-s-semiconductor-production/
[97] https://www.theregister.com/2023/04/14/semiconductor_manufacturing_gear_sales/

new fabrication facility.[98] Companies based in the United States, Japan, and the Netherlands account for 90 percent of the SME market share, with market share of U.S.-based companies nearing half of that total.[99]

BIS collected data on 12 categories of SME used in design, front-end, and back-end fabrication, asking respondents about their key suppliers, share of equipment supplied, lead times, reasons for supplier selection, and challenges in acquiring equipment. Respondents identified over 1,000 pieces of equipment from nearly 300 different suppliers, though four suppliers accounted for over one-quarter of all identifications: U.S.-based Applied Materials, Cadence Design Systems, and KLA Corporation, and Japan-based Tokyo Electron.

For nearly all categories of SME, U.S.-based suppliers were the primary source of equipment. Key exceptions include lithography and photoresist processing. In lithography equipment, Netherlands-based ASML accounts for an estimated two-thirds of the market share, with Japan-based Canon and Nikon making up virtually all of the remainder.[100] In photoresist processing equipment, Tokyo Electron is dominant—the company claims 90 percent market share in photoresist coating/developing—[101]and was identified as respondents' primary supplier more than ten times as frequently as the next most common supplier.

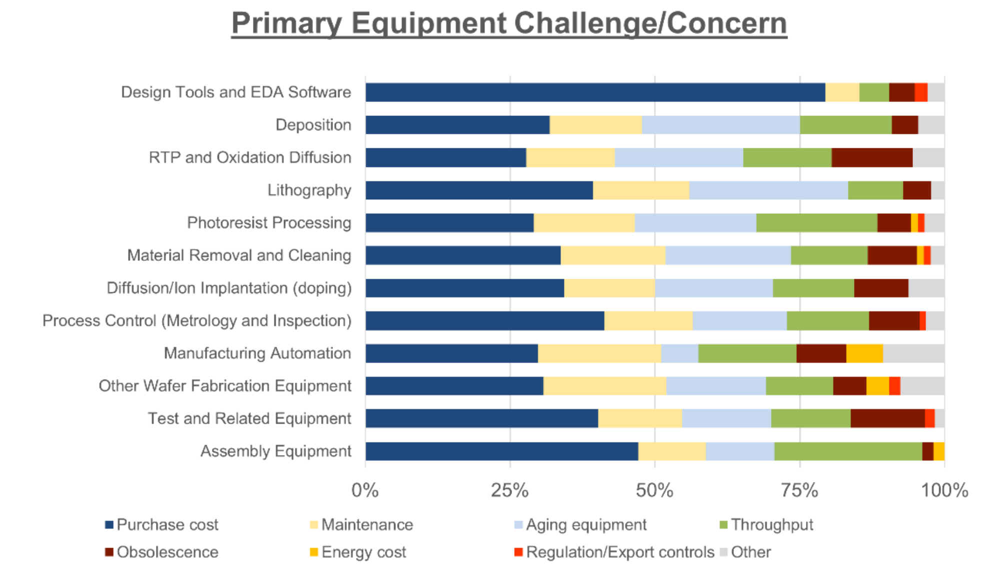


Source: BIS survey data

[98] https://web-assets.bcg.com/27/cf/9fa28eeb43649ef8674fe764726d/bcg-government-incentives-and-us-competitiveness-in-semiconductor-manufacturing-sep-2020.pdf
[99] https://cset.georgetown.edu/wp-content/uploads/The-Semiconductor-Supply-Chain-Issue-Brief.pdf, Company annual reports
[100] https://cset.georgetown.edu/wp-content/uploads/The-Semiconductor-Supply-Chain-Issue-Brief.pdf
[101] https://www.tel.com/product/

Respondents indicated there were extended lead times for equipment virtually across the board. The median lead time to receive equipment was at least one year for all categories of equipment except Assembly, Manufacturing Automation, and Test, which averaged 26 to 32 weeks. Lead times for lithography equipment were especially long—averaging 74 weeks—with lithography equipment for 300mm wafers even higher, averaging 95 weeks.

BIS asked respondents to identify their primary challenge or concern for each category of equipment. A list of seven potential concerns was provided—aging equipment, energy cost, maintenance, obsolescence, purchase cost, regulation/export controls, and throughput—with respondents also able to manually enter their own concern. Responses were largely consistent across categories of equipment, with purchase cost being the primary concern, representing 41 percent of identifications, followed by aging equipment, maintenance, and throughput, each with approximately 15 percent of identifications.



Source: BIS survey data

Four categories had notable deviation from the typical responses. For Design Tools and EDA Software, nearly all respondents identified purchase cost as their primary concern. For Deposition equipment and lithography equipment, the share of respondents listing aging equipment as their primary concern was 60 percent higher than average. With regard to Assembly equipment, respondents were disproportionately concerned about throughput, which was identified nearly twice as frequently as for other categories.

In a separate section of the survey addressing general business challenges, several respondents provided additional insight on the challenges of aging equipment and facilities:

- *"Our U.S. manufacture facility is a [decades old] 8-inch fab with more than 20 obsolete tools with no spare parts."*
- *"CapEx costs outweigh the wafer demand and ROI from the [defense industrial base]."*
- *"Technology advancements into larger and larger diameter wafers requiring upgrading or replacement of key equipment."*

- *"Current fabrication facilities are beyond their design life. A significant fraction of equipment is past OEM support and often third-party support."*
- *"Due to the substantial additional costs associated with building and running Fabs in the US with respect to other countries in Asia, Fab facilities, infrastructure and equipment must be kept longer to keep profit margins up. This becomes difficult to maintain as facilities and equipment become obsolete."*

3.4 Capital Requirements

Front-end fabrication facilities are expensive to build, and increasingly so for leading-edge facilities. As noted above, each of the new facilities being built in the United States by TSMC and Intel are expected to cost $20 billion, while Micron's Boise, Idaho facility is expected to cost $15 billion. TSMC has indicated that it plans to spend in excess of $60 billion on its leading-edge Fab 18 in Taiwan—which it describes as double the size of a standard logic fab—being built in the Southern Taiwan Science Park.[102]

New fabrication facilities based on larger feature sizes also run in the billions of dollars to construct. Texas Instruments plans to spend over $7 billion per fab in its new Sherman, Texas facilities,[103] SkyWater Technology plans to spend nearly $2 billion on the construction of a new facility in West Lafayette, Indiana,[104] and GlobalFoundries is spending $1 billion to increase wafer capacity by 40 percent at its Malta, New York facility.[105]

Equipment is estimated to account for half of the cost of a new fab but also contributes to operating expenses for existing fabs. Equipment maker Applied Materials, for instance, reported in 2022 that 30 percent of its revenue was attributable to its Applied Global Services division, which provides "spares, upgrades, services, remanufactured earlier generation equipment and factory automation software."[106]

Among survey respondents, half of those providing data on their capital expenditure priorities indicated that equipment was their top capital expenditure priority. Total identifications of equipment as a priority exceeded the second and third most common priorities (expansion of existing facility and building of a new facility) by a factor of three. Equipment priorities tended to be disproportionately focused on use for discretes and analog ICs, with micro and logic underrepresented.

For the second most frequently identified capital expenditure priority—expansion of an existing facility—respondents indicated they plan to expand or modernize 59 percent of their U.S. front-end fabrication facilities within the next 10 years, and 74 percent of their non-U.S. front-end facilities. Much of this activity is already underway, with respondents indicating they expect to

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[102] https://pr.tsmc.com/english/news/2986
[103] https://gov.texas.gov/news/post/governor-abbott-announces-texas-instruments-potential-30-billion-investment-in-sherman
[104] https://www.skywatertechnology.com/skywater-plans-to-build-advanced-1-8b-semiconductor-manufacturing-facility-in-partnership-with-the-state-of-indiana-and-purdue-university/
[105] https://www.forbes.com/sites/willyshih/2021/07/20/globalfoundries-fab-expansion-doing-a-little-math/
[106] Applied Materials Form 10-K

both modernize *and* expand 25 percent of their U.S. front-end facilities and 24 percent of their non-U.S. front-end facilities in the next one to two years.

While equipment costs account for the majority of the cost of a new fabrication facility and have minimal variance between countries, costs of construction may be significantly higher in the United States than in East Asia where much of fabrication capacity currently exists. TSMC Chief Financial Officer Wendall Huang suggested the cost of the construction portion of a new fab may be four to five times higher in the United States than in Taiwan, attributing the difference to cost of labor, permits, health and safety regulations and "people and learning curve costs."[107] The company further indicated that their overall fab costs for their facilities outside of Taiwan may be as much as 50 percent higher per wafer due to these costs, smaller production scales, and a less robust semiconductor ecosystem as a whole.[108]

Several of these increased costs result from the minimal level of fab construction in the United States in recent years. TSMC indicated it delayed the opening of its Arizona facility from 2024 to 2025 due to "an insufficient amount of skilled workers with the specialized expertise required for equipment installation in a semiconductor-grade facility," further noting it was sending experienced workers from Taiwan to train workers in the United States.[109] The lack of skilled construction workers has been disputed by local unions, with the president of the Arizona Building and Construction Trades Council arguing that "our workers are well-equipped and able to meet semiconductor construction demands" and noting that "union workers complete rigorous multiyear apprenticeship programs that include hundreds of hours of classroom training and field experience."[110]

Intel has reportedly run into similar challenges in the construction of their Ohio facilities, with demand for electricians and pipe fitters "significantly outstripping the supply of labor in the local area," and the company's lead contractor indicating it expected its construction workforce would rely on over 40 percent of workers from outside the immediate area, and 30 percent would be apprentices.[111] Another survey respondent commented: "Semiconductor manufacturing facilities are supported by broader manufacturing clusters developed in coordination with materials suppliers and other specialized vendors. Low investment in recent years in the United States means that this industrial support capacity is underdeveloped."

The number of new fabs built in the United States fell from 55 in the 1990s to 43 in the 2000s and 22 in the 2010s. None of these new facilities have been large fabs (capacity greater than 100,000 wafer starts per month), while 56 new large fabs were built worldwide since 1990, more than half of which were in China.[112] New fab construction times in the United States, which were

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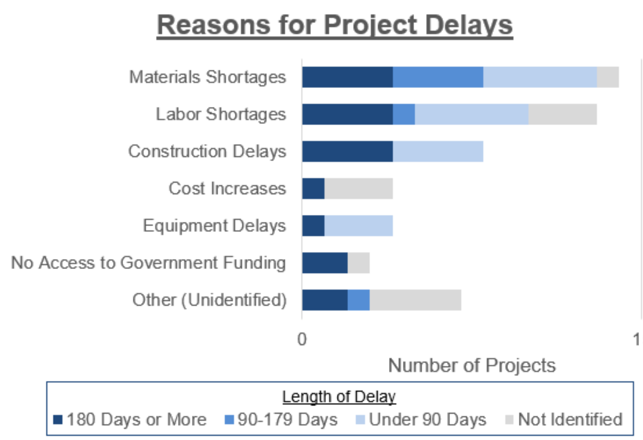
[107] https://www.cnbc.com/2023/03/09/why-manufacturing-chips-in-us-may-make-smartphones-more-expensive.html
[108] https://investor.tsmc.com/english/quarterly-results/2023/q2
[109] https://investor.tsmc.com/english/quarterly-results/2023/q2
[110] https://www.bizjournals.com/phoenix/news/2023/07/27/tsmc-worker-shortage-phoenix.html
[111] https://www.bloomberg.com/news/features/2023-03-09/worker-shortages-are-hurdle-for-52-billion-us-plan-to-boost-chip-manufacturing
[112] https://cset.georgetown.edu/publication/no-permits-no-fabs/

on par with those in China and Taiwan in the 1990s, rose to 2.5 years in the 2010s, 36 percent longer than in China and 41 percent longer than in Taiwan.[113]

For current projects, a total of 35 survey respondents identified 52 projects that had experienced unexpected delays in the prior year. The majority of these delays were attributable to either material or labor shortages. The median identified delay was 120 days, with an associated budget increase of 15 percent. Construction delays were the most costly, leading to an average budget increase of 34 percent.



In aggregate, 136 respondents identified over 350 individual capital projects with expected ten-year expenditures of nearly $350 billion, of which $208 billion was expected to take place in the United States. Respondents anticipated that government funding (at any level) would account for 15 percent of the total expenditures, and 19 percent of expenditures in the United States.

Thirty-six respondents explicitly indicated that some of their investment plans were contingent on, on hold, or pending the availability of government funding. Several of these respondents provided notable comments on these plans:

- *"Our U.S. investment plans are contingent on government funding. Without this funding, it would not be economically viable to complete these projects in the U.S."*
- *"The additional cleanroom building will be dependent on receiving CHIPS Act funding. If not received, expansion is likely to take place in [Asia] due to favorable cost factors."*
- *"U.S. government funding would impact the amount of investment we make in the U.S. versus in Europe and Asia."*
- *"The viability of making some of these investments in the U.S. is dependent upon obtaining funding from the U.S. government."*
- *"We will continue to invest, as we have for many years, however timing, duration and scale of our expansion efforts would be positively impacted with Government assistance."*
- *"The current non-government plan will only provide slow incremental progress."*
- *"While government funding will be critical to the project's success and expansion, [our company's] plans are not contingent on funding." "[New investments] were announced in good faith after the CHIPS for America Act was enacted, and their full use and production timeline also are contingent on sufficient USG funding."*

[113] https://cset.georgetown.edu/publication/no-permits-no-fabs/

3.5 Workforce

Employment Levels

The semiconductor industry requires a highly educated labor force, directly employing over 200,000 people in the United States, with over one-third of positions requiring an advanced degree. Increased investments in semiconductor production in the United States are driving a need for additional workers, with survey respondents indicating expectations to add 70,000 new jobs by 2032.

Semiconductor employment is concentrated in several large companies. Intel alone accounts for one-quarter of total estimated U.S. semiconductor employment, with four additional companies—Qualcomm, Texas Instruments, NVIDIA, and Broadcom—collectively accounting for an additional one-quarter of semiconductor jobs in the United States. Twenty of the largest semiconductor companies that publicly report U.S. workforce data (a group accounting for 85 percent of U.S.-based semiconductor revenue) collectively employed 171,050 workers in the United States in 2022, an estimated 83 percent of total direct U.S. company semiconductor employment.[114]

Publicly Reported U.S. Employment of Large Semiconductor Companies

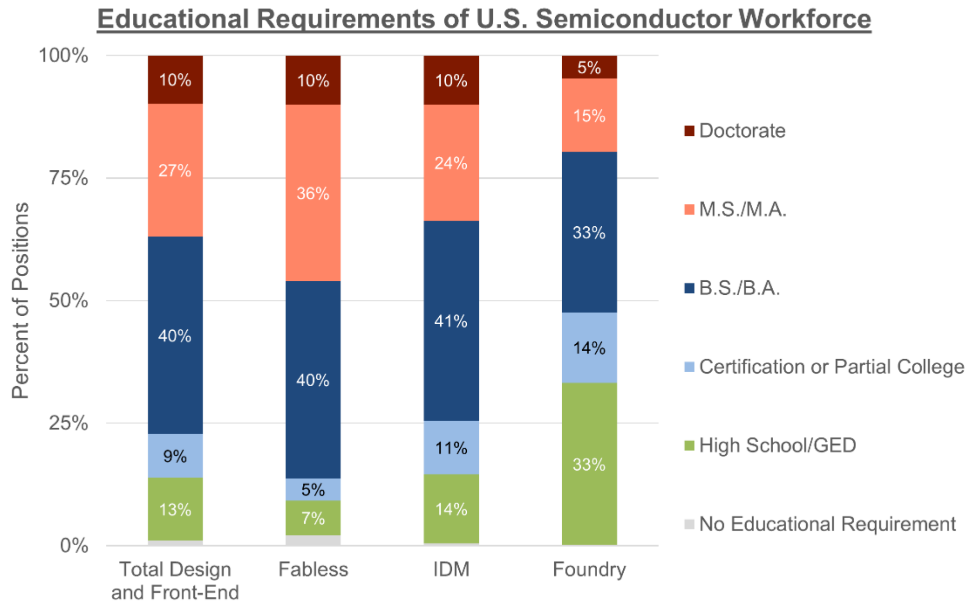
Company	Global Employment	U.S. Employment	Share of Company Workforce in U.S.	Share of Estimated U.S. Employment
Intel	131,900	53,938	41%	26%
Qualcomm	51,000	15,902	31%	8%
Texas Instruments	33,000	12,718	39%	6%
Nvidia	26,196	10,525	40%	5%
Broadcom	20,000	10,302	52%	5%
Micron Technology, Inc.	48,000	9,137	19%	4%
Western Digital	65,000	7,851	12%	4%
Microchip Technology Inc	21,000	6,256	30%	3%
NXP Semiconductors	34,500	6,210	18%	3%
GlobalFoundries	14,000	5,880	42%	3%
Advanced Micro Devices	25,000	5,461	22%	3%
Analog Devices	24,450	4,579	19%	2%
Qorvo	8,900	4,555	51%	2%
onsemi	33,690	3,639	11%	2%
Marvell Semiconductor	6,741	3,505	52%	2%
Infineon Technologies	56,200	3,354	6%	2%
Skyworks Solutions	11,150	2,611	23%	1%
Vishay Intertechnology	23,900	2,300	10%	1%
Tower Semiconductor	5,887	1,538	26%	1%
STMicroelectronics	51,370	789	2%	0%
Total	**691,884**	**171,050**	**25%**	**83%**

Source: Corporate annual reports, company websites, and public EEO-1 filings

[114] Note that this does not include non-corporate semiconductor employment (such as academic research), nor employment within the semiconductor supply chain (such as at providers of semiconductor manufacturing equipment). The Semiconductor Industry Association estimates that for each direct semiconductor job there are an additional 5.7 jobs supported in the broader United States, suggesting that the U.S. semiconductor industry supports more than 1.2 million U.S. jobs.

Educational Requirements

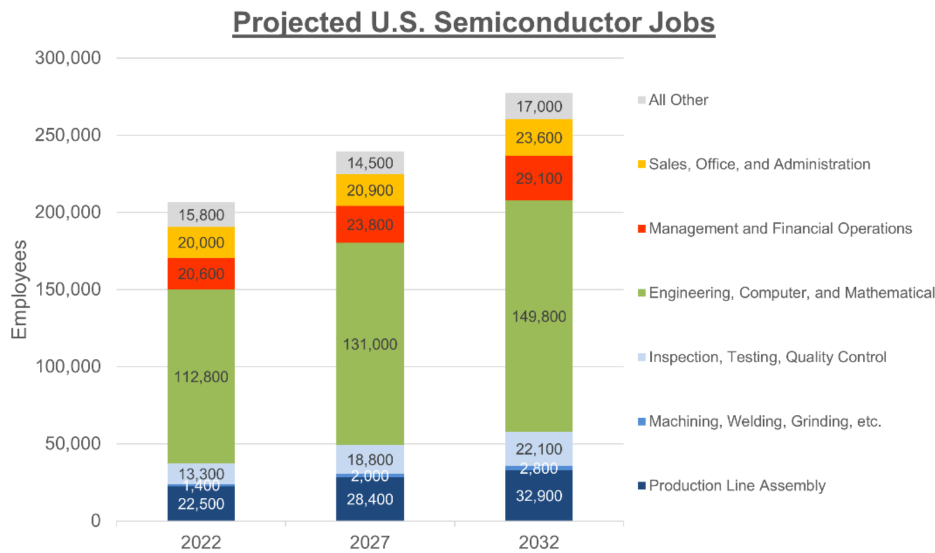
Survey respondents indicated that in 2022, just over three-quarters of their employees held positions that required at least a four-year degree, with nearly half that portion required to hold an advanced degree. Fabless companies required significantly more education than did foundries, with nearly half of the positions at fabless companies requiring an advanced degree and 86 percent requiring at least a four-year degree. While foundries reported that half of their positions required a four-year degree, they also indicated that one-third of positions required no more than a high school diploma.



Source: BIS survey data

Much of the difference in educational requirements is driven by differences in job categories. Two-thirds of fabless jobs were categorized as Engineering, Computer, or Mathematical, twice as high a share as at foundries. At foundries, nearly half of jobs were in production line operations, with far less stringent educational requirements—foundries reported that 82 percent of their production line positions required no more than a high school diploma, with only one percent requiring an advanced degree.

Respondents' projections for future job availability indicated they plan to add 70,000 jobs by 2032. Production jobs were projected to expand from 18 to 21 percent of semiconductor jobs by 2032, with Production Line Assembly increasing from 11 to 12 percent of all jobs and Inspection, Testing, and Quality Control from six to eight percent.



Source: BIS survey data

Despite the expanding share of production jobs, the overall share of jobs not requiring a four-year degree is expected to stay constant through 2032. Foundries indicated a slight tightening of educational requirements, with the share of foundry jobs requiring at least a four-year degree rising from 52 percent in 2022 to 56 percent in 2032. The overall expansion of the semiconductor workforce is projected to create thousands of new jobs across educational requirements, with an estimated 54,000 new jobs requiring at least a four-year degree and 16,000 new jobs not requiring a four-year degree.

Pay, Turnover, and Vacancies

Semiconductor jobs are generally well-paid. The average reported salary for production occupations among semiconductor companies was $60,000, well above the mean annual wage of $45,370 for production occupations in the United States as a whole.[115] Pay in Engineering, Computer, and Mathematical occupations also significantly exceeded the national average of $103,670,[116] averaging $145,000 across all respondents and reaching $173,000 at fabless respondents.

Jobs in the semiconductor industry typically require specialized skills or prior industry experience. Respondents overwhelmingly cite competition as a major challenge to recruiting and maintaining employees, not limited to competition among semiconductor firms but also across different industries where STEM candidates are in high demand. The competition is even more stringent for smaller companies, with vacancy rates among respondents with fewer than 100 employees reaching 14 percent, over twice the level of larger respondents.

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[115] Based on BLS data for employment group 51-0000 Production Operations https://www.bls.gov/oes/current/oes510000.htm

[116] Based on BLS data for employment groups 15-0000 Computer and Mathematical Occupations (https://www.bls.gov/oes/current/oes150000.htm) and 17-0000 Architecture and Engineering Occupations (https://www.bls.gov/oes/current/oes170000.htm)

Overall, respondents indicated having over 15,000 current vacancies—a vacancy rate of seven percent. The majority of the semiconductor industry's U.S.-based workforce is employed in the Engineering, Computer, and Mathematical occupational category, which accounts for about half of all industry-related jobs and roughly 55 percent of all vacancies reported in 2022.

The highest vacancy rate by far was reported in the Machining, Welding, Grinding occupational category. This was the smallest surveyed job category, accounting for 0.7 percent of total jobs, yet accounted for three percent of all vacancies in 2022 with nearly one-third of positions unfilled. These jobs are required for the construction of new fabs. Respondents noted shortages of "trade workers with specialized concrete, electrical, mechanical, pipefitting, and other skills needed to construct and maintain fabs and packaging facilities," of "hands-on electrical and mechanical skills for preventative maintenance and troubleshooting of high-tech cleanroom equipment," and of "Trades/Facilities and Equipment Technicians."

For production line assembly jobs, several respondents note they experience higher turn-over for their entry-level positions, typically attributed to factors such as the challenges of working in clean room environments with protective clothing, limited opportunities for advancement, and competition for workers. Notable comments include:

- *"Requires comfort working in a clean room environment and wearing protective clothing for duration of the shift. "*
- *"Having workers with some level of skills either from previous work or from a 2-year school or trade school significantly reduces the time need to train in the facility. It also helps with turnover as the employee knows what to expect and are less likely to leave because the type of work is 'not for them'."*
- *"Across the industry, [we are] seeing increased demand with no real expansion of the supply. This has made it highly competitive to land Silicon talent and retain these employees once hired."*
- *"Lack of large enough candidate pool with hands-on mechanical skills, potential candidates unaware of semiconductor industry"*

In BIS's 2017 survey of the U.S. integrated circuit industry, respondents identified finding both qualified or experienced workers, employee turnover, attracting workers to their locations, and finding U.S. citizens to be the key workforce issues anticipated in 2018 to 2022. Respondents continue to generally perceive there to be a limited talent pool and shortage of available workers, with a limited education pipeline in specific technology fields and/or STEM-related degrees. One respondent summarized: "In many STEM areas, there are insufficient numbers of workers with advanced degrees to meet the needs of the entire technology sector. This shortage is exacerbated by the fact that a majority of graduates in key STEM fields are [increasingly] foreign nationals. Restrictive numerical limits on immigrant and nonimmigrant visas makes it extremely challenging to hire and maintain such students."

In 2019, students on temporary visas earned 36 percent (just under 75,000) of all science and engineering master's degrees—a ten percentage point increase from 2011—and one-third of all science and engineering doctorates.[117] According to the American Semiconductor Industry Coalition, the industry "continues to look to foreign nationals under the H1-B [visa] category to supplement the talent pool" in the short term[118], as fewer U.S. citizens pursue advanced degrees in STEM[119] and the shortage of specialized, domestic talent remains.

In addition to a perceived insufficient supply of U.S. citizen workers, respondents report significantly higher turnover rates among U.S. citizens than among non-citizens, further increasing the attraction of non-citizen workers. Three-quarters of respondents reported higher turnover rates among U.S. citizens, and the average turnover rate of U.S. citizens was 45 percent higher than the non-citizen rate. Visa restrictions may be a significant factor in lower turnover rates among non-U.S. citizens, as visas are often linked to employment. There is no data that indicates that non-U.S. citizens are used instead of U.S. citizens to cut costs; average salaries tended to increase with higher shares of non-U.S. citizen workers.

The overwhelming majority of respondents report great or moderate difficulty recruiting or hiring workers at all levels of industry experience.

Training and Recruitment

Candidates with little industry experience require extensive training, which can be time consuming and costly for companies, especially those with limited or strained resources. Companies estimate at least six months of foundry training is needed to prepare a worker with little industry knowledge, whereas for engineers and fabless workers it could take nine to 12 months or more to have them fully operational. An IDM respondent cites "for engineers, training can be 1 to 2 years because the job becomes more specialized by skill level." While some companies have training programs in place, many do not and will not necessarily look to hire candidates with limited experience due to the high costs of training.

Respondents primarily report offering internships to undergraduate and graduate students to offer hands on experience in the semiconductor sector and will recruit from universities. Respondents will also partner with universities and community colleges to collaboratively develop curricula and certificates.

Intel, for example, has announced a series of such partnerships as part of the preparation for its new Ohio facilities, where there is not a major existing semiconductor production ecosystem. The company has announced plans to contribute $50 million to higher education institutions in Ohio to help develop the workforce, with more than 80 institutions participating. Among the announced projects are plans to create "rapid technician certification" programs, to "prioritize adding semiconductor courses to existing manufacturing and computer science programs," to "recruit students from underrepresented groups and offer training programs for fab technicians,

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[117] https://ncses.nsf.gov/pubs/nsb20221/u-s-and-global-stem-education-and-labor-force

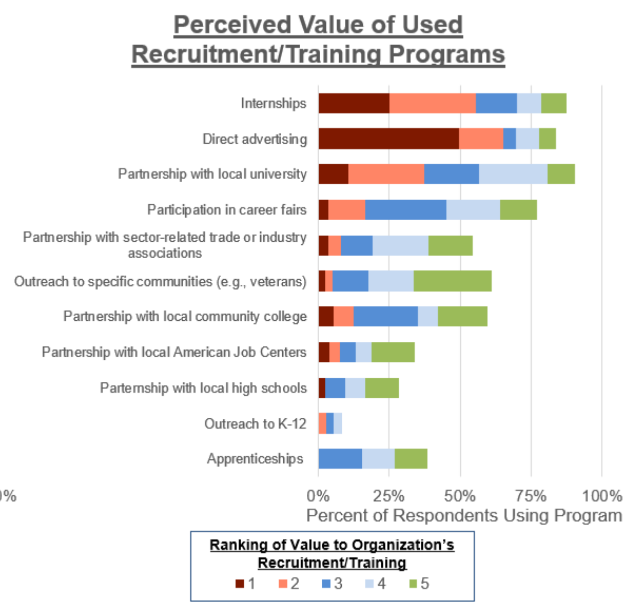
[118] https://asicoalition.org/response-to-rfi

[119] According to the National Science Foundation's 2022 Science and Engineering Indicators report, 49% of students on temporary visas study science and engineering, compared to only 35% of U.S. citizens and permanent residents.

entry-level engineers, and advanced-degree graduates," and development of augmented and virtual reality training programs.[120]

Internship programs are an especially important channel through which companies recruit and train new talent for full-time positions. NVIDIA, for instance, identifies internship programs as their "primary pipeline for new college grad and early-in-career hiring,"[121] while onsemi notes that "73 percent of entry level hires were previously interns."[122] Multiple survey respondents noted similar levels of importance, identifying goals of "converting as many as possible to full time employees," "high conversion rate into full-time hires post-graduation," and "great results for interns and the company."

When asked to identify and rank the value provided by their recruitment programs, survey respondents indicated they most frequently used (and found most effective) internships and direct advertising, followed by partnerships with local universities and participation in career fairs.



Nearly half of respondents also indicated partnership with sector-related trade or industry associations and outreach to specific communities. Less than a third of respondents indicated partnership with local community colleges, local American job centers, or local high schools; and less than a fourth of respondents indicated the use of K-12 outreach programs or apprenticeship programs. Apprenticeship programs were minimally used by fabless respondents in particular; their overall low level of use may thus be more indicative of the relatively low share of manufacturing jobs in the United States than their overall effectiveness. The perceived value of outreach to specific communities and partnerships with local community colleges or

[120] https://download.intel.com/newsroom/2022/manufacturing/Ohio-Fact-Sheet-Education.pdf
[121] https://www.nvidia.com/en-us/about-nvidia/careers/university-recruiting/
[122] https://www.onsemi.com/careers/internships/university-relations

sector-related associations, however, was relatively high for those respondents that did use these programs.

Workforce Challenges

Throughout the survey, respondents consistently identified workforce-related challenges as the most crucial to their business. When asked to identify and rank the top five factors most important to their decision on where to invest in expansion or construction, the three most frequently identified factors were workforce-related: labor availability, labor cost, and labor quality. When asked to identify the issues that have most impacted their organization since 2017 as well as those expected to through 2027, the two most frequently identified issues were labor availability/costs and worker skills/retention, each listed by more than two-thirds of respondents.

Survey respondents provided responses totaling over 3,500 words when asked to "identify the skills that impact your industry overall that are currently least available." The provided skills perceived to be in shortage were highly diverse. Half of the responses identified engineers. The most frequently identified specific skillsets included design (34 percent of responses) analog or RF (20 percent), test or verification (15 percent), and software (15 percent).

The suggestions for ways the U.S. government could assist in addressing these difficulties were even more diverse, with 146 comments totaling over 4,600 words ranging from pithy ("invest in education" and "child care support") to multi-paragraph responses covering a variety of topics. One of the most frequently identified general topics were the need to provide increased opportunities to attract and retain talent from outside the United States, mentioned in nearly one-quarter of responses:

- *"International students and foreign-born scientists and engineers are a significant source of technical talent that can help U.S. employers fill critical gaps in the semiconductor sector. Maintaining a welcoming policy towards international students and removing key immigration barriers is essential to preserving America's role as a center of technological innovation. This means reasonable visa policies for international students and making it easier for students to work after graduation, including preserving STEM OPT (Optional Practical Training) and improved policies on H-1B visas, employment-based green cards, and higher per-country limits."*
- *"Increase H-1B visa numbers; create new visa category(ries) for specialized skills to fulfill impacted roles. Simplify L-1 visa process to enable companies to transfer individuals with requisite skills and expertise outside of the U.S. to come to US and hit the ground running on specialized projects. Extend F-1 student visa Optional Practical Training (OPT) or STEM OPT period to enable those who graduated from highly regarded universities in the field of semiconductors to remain in the U.S. longer."*
- *"Consider extending the length of time a person on a visa can remain in the US in the event of a reduction in force/termination from their current role; allowing the individual adequate time to find another role within the country will alleviate the incredible stress and burden of having to leave the country and increases the market availability of talent; the 60 day grace period is nearly impossible to meet due to processing times for change*

of employer cases on top of the length of time required for interviewing and hiring decisions."

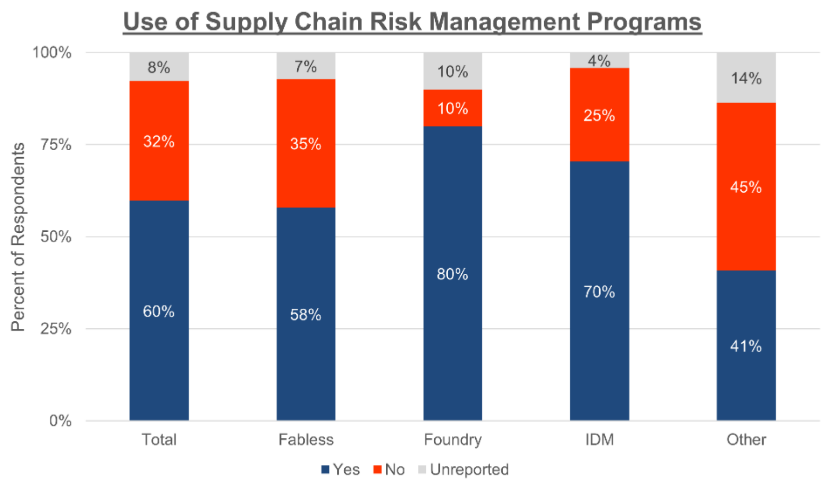
- *"Increase H1B visa cap for tech workers, particularly those who graduate from US Universities with MS/PhDs in Engineering. Lower the time it takes for H1B holders to receive a green card."*
- *"First address the immigration challenges by recognizing that it will take years to improve our own educational system."*

Respondents also frequently provided suggestions on increased financial assistance to students in STEM fields and broader support schools to enhance education in technology at all levels:

- *"We do not have the appropriate training infrastructure for younger students and workers, many dependent on current local/state funding or through bond elections. There are many areas where people will also have difficulty accessing these programs and broadband is not located everywhere."*
- *"Efforts to scale talent pipelines will likely fail without the government support needed to significantly increase student enrollment in relevant STEM fields and expand awareness of the industry. New K-12 programs, for example, are critical for attracting students into fields relevant to the industry, including by promoting STEM education and demonstrating the importance of semiconductors and the rewards of working in the industry. The government should support relevant educational and experiential learning opportunities to attract and retain students in STEM fields throughout the K-12 system, as well as programs to effectively lead high school students to relevant programs in two- and four-year institutions of higher education."*
- *"Provide more scholarships to EE and related majors to encourage more students to pursue these degrees. Develop more STEM education programs from elementary school through high school so that we will have a larger local talent pool in the future. Provide incentives and opportunities for university and industry partnerships in developing semiconductor specific curriculum."*
- *"Support all high-schools in offering at least one engineering course such as robotics."*
- *"Foster Training and Tuition Programs that incent high school grads and those in the workforce who would like to change careers. Focus on minorities, veterans, underprivileged, communities."*

3.6 Supply Chain Risk Management

Sixty percent of survey respondents reported that their organization had a supply chain risk management program (SCRM), while 32 percent reported that they did not. Foundry and IDM organizations, with more extensive supply chains, were most likely to have a SCRM program. Eighty percent of foundry respondents and 70 percent of IDM respondents reported having a program in place, compared to 58 percent of fabless and 41 percent of all other respondents.

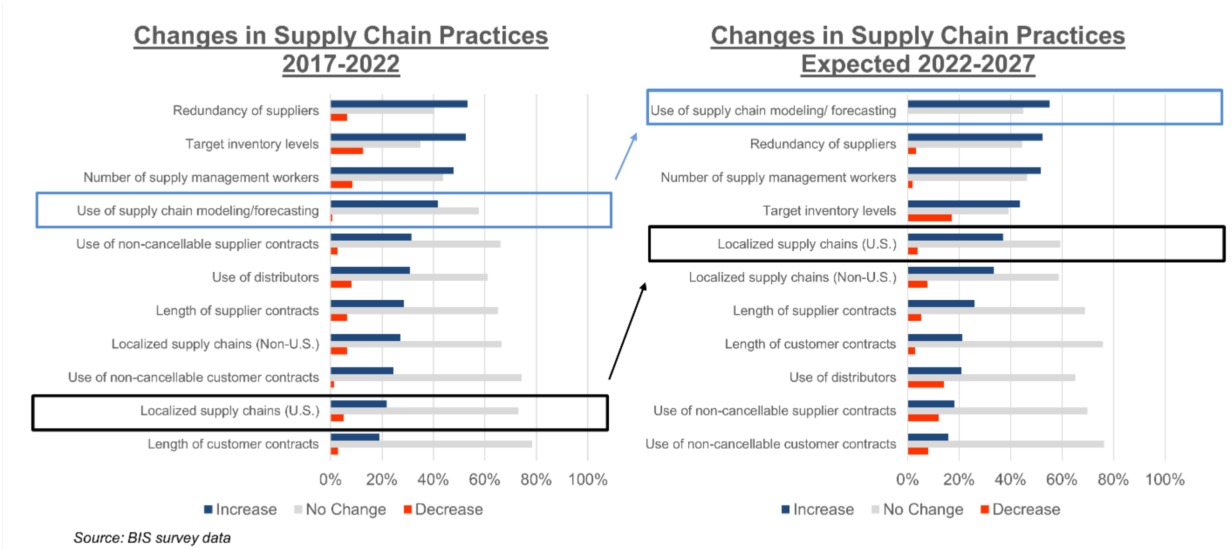


Source: BIS survey data

In response to the question "what software, subscriptions, and/or tools does your organization use to help anticipate and monitor supply chain risks," more than 80 percent of these respondents indicated the use of an internally developed or homegrown software or tool, often in combination with third-party Enterprise Resource Planning (ERP) or Manufacturing Execution System (MES) software:

- *"In-house tool development to track the Supply Chain and also act as a partial ERP tool."*
- *"We utilize our internal ERP system to track down any potential disruption."*
- *"We utilize in-house developed software tools that monitor the installed capacity across the various foundries and OSATs we source from along with their respective, confirmed supply allocations against our long-term forecast."*
- *"We have developed Excel-based programs and tools to identify upstream and downstream disruptions, bottlenecks, and other delays to the procurement processes."*
- *"[Our organization] leverages a custom set of in-house developed WIP monitoring tools we generated using Microsoft's 'Power BI' platform."*
- *"Our ERP system tracks committed delivery dates. We use no other systems to anticipate or monitor supply chain risk."*

The specific ERP, MES, and other third-party software used to monitor risk varies across the respondents, with more than 60 vendors or subscription services reported. SAP or Oracle ERP programs were most commonly cited among respondents with a SCRM program in place, each identified by nearly 15 percent of respondents—nearly five times as often as the next most frequently listed program.



BIS asked survey respondents to identify how their organization's supply chain management activities have changed since 2017 and how they are expected to change from 2022 to 2027. For each supply chain practice or feature, respondents indicated whether there was an increase, decrease, or no change that occurred since 2017, or anticipated to occur from 2022 to 2027.

The use of supply chain modeling and forecasting and localization of supply chains in the United States were the practices with the largest increases in the share of respondents expecting increases through 2027. Respondents anticipate the need to adopt more sophisticated modeling and forecasting tools in the future, such as those leveraging automation:

- *"We expect to increase the use of modeling and forecasting tools even more from now, with more sophisticated approach."*
- *"Advancements in advanced analytics (AI and machine learning) applications in supply chain management are expected to continue to provide significant value in supply assurance, cost, and risk reduction."*
- *"Anticipated trend for further supply chain fulfillment models and additional extended forecasting efforts to continue to improve supply assurance."*
- *"We anticipate forecast based ordering to be a long-term industry shift (which we will be compelled to support)."*

An IDM explained the expected increase in U.S.-based supply chains was due to an "increased awareness and desire for supply chain resilience globally [stimulating additional] ecosystem development efforts," as well as the "potential of CHIPS Act to alleviate prior barriers." Respondents also expected to increase the use of localized supply chains outside the United States as organizations are increasingly driven by regionalization of supply chains and "China Plus One" strategies.

Respondents indicate varied methods for maintaining inventory of critical materials. Most describe regular monitoring of market conditions such as customer demand, sales forecast, or supplier lead times, as well as other inventory management metrics to prepare for potential shocks to supply.

- *"Critical material inventory is determined on a case by case basis depending on expectations around demand, supply risks, and manufacturing cycle times."*
- *"Critical material inventory levels are developed based upon region, number of qualified sources and lead-time."*
- *"Inventory levels are based on a reorder point. Reorder point is determined by such factors as usage history, lead time and cost."*
- *"Inventory levels are defined based on overall leadtime, supplier performance and market situation."*
- *"Inventory targets are determined based on forecast and supply conditions."*
- *"Inventory strategies determined by supplier risk level, lead times and customer criticality."*
- *"Metrics are in place for right-sizing inventory levels at various build stages according to cycle time and demand estimates."*
- *"Monitor commodity base market status and try to secure certain desired levels of inventory, measured in weeks, at all times and purchase ahead of demand when warranted."*

Many respondents secure long-term relationships and maintain close coordination with their key suppliers, which for the majority lend to supporting the maintenance of a buffer, or safety stock, of high criticality materials.

- *"Critical inventories with risk to supply are proactively managed by adding various types of buffered inventory including elevated stock levels and early supplier deliveries."*
- *"For critical supply, we have locked into contractual obligations with key suppliers to provide material with set terms and timelines to ensure our inventory levels."*
- *"Rolling 2 year forecast from customers. High percentage of that forecast is secured with long term supply agreements and firm backlog."*
- *"Our general method is to ensure at least 2-4 weeks of critical materials held in inventory. In addition, our suppliers also hedge any shortage risk by maintaining additional, significant buffers depending on the criticality of the material along with lead-time."*
- *"We maintain inventory levels through volume contracts (i.e., supply a fixed quantity for a certain period of time) with suppliers for critical materials."*
- *"We set safety stock on [critical] items, manage suppliers by following up on committed delivery dates, drive escalations when deliveries are late."*
- *"We use a basic MRP with statistical forecasting and standard safety stock methodologies. The safety stock varies based upon product type, customer breadth and overall risk. MRP runs and exceptions processed daily."*
- *"[We are] regularly revising the forecast in accordance with changing business needs. We coordinate with our manufacturing suppliers to ensure that they secure adequate*

inventory to meet our manufacturing needs. [We seek] diversification with second and dedicated sourcing when available."

3.7 Export Controls

Protecting technologies developed in the United States is essential to U.S. national and economic security. Export controls are a critical tool in protecting these technologies and preventing their use in ways that harm the interests of the United States and its allies. BIS works cooperatively with industry to ensure that dual use export controls advance national security objectives, promote a robust defense industrial base, and do not result in unreasonable restrictions on commercial activities necessary for the health of U.S. industry.

BIS distributed the survey to respondents on October 21, 2022, two weeks after announcing a set of export control updates (commonly referred to as the October 7 rule) aimed at protecting U.S. national security by restricting China's ability to acquire or manufacture advanced computing chips used to produce advanced military systems including weapons of mass destruction.[123]

Within the survey, BIS asked respondents how they had been impacted by the October 7 rule, as well as general questions on their experiences with export controls. Responses to these questions are likely impacted by respondents receiving the survey shortly after the publication of the October 7 rule and reflect their temporary uncertainty on the long-term impact of the rule on their business.

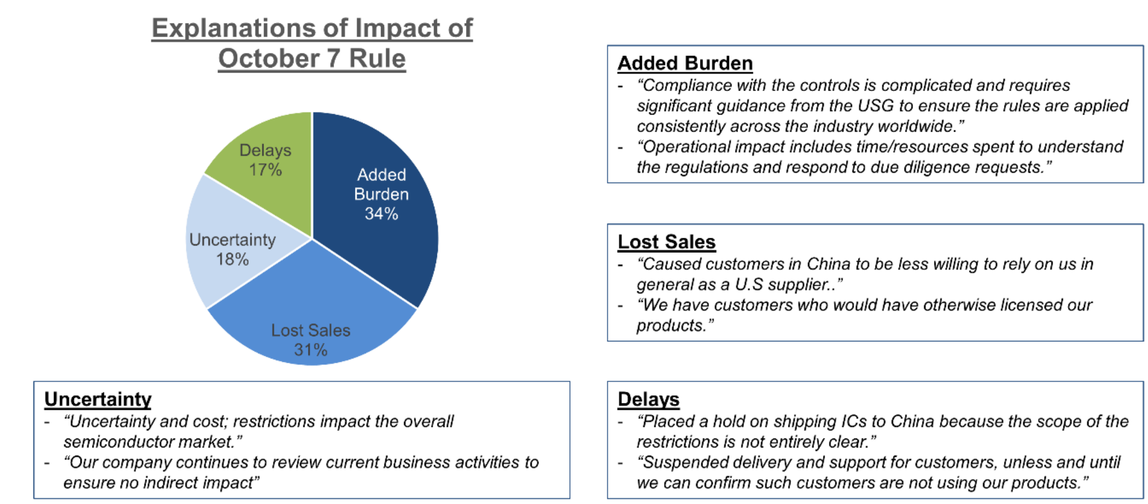
One hundred thirty-four respondents (69 percent) indicated that they design, manufacture, or distribute export-controlled products or services, with 58 (30 percent) reporting they were impacted by the October 7 rule. Of the 58 respondents who indicated the rule affected them, 32 indicated the rule directly impacted them, 14 that it impacted them only indirectly, and 12 did not indicate how they were impacted.

[123] https://www.bis.doc.gov/index.php/documents/about-bis/newsroom/press-releases/3158-2022-10-07-bis-press-release-advanced-computing-and-semiconductor-manufacturing-controls-final/file

Expected Impact of October 7, 2022 Export Control Rules			
Product Area	**Direct**	**Indirect**	**Total**
Advanced Computing Chips	21	15	36
Semiconductor Design Software	7	8	15
Semiconductor Manufacturing Equipment	7	6	13
Semiconductor Manufacturing Equipment Components	6	8	14
Total	**32**	**14**	**58**

Source: BIS survey data
Note: Respondents could provide mixed responses; some respondents were directly impacted in one product area and indirectly impacted in another area. For the total, the "Direct" category covers any respondents who reported experiencing a direct impact. The "Indirect" category covers respondents who reported experiencing only indirect impacts. The Total includes the 12 respondents who did not indicate how they were affected.

Given that the survey was distributed to companies that design, manufacture, or distribute semiconductor products, the greatest impact was in the product area of advanced computing chips. Most respondents did not have products that are immediately controlled by the October 7 rule, but indicated that the existence of the rule added burden and caused uncertainty and delays that impacted their business. BIS subsequently addressed questions and uncertainty related to the October 7 rule via presentations, public briefings, and FAQs.[124]



Source: BIS survey data

BIS also asked respondents whether they had lost sales opportunities due to export controls as a whole, with 74 respondents (39 percent) indicating that their organization had lost sales opportunities. Many of these respondents indicated that they had lost business due to companies being placed on the Entity List, with one-quarter of the comments specifically citing Huawei. Respondents had little visibility into companies that benefitted from their lost sales, but generally believed that companies based in China had benefitted. Several companies also further

[124] https://www.bis.doc.gov/index.php/about-bis/newsroom/2082

commented that the complexity of export controls had caused them to avoid transactions rather than incur the time and expense of ensuring compliance. Select comments on lost sales due to export controls include:

- *"[Our company] faces potential risks of being designed out of products and systems in the China market. We are seeing a trend of China moving to local or non-US suppliers (i.e. European and Japanese companies that are not subject to US controls) where they can. We also face the potential risk of losing opportunities to be designed into future products due to increased inability to introduce [our] technology in university settings in China. Universities are a pipeline for exposing students to [our] products and technologies who may later design them into future downstream products."*
- *"Due to the complexity of the Foreign Direct Product Rule involving some of the entity list parties, we take the conservative approach to not having transactions with such entities."*
- *"We avoid … engagements with Chinese companies due to the increased restrictions."*
- *"A lot of foreign firms will ask first, and if there is a license requirement, they tend to go elsewhere."*
- *"China has reduced its purchases of optical networking components from U.S. suppliers and have moved aggressively to use domestic Chinese suppliers or suppliers from Japan, South Korea, or Europe."*

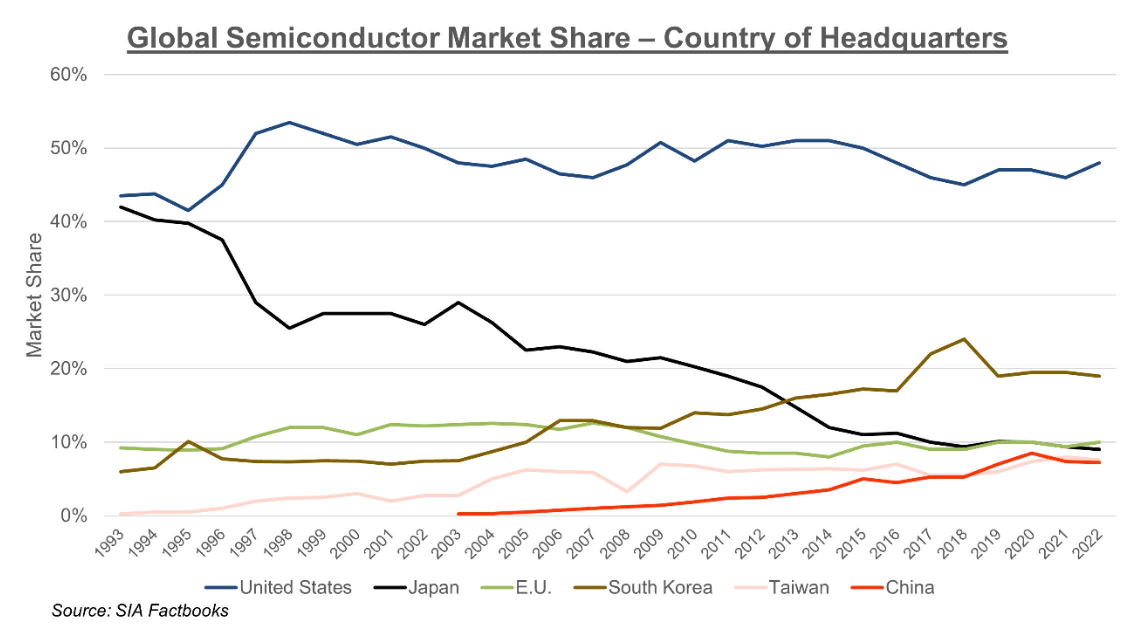
A significantly smaller set of respondents reported that export controls had affected their ability to acquire or service equipment. A limited number of respondents indicated that they either had avoided purchasing their preferred piece of equipment due to export controls or had equipment that needs to be serviced by foreign nationals, thus requiring disruptions to their business.

The survey did not directly address the value of export controls or their contribution to national security. In general, respondent comments on the challenges presented by export controls indicated they believed that a primary way in which export controls harmed their business was through increased burden and uncertainty, both for their own part and for their customers.

4. Financial Performance and Outlook

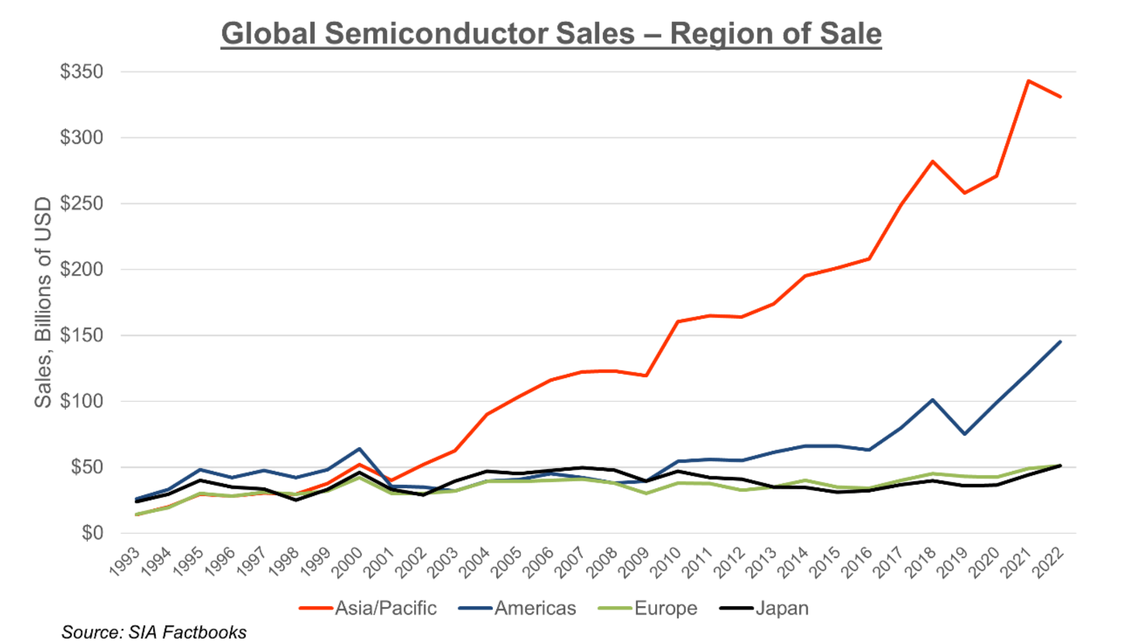
4.1 Sales

Companies based in the United States account for half of global semiconductor product sales, a figure largely unchanged for the past 30 years. Significant changes in market share have largely come at the expense of companies based in Japan, with the growth of companies based in South Korea, Taiwan, and China. It is important to note that market share figures do not fully represent the role each country plays in the production of semiconductors; market share is reflective of the headquarters of semiconductor providers (fabless and IDMs), and thus excludes the contributions of outsourced foundry and AT&P services, many of which are headquartered and located in Taiwan and China.

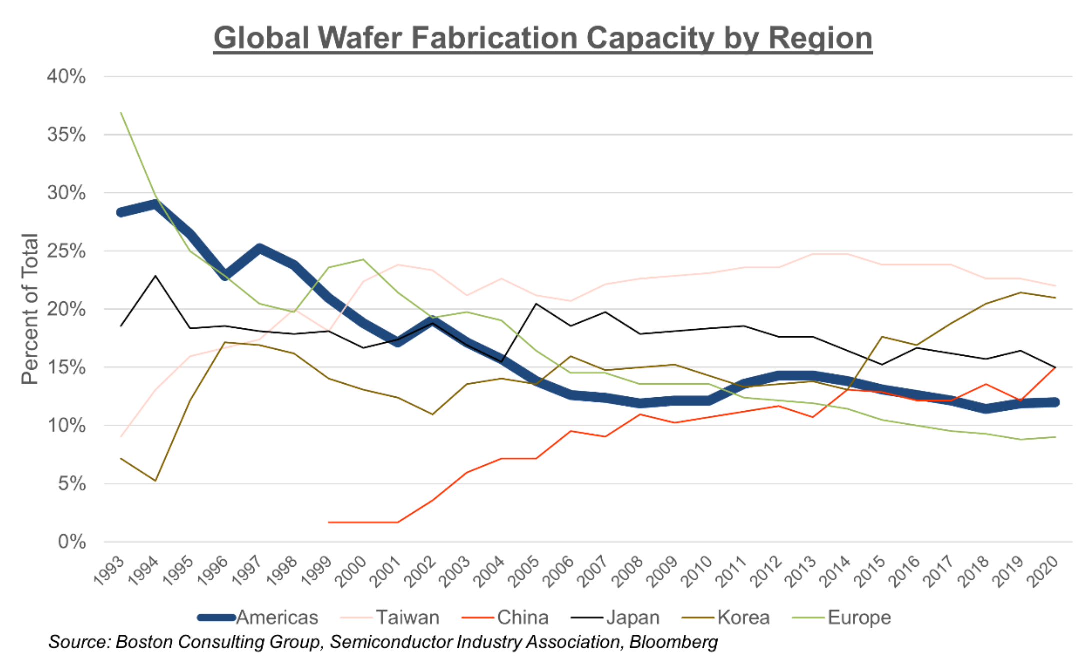


Market share of U.S.-based companies has been bolstered by the growing market share of fabless companies, an area that is particularly concentrated in the United States. Fabless revenue has risen from approximately 20 percent of global semiconductor sales in 2017 to nearly one-third in 2022. Much of this trend is attributable to stagnating sales growth in the memory segment (which is virtually entirely IDMs), as well as rapid growth in the fabless-heavy logic segment, with GPU providers NVIDIA and AMD both more than tripling their sales from 2017 to 2022.

While the overall market share of companies based in the United States has not significantly changed, the distribution of sales has changed. In 1993, according to Semiconductor Industry Association data, the Americas region was the primary sales market for semiconductors, accounting for one-third of all semiconductor sales. This share fell rapidly from 2000 to 2008, reaching a low of 15 percent as sales to the Asia/Pacific region expanded rapidly. Only since 2020 has the share of semiconductors sold in the Americas consistently risen above 20 percent, reaching 25 percent in 2022.



Also significantly changed over the last 30 years is the location of semiconductor fabrication. In 1993, the United States and Europe each accounted for roughly one-third of global fabrication capacity; by 2020 the two combined for less than one-quarter of global capacity.



The decline in U.S. fabrication capacity preceded the dominance of the Asia/Pacific region in semiconductor sales. It was not until 2001 that semiconductor sales to the Asia/Pacific region first surpassed that of the Americas; by this point U.S. fabrication capacity had fallen to an estimated 17 percent of global capacity and capacity in Taiwan had already reached the nearly one-quarter of the world's total it has since represented.

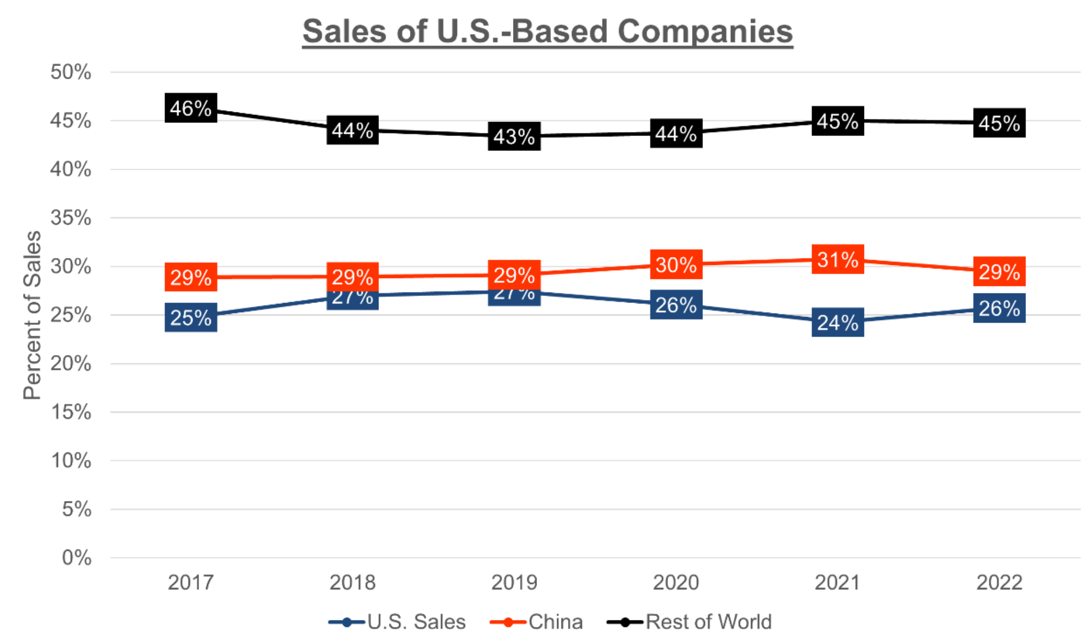
This suggests that regional fabrication capacity may be a significant driver of the broader electronics ecosystem. Rather than being drawn to the Asia/Pacific region by large existing semiconductor sales demand, fabrication capacity preceded the subsequent explosive growth in semiconductor sales in the region and was an enabling factor in the region's dominance in downstream electronics production.

Evidence from recent investments further suggests that semiconductor fabrication facilities serve as an ecosystem foundation point with broader benefits. The Semiconductor Industry Association reports that each job in the semiconductor industry supports 5.7 jobs in other industries, a jobs multiplier nearly twice that of the median U.S. industry.[125] The organization is also tracking more than 50 new investments planned in the United States since 2020 worth over $200 billion, largely clustered around existing or newly planned fabrication facilities.[126] A 2022 study of the economic benefit of TSMC's $8.6 billion investment for a new fab in Kumamoto, Japan estimated a total 10-year economic benefit to the region of $295 billion, with estimates of the benefits raised an additional 60 percent in 2023 based on the greater than expected "attraction effect" of the fab for other factories, industries, and related supply chains.[127]

Sales Destination

Companies based in the United States—which account for half of global chip sales and nearly 20 percent of global chip fabrication (two-thirds of which takes place inside the United States) —are highly dependent on sales to locations outside of the United States. No single location accounted for a higher share of sales than China. In 2022, U.S.-based companies reported that approximately one-quarter of their semiconductor sales were to customers in the United States, with a slightly higher share to customers in China.

[125] https://www.semiconductors.org/wp-content/uploads/2021/05/SIA-Impact_May2021-FINAL-May-19-2021_2.pdf
[126] https://www.semiconductors.org/the-chips-act-has-already-sparked-200-billion-in-private-investments-for-u-s-semiconductor-production/
[127] https://www.digitimes.com/news/a20230901PD212/japan-semiconductors-tsmc.html



Source: Company annual reports, Aggregate BIS survey data

The listed sales for China are likely a minimum figure. Companies varyingly report the location of their sales on a ship-to basis or a bill-to customer headquarters basis, which has the result of lowering the sales to China figure, as it excludes a significant portion of products sent to Chinese locations of companies headquartered elsewhere. Among companies reporting sales on a ship-to basis, sales to China accounted for 44 percent of semiconductor sales of U.S.-based companies.

This reliance on sales to China is reflective of both the size of the Chinese market, with over 1.4 billion people, as well as the size of the country's electronics assembly industry, which is several times larger than the next largest country. In 2022 China accounted for 37 percent of global exports of electronics, including over half of the exports of phones, flat panel displays, and computers.[128] No other location accounted for more than seven percent of global exports of electronics.

Outside of China, only one other country was the primary non-U.S. destination across any of the ten commercial sectors included in the BIS survey: Germany. Survey respondents reported that Germany was the primary non-U.S. destination in the automotive and commercial aerospace sectors.

4.2 End Uses

On the whole, semiconductors are heavily concentrated in Information and Communications Technology (ICT) sectors, with BIS survey data finding that 68 percent of semiconductor revenue is derived from four sectors: Personal Computers, Mobile Devices, Servers and Network Infrastructure. This concentration is attributable largely to the heavy use of logic and memory

[128] HTS codes 85, 8517, 8524, and 8471, respectively. Data from International Trade Centre.

chips for these sectors, with both segments seeing ICT end uses account for over 80 percent of their end uses.

Respondent End-Use Projections – Percent of Chip Segment Revenue for Given End Use

	Appliances/ Consumer Goods	Automotive	Commercial Aerospace	Healthcare/Medical	Industrial	IT/Computers: Consumer	IT/Computers: Servers	Mobile Devices	Network Infrastructure	Other Commercial	U.S. Defense	Foreign Defense
Analog	7%	15%	1%	3%	19%	10%	3%	28%	9%	3%	3%	1%
MCU/MPU	8%	19%	1%	1%	21%	14%	4%	15%	12%	3%	2%	0%
Logic	5%	3%	0%	0%	2%	44%	13%	20%	11%	2%	1%	0%
Memory	8%	5%	0%	0%	3%	20%	33%	24%	3%	4%	1%	0%
Discretes	8%	30%	1%	1%	29%	8%	1%	6%	5%	6%	5%	1%
Optoelectronics	4%	21%	0%	2%	21%	2%	0%	32%	12%	2%	5%	0%
Sensors & Actuators	4%	40%	1%	3%	19%	3%	0%	8%	2%	3%	16%	3%
Total	***6%***	***10%***	***0%***	***1%***	***10%***	***24%***	***14%***	***22%***	***8%***	***3%***	***2%***	***0%***

Source: BIS Survey Data

The next largest end uses—automotive and industrial—have relatively minimal use of logic and memory chips, instead accounting for over half the usage of discretes and sensors & actuators, over 40 percent of the usage of optoelectronics and micro chips, and over one-third of analog chips.

Just as ICT end uses are a major factor in the size of the logic and memory segments, these same sectors account for the largest use of leading- and current-edge technology nodes, with significant majorities of ICT sectors using chips under 28 nanometers. Conversely, most other sectors remain reliant on more mature technology nodes, with most chips in the defense, aerospace, medical, industrial, and automotive sectors relying on chips with feature sizes larger than 90 nanometers.

Respondent End-Use Projections – Percent of End Use Revenue for Given Node

	Under 28 nm	28 - <90 nm	90 - <350 nm	350+ nm
Appliances/Consumer Goods	63%	8%	20%	9%
Automotive	17%	22%	51%	9%
Commercial Aerospace	4%	17%	59%	21%
Healthcare/Medical	2%	19%	64%	15%
Industrial	13%	19%	58%	11%
IT/Computers: Consumer	88%	2%	9%	1%
IT/Computers: Servers	92%	4%	3%	1%
Mobile Devices	73%	8%	11%	8%
Network Infrastructure	72%	2%	17%	9%
Other Commercial	74%	7%	7%	11%
U.S. Defense	11%	18%	66%	6%
Foreign Defense	5%	17%	71%	7%
Total	***66%***	***8%***	***20%***	***6%***

Note: Calculations are based on survey data of respondents' reported "primary" nodes and thus may not fully represent the array of nodes used. End use category definitions were left to respondents' discretion and some categories include a wide variety of product types. Notably, the Applicance/Consumer Goods category often includes both items like SoCs for TVs or displays as well as PMICs for appliances.

BIS collected data from survey respondents on their expectations for how the distribution of their sales would change by 2027 and 2032. Respondents provided numerous caveats on the volatile and unpredictable nature of such extended projections, and end users were not surveyed; these projections should thus be viewed not as business plans or guidance, but rather as a snapshot of the aggregated expectations of semiconductor suppliers.

Overall expectations are for strong growth in the defense and aerospace sectors, though the relatively small base means these sectors would still account for under five percent of semiconductor end uses in 2032. Automotive end uses are also expected to grow rapidly, at nearly 10 percent per year, as are industrial end uses, at over nine percent per year. ICT end uses are expected to grow somewhat more slowly than the overall industry, though these sectors will remain vitally important, still being expected to account for 60 percent of all end uses in 2032.

End Use Market Size and Growth Expectations, 2022-2032 (in Billions of USD)				
Sector	**2022**	**2027**	**2032**	**CAGR**
U.S. Defense	$13	$35	$49	14%
Commercial Aerospace	$2	$5	$7	13%
Foreign Defense	$2	$5	$6	12%
Automotive	$67	$108	$168	10%
Industrial	$66	$110	$160	9%
Healthcare/Medical	$6	$9	$14	8%
IT/Computers - Servers	$90	$124	$177	7%
Other Commercial	$19	$28	$38	7%
Appliances/Consumer Goods	$41	$57	$77	6%
IT/Computers - Personal and Consumer Products	$157	$205	$271	6%
Network Infrastructure	$54	$67	$94	6%
Mobile Devices	$143	$172	$237	5%
Total	***$660***	***$926***	***$1,299***	***7%***
Source: BIS Survey Data				

Respondents expected minimal changes in country of end use through 2032. The share of products with end uses in the United States was expected to tick up slightly, from 36 percent in 2022 to 37.5 percent in 2032. BIS did not collect survey data on respondents' end use expectations for all countries, but only for the United States and the primary non-U.S. country, by each of the identified 12 sectors. China is in 2022 by far the most frequently identified non-U.S. end use destination, accounting for 44 percent of all non-U.S. primary end use listings. This dominance is expected to ebb moderately by 2027, with China falling to 37 percent of non-U.S. primary end use identifications, and Germany rising from 15 percent to 20 percent.

4.3 Financial Health

Survey respondents provided data on selected financial line items, including net and operating income, assets, liabilities, and inventories. In addition to assessing these items individually, BIS implements a customized metric to provide a single basis for simple financial risk assessment. The model is based largely on standardized financial ratios covering profitability, liquidity, leverage, and default probability. Based on this score, respondents were categorized as low, moderate, or high risk, with the moderate and high categories together grouped as "elevated" risk.

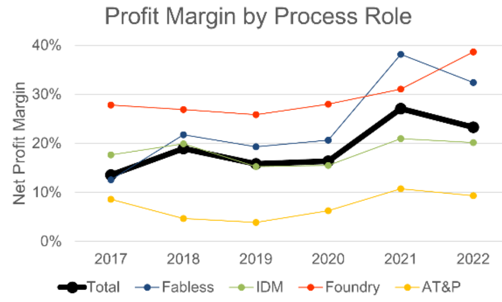
Overall, 25 percent of respondents were assessed to be at elevated financial risk (with 3.5 percent of the total at high risk), matching trends from recent BIS surveys of other industries.[129] BIS also asked survey respondents to assess their own financial health, with results similar to the BIS financial risk metric; 20 percent of respondents judged their own financial health to be six or lower (on a scale of one to ten), with four percent in poor financial health (three or lower).

There were no significant differences in financial risk based on respondents' primary technology node or chip segment, but fabless companies had higher financial risk, with 37 percent of fabless companies at elevated risk compared to 16 percent of IDMs. This trend is consistent with the

[129] Based on data from over 15,000 survey responses from BIS industrial base assessment conducted since 2015.

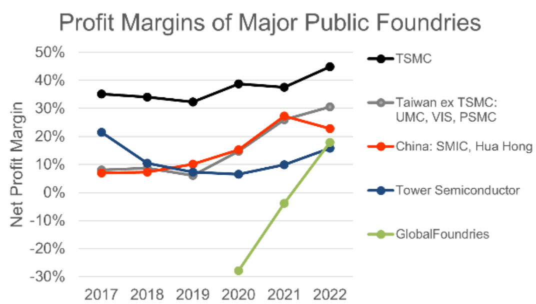
general fabless model, wherein the limited need for capital expenditures allows for increased spending on research and development, with resulting higher variability in performance.

Fabless companies as a group exhibited higher net profit margins in all but one of the years covered by the survey, and in 2022 fabless profit margin exceeded IDM profit margin by 12 points (32 percent to 20 percent). At the same time, over twice as high a share of fabless companies reported a net loss in any given year, with an average of 44 percent of fabless companies reporting a net loss in any year from 2017 to 2022, compared to 17 percent of IDMs. These features are reflective of the high-risk, high-reward nature of fabless companies, as well as the higher number of start-ups enabled by the lower barriers to entry.



Source: Company annual reports

As with fabless companies, foundries as a group have reported remarkable profit margins in recent years. While large publicly-traded foundries have been nearly universally profitable in recent years, the outsized profit margin of foundries is largely driven by the size and performance of TSMC. The company reported net income of $34 billion in 2022, while the net income of all other large foundries (those with over $1 billion in revenue) combined was less than $20 billion.[130]



Source: Company annual reports

Providers of outsourced assembly, test, and packaging (OSAT) services tend to have relatively low margins within the microelectronics industry, though are consistently profitable. Average profit margin for the seven large OSATs did not exceed 10 percent for the 2017-2022 period, less than half that of the rest of the industry. Despite relatively low profits, in only a single year since 2017 did any of these companies report a net loss—China-based JCET in 2018.

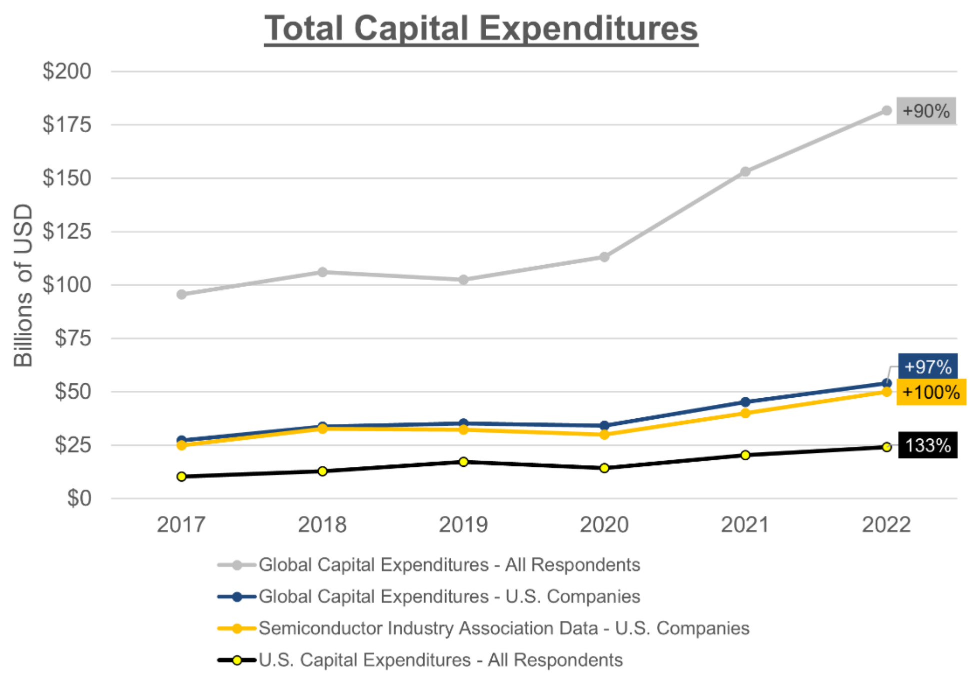
4.4 Capital Expenditures

The semiconductor industry is highly capital intensive, with large and growing expenditures required, particularly for production of leading-edge chips. The industry as a whole spent an estimated $182 billion on capital expenditures in 2022, nearly doubling in five years.[131] Capital expenditures by U.S.-based companies were largely in-line with their global share of manufacturing; U.S.-based companies spent an estimated $54 billion on capital around the world

[130] Based on BIS estimates, all foundries with over $1 billion in revenue are publicly traded, though Samsung does not break out the profitability of its foundry business. BIS estimates the plausible range of combined net income of this group (Samsung Foundry, UMC, SMIC, GlobalFoundries, Powerchip, Vanguard, Hua Hong, Tower) is between $10 billion and $19 billion.

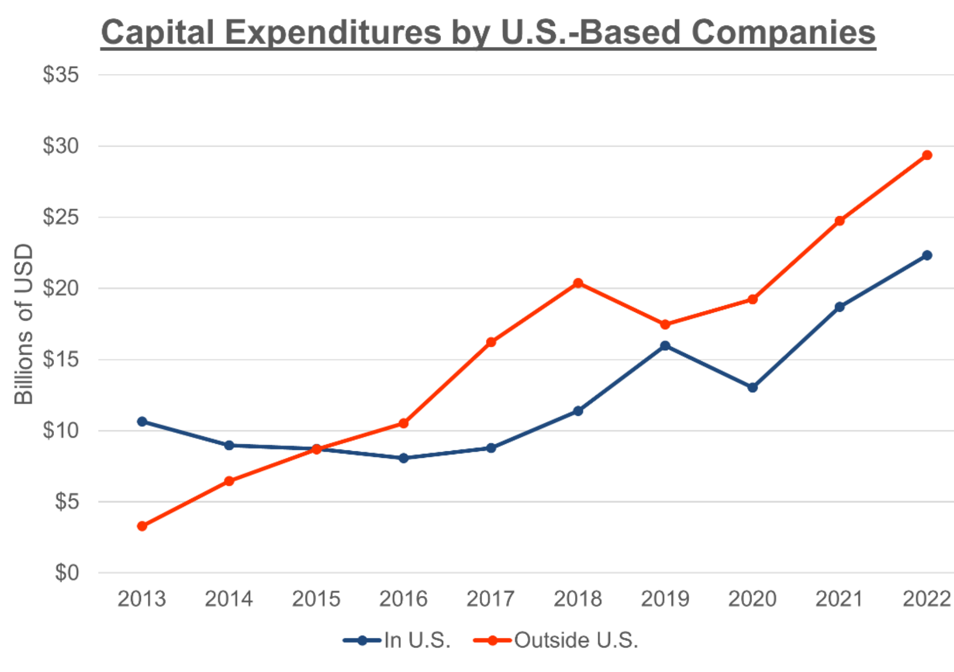
[131] Based on estimates from ICInsights/TrendForce

in 2022 (30 percent of the global total), and capital expenditures inside the United States totaled $24 billion (13 percent of the global total).



Source: BIS survey data, SIA Factbooks, ICInsights

Semiconductor industry capital expenditures inside the United States have rebounded after reaching a recent-era low in 2016. U.S.-based semiconductor companies increasingly globalized in the years leading up to 2017, spending more outside the United States than inside for the first time in 2016. Recent increases in U.S.-based expenditures have stabilized this trend, though expenditures outside the country remain higher than those inside the United States.



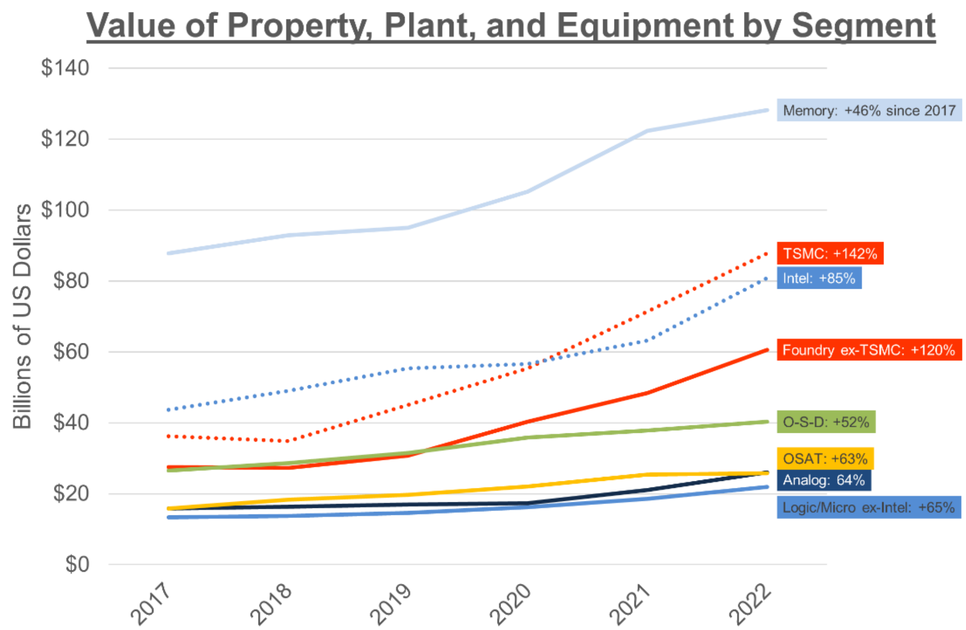
Source: BIS survey data

Capital expenditures—and the resulting value of property, plant, and equipment (PP&E)—differ greatly by semiconductor segment, and within that by individual company. With two notable exceptions, the production of leading-edge is largely carried out through the use of foundries, most significantly by TSMC, which in 2022 accounted for an estimated 60 percent of total foundry PP&E value, and nearly 20 percent of total industry PP&E.

One exception to the use of foundries for leading-edge chips is the memory segment, where several large IDMs dominate and need to continually update their facilities to produce the latest chip architectures. The memory segment—led by Samsung, SK hynix, Kioxia/Western Digital Flash Ventures, and Micron—accounts for approximately one-quarter of total semiconductor PP&E.

The other notable exception is Intel. While most logic and microprocessor chip production has shifted to foundry-based production, Intel continues to function as an IDM, though the company announced plans in 2022 to move toward a more segmented internal foundry model.[132] Intel accounts for more than three-quarters of logic/micro segment PP&E (outside of pure-play foundries). Intel and TSMC alone account for one-third of the value of all semiconductor PP&E.

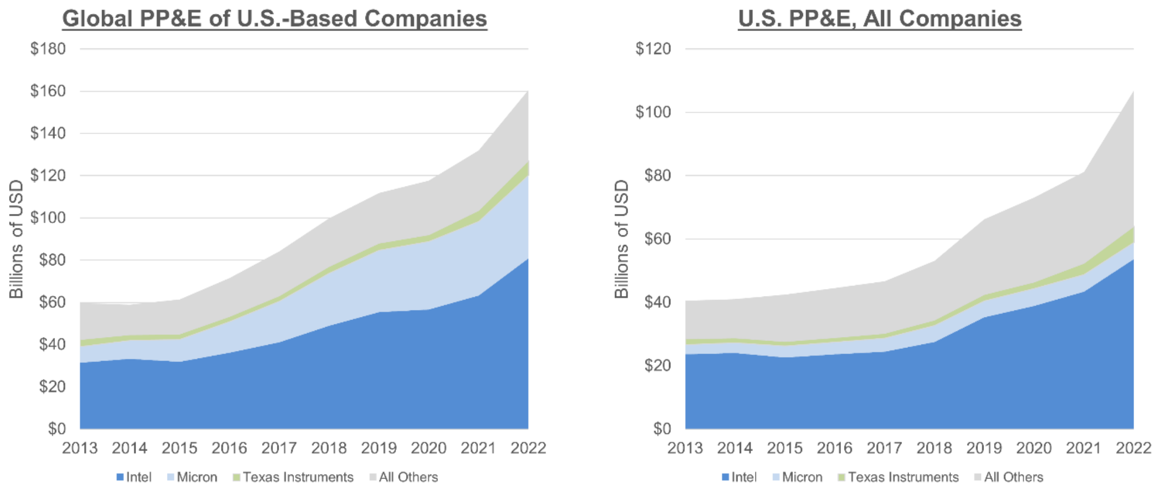
[132] https://www.intel.com/content/www/us/en/newsroom/news/intel-embraces-internal-foundry-model.htm



Source: Company annual reports, Aggregate BIS data

Beyond leading-edge chips, the need for continually massive capital expenditures is smaller. Producers of analog, microcontrollers, optoelectronics, sensors, and discretes have less need for the most expensive modern equipment and are able to rely on prior generations of technology for longer periods of time. These segments thus have less expensive PP&E without the same acceleration in costs as with leading-edge nodes, yet have still expanded the value of their PP&E by nearly 10 percent per year since 2017.

Among U.S.-based companies, two companies are vital when it comes to the value of PP&E and resulting manufacturing capability. Intel alone accounts for half of the value of global PP&E owned by U.S.-based companies as well as half of the value of semiconductor PP&E inside the United States. Micron accounts for another one-quarter of global PP&E owned by U.S.-based companies.



Source: Company annual reports

One-quarter of respondents indicated they expect to use the investment tax credit included in Section 107 of the CHIPS Act of 2022, with currently planned investments worth $109 billion expected to be eligible for the tax credit. Based on a 25 percent tax credit, respondents expect to receive total benefits valued at $27 billion, marginally above the $24 billion estimated by the Congressional Budget Office.[133]

4.5 Research and Development

The United States has an outsized role in semiconductor research and development. While U.S.-based companies are responsible for approximately half of global semiconductor sales, they account for three-quarters of global R&D expenditures among semiconductor providers, with the average U.S.-based chip provider devoting 40 percent more of its revenue to R&D than companies based outside the United States.

A significant portion of the United States' R&D dominance stems from the fact that most of the world's fabless companies are U.S.-based. Fabless companies are generally more focused on R&D, devoting on average 20 percent of their revenue to R&D. U.S.-based companies account for 73 percent of the world's fabless companies and 78 percent of global R&D carried out by fabless companies.

	R&D Intensity	
Process	**United States**	**Rest of World**
Total	18%	10%
Chip Providers	18%	13%
Fabless	20%	18%
IDM	17%	11%
IDM ex-Intel	11%	11%
Foundry	6%	7%
OSAT	3%	4%

Source: Aggregate BIS survey data, Company annual reports

The other major reason for the United States' commanding R&D share is Intel. With 2022 R&D expenditures of $17.5 billion, Intel alone accounts for approximately 20 percent of global semiconductor provider R&D. With Intel included, U.S.-based IDMs devoted 17 percent of their revenue to R&D in 2022, 50 percent higher than the rest of the world's IDMs; excluding Intel, both U.S. and non-U.S. IDMs devoted 11 percent of revenue to R&D.

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[133] https://www.cbo.gov/system/files/2022-07/hr4346_chip.pdf

Highest Semiconductor R&D Expenditures				
Company Name	**Headquarters**	**2022 Sales**	**2022 R&D Expenditure**	**2022 R&D Intensity**
Intel	U.S.	$63.1	$17.5	28%
Qualcomm	U.S.	$43.0	$8.5	20%
NVIDIA	U.S.	$29.6	$6.9	23%
Samsung	Korea	$76.2	$6.0*	8%
TSMC	Taiwan	$75.9	$5.5	7%
AMD	U.S.	$23.6	$5.0	21%
Broadcom	U.S.	$33.2	$4.9	15%
MediaTek	Taiwan	$18.4	$3.9	21%
SK Hynix	Korea	$34.5	$3.7	11%
Micron	U.S.	$27.2	$3.3	12%
Western Digital	U.S.	$18.8	$2.3	12%
NXP	Netherlands	$13.2	$2.1	16%
Infineon	Germany	$15.8	$2.0	13%
STMicroelectronics	Switzerland	$16.1	$1.9	12%
Marvell	U.S.	$5.9	$1.7	29%
Analog Devices	U.S.	$12.0	$1.7	14%
Texas Instruments	U.S.	$20.0	$1.7	9%
Microchip	U.S.	$8.1	$1.1	14%
Realtek	Taiwan	$3.8	$1.0	26%

Source: Company annual reports
**Samsung R&D figure is estimated based on ICInsights 2020 estimate*

Much, but not all, of the R&D carried out by U.S.-based companies is performed inside the United States. Based on survey responses, BIS estimates that U.S.-based companies carried out two-thirds of their R&D from locations inside the United States. Combined with R&D carried out inside the United States by non-U.S. based companies, an estimated 47 percent of global semiconductor provider R&D activity takes place inside the United States, and 43 percent when including foundry and OSAT R&D.[134]

R&D expenditures are heavily toward current generation and leading-edge chips. Survey respondents whose primary technology node was 28 nanometers or smaller accounted for over 75 percent of reported R&D expenditures, as smaller feature sizes require increasingly large R&D and design costs. Companies focused on legacy chips nevertheless maintain robust R&D expenditures; survey respondents whose primary technology node was greater than 90 nanometers accounted for 15 percent of overall R&D, suggesting global R&D expenditures of $14 billion by companies focused on chips with feature sizes larger than 90 nanometers.

Future expectations for R&D were largely in line with sales growth expectations. In aggregate, respondents expected their R&D expenditures would grow 6.8 percent per year through 2032,

[134] These figures do not include all semiconductor-related R&D, only the R&D by companies directly engaged in the production of semiconductors. In addition to significant basic research carried out at universities and other research institutions, the United States has robust capabilities in the production (and research and development) of equipment and software used for the design and manufacture of semiconductors.

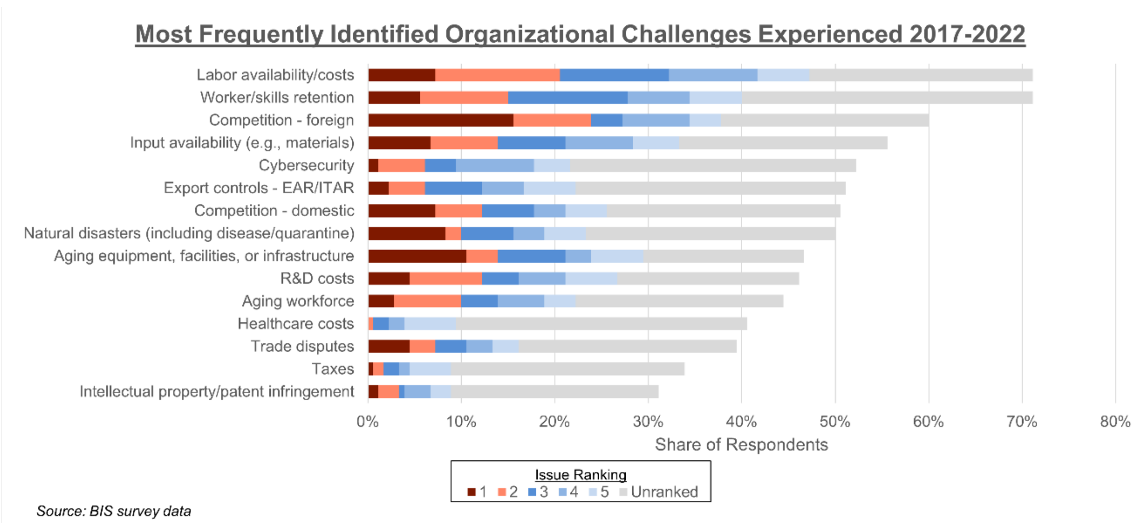
nearly doubling overall R&D expenditures. Respondents whose primary end uses are defense, aerospace, or automotive tended to forecast higher R&D growth rates, of 8.8 percent, 8.6 percent, and 7.8 percent per year, respectively.

5. Challenges and International Comparisons

5.1 General Business Challenges

BIS gathered data on the general business challenges facing companies in the semiconductor industry, providing respondents with a list of 32 broad issues and asking that they identify the challenges they experienced since 2017 and expect to experience through 2027, ranking the five most important. Responses, including comments on the specifics of the issues experienced and ways in which the U.S. government might be able to mitigate the challenges, were provided by 180 respondents.

As identified in the Workforce section above, the two most frequently identified challenges were employment-related, with both labor availability/costs and worker/skills retention identified by over 70 percent of respondents and ranked as one of their five greatest challenges by at least 40 percent of respondents.



The third most-frequently identified challenge was foreign competition, which was identified by 60 percent of respondents, and was the most frequently ranked number one issue for respondents. Specific comments were provided by 55 respondents, with the most frequently mentioned issues (outside of the generally competitive semiconductor industry) including low-cost Chinese production (mentioned by 31 percent of commenters) and higher subsidies outside of the United States (mentioned by 22 percent of commenters). Select comments include:

- *"Like all US technology companies, [our company] faces increasing pressure from low-cost, copy-cat competitors in China."*
- *"Foreign companies in both allied and competitive countries receive extensive financial support that exceeds that received by [our company] in the United States and the other countries where we operate. This puts our company at a distinct advantage in investing in future technology development and advanced manufacturing."*

- *"Current model is difficult to compete with foreign labor and limited environmental restrictions overseas."*
- *"Competition with foreign competitors such as [competitor] and Chinese competitors are not only for customers, but also needed equipment."*
- *"Many times the foreign competitors have significant labor subsidies. They also receive preferential treatment in sales."*

In addition to comments on the nature of the foreign competition challenge, 35 respondents provided feedback on ways in which the U.S. government might help mitigate the challenge. Nearly all responses were focused on increased domestic subsidies or tax credits, increased action to combat unfair trade practices (including imposition of tariffs or expansion of export controls), and reduced or streamlined export controls.

The fourth most frequently identified challenge, and only remaining challenge ranked as one of their five biggest challenges by more than 30 percent of respondents, was input availability. As discussed in the Availability of Inputs section above, semiconductor manufacturing requires hundreds of different inputs sourced from around the world.

Shortages and delays associated with the COVID-19 pandemic, the war in Ukraine, and increased international trade disputes came as a surprise to many respondents. In a 2017 survey of the U.S. integrated circuit industry, BIS asked the same business challenges question of respondents; input availability was by far the biggest difference between challenges companies expected to encounter from 2017 to 2022 and those they did encounter. Among common respondents between the two surveys, 38 percent of respondents in 2017 expected to encounter input availability challenges between 2017 and 2022—the sixteenth most frequently listed challenge. In 2022, 60 percent of those respondents indicated they had experienced input availability challenges.

Comments on input availability were largely divided into three categories: wafer and fabrication capacity, significantly increased prices, and concerns about geopolitical ramifications on supply chains, including the war in Ukraine and concentrated supply of raw materials. For wafer and fabrication capacity, much of the focus was related to abnormally high demand for semiconductors themselves in the 2020-2022 period, with particular emphasis on the availability of 200mm wafers and fabrication capacity for larger feature sizes, such as those above 90 nanometers.

The primary other unexpected challenge was export controls, which increased from being expected by 30 percent of respondents in 2017 to experienced by 39 percent in 2022. Most of the comments related to export controls related to the rule announced by BIS on October 7, 2022—shortly before the distribution of the survey—aimed at restricting the ability of the People's Republic of China (PRC) in obtaining advanced computing chips, in developing and maintaining supercomputers, and in manufacturing advanced semiconductors.[135]

[135] https://www.federalregister.gov/documents/2022/10/13/2022-21658/implementation-of-additional-export-controls-certain-advanced-computing-and-semiconductor

Outside of the most frequently identified challenges, the category "Aging Equipment, Facilities, or Infrastructure" is notable for the intensity of its identifications. Though identified by less than half of respondents, this category was second highest in share of respondents identifying it as their primary challenge (behind labor availability/costs). Several respondents noted that their facilities use older, obsolete equipment that has significant costs to upgrade, with one respondent summarizing: "Due to the substantial additional costs associated with building and running Fabs in the US with respect to other countries in Asia, Fab facilities, infrastructure and equipment must be kept longer to keep profit margins up. This becomes difficult to maintain as facilities and equipment become obsolete."

Most of the respondents providing comments on mitigation suggestions related to aging equipment, facilities, or infrastructure mentioned interest in CHIPS Act funds or tax incentives to assist in their modernization efforts.

On the whole, respondents expected to continue to experience the same types of challenges from 2023 to 2027 than they did from 2017 to 2022, with only natural disasters (including disease/quarantine) falling by more than two percentage points and four factors—environmental regulations/remediation, cybersecurity, foreign industrial espionage, and intellectual property/patent infringement—rising by more than five percentage points.

The latter three topics are all essentially subsets of the broader topic of information security concerns, presenting perpetual and growing challenges for semiconductor businesses. The semiconductor industry has increasingly been targeted by cyberattacks that not only impact production operations but also result in the loss of intellectual property. In 2022 alone, the industry experienced eight major ransomware attacks that impacted industry leaders such as NVIDIA, AMD, and Samsung.[136] Additionally, from 2018 to 2020, seven Taiwanese semiconductor companies had their systems compromised by a Chinese-based Advanced Persistent Threat actor with the perceived motivation of stealing sensitive intellectual property including integrated circuits designs, source code, and software development kits.[137]

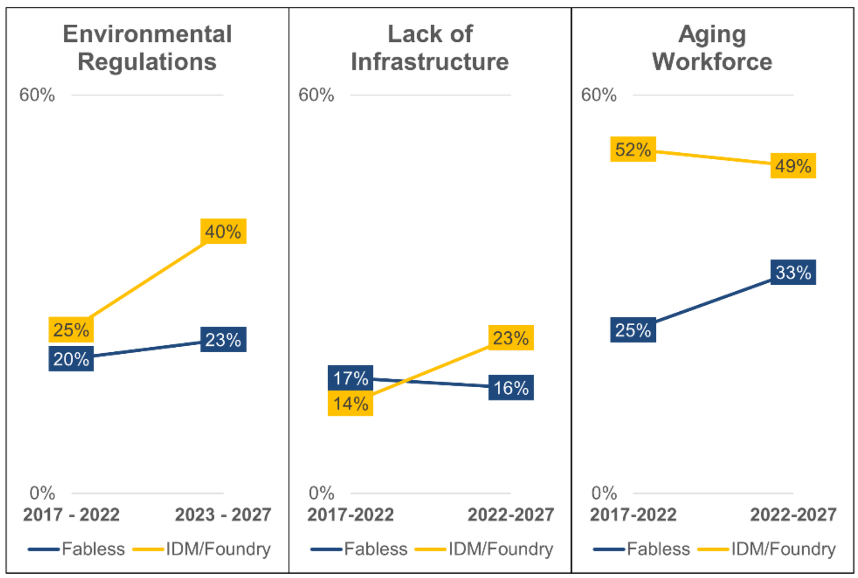
The survey findings reflect the industry's growing concerns over cyberattacks and cyber-enabled industrial espionage. In BIS's 2017 integrated circuit survey, cybersecurity and intellectual property/patent infringement represented the 8th and 9th most frequently identified expected challenges for the 2018-2022 period, with foreign industrial espionage showing the highest percentage increase between previously experienced challenges (2013-2017) and expected (2018-2022), a feature that is replicated in this survey, with the share of respondents expecting challenges from foreign industrial espionage rising to 21 percent from the 15 percent that identified it as a challenge in the prior five years.

[136] "Semiconductor Companies Targeted by Ransomware", *Recorded Future*, September 29, 2022, https://www.recordedfuture.com/semiconductor-companies-targeted-by-ransomware.
[137] *APT Group Chimera – APT Operation Skeleton Targets Taiwan Semiconductor Vendors*, CyCraft, https://cycraft.com/download/CyCraft-Whitepaper-Chimera_V4.1.pdf Also *https://www.wired.com/story/chinese-hackers-taiwan-semiconductor-industry-skeleton-key/*

The interconnected nature of the semiconductor supply chain presents an additional challenge to protecting against cyberattacks and industry espionage. Semiconductor companies must not only protect against direct attacks on its systems but also against vulnerabilities introduced by its vendors. For example, in 2023 chip giant TSMC was implicated in two separate ransomware attacks on two of its vendors, one of which resulted in the loss of TSMC data.[138]

The increase in concerns related to environmental regulations/remediation was entirely driven by respondents that operate production facilities (IDMs and Foundries). While just 25 percent of these respondents indicated that environmental regulations/remediation presented a business challenge in the 2017 to 2022 period, 40 percent expected it to be a challenge between 2023 and 2027. Among fabless respondents, the corresponding figures were lower and much closer together, at 20 percent for past concern and 23 percent for future concern.

Divergence In Direction of Fabless and IDM/Foundry Expectations



Source: BIS survey data

Two other categories showed significant differences in the direction of expectations between fabless respondents and those with fabs: lack of infrastructure and aging workforce. Lack of infrastructure presented a rising concern among IDMs and foundries as they invest in facility expansions, a concern not reflected among fabless respondents. With regard to aging workforces, while a significantly higher share of IDMs and foundries identified it as a business challenge, future concerns were slightly lower. The challenge of aging workforces appears to be more emergent for fabless respondents, with expectations for future challenges among one-third of respondents, up from the one-quarter that experienced challenges related to an aging workforce between 2017 and 2022.

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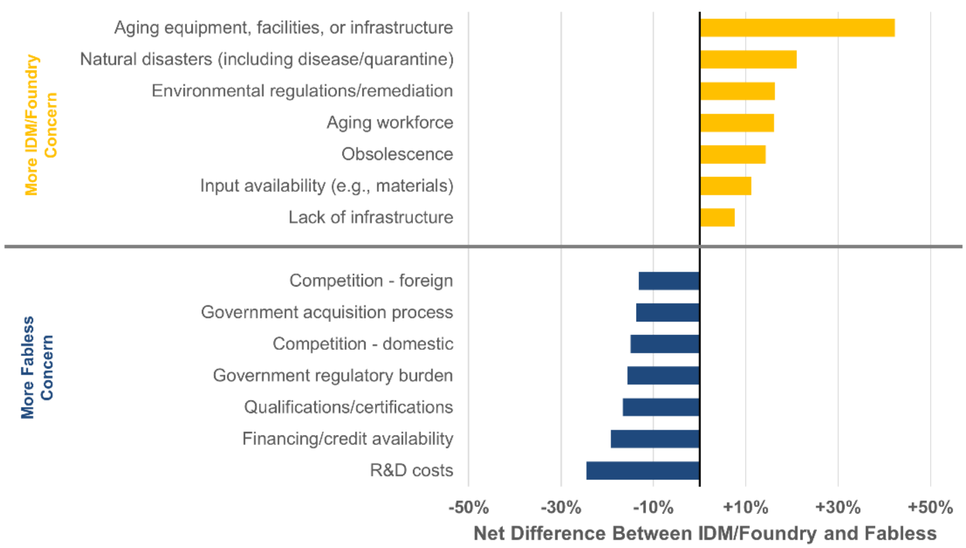
[138] TSMC confirms supplier data breach following ransom demand by Russian-speaking cybercriminal group", *CNN Business*, June 30, 2023, https://www.cnn.com/2023/06/30/tech/tsmc-supplier-ransomware/index.html; "Ransomware attack on chip supplier causes delays for semiconductor groups", Financial Times, February 28, 2023, https://www.ft.com/content/b8669140-8dde-493e-bb30-f5f1e9830804

There are several categories of business challenges with large differences in expectations between IDMs/foundries and fabless companies. The most significant is aging equipment, facilities, or infrastructure, identified nearly three times as frequently by IDMs and foundries as by fabless respondents. Sixty-five percent of IDMs and foundries identified this issue as a challenge, compared to 23 percent of fabless respondents. IDMs and foundries are relatively more concerned by other items with significant potential for impacts on fabrication: natural disasters, environmental regulations, aging workforces, obsolescence, input availability, and lack of infrastructure.

Fabless respondents, with high R&D intensity, found that R&D costs presented significantly more concern than for IDMs and foundries, though both groups frequently identified it. Two-thirds of fabless companies selected R&D costs as a business challenge, compared to 41 percent of IDMs and foundries. Other challenges more specialized to fabless companies included availability of financing, challenges from government regulatory burden and acquisition, and competition.

Largest Differences Between Fabless and IDM/Foundry Expected Challenges



Source: BIS survey data

5.2 Cost Structures and Comparisons

Cost Structure

Costs and types of costs vary widely for different roles in the semiconductor industry. Fabless companies minimize their capital costs by outsourcing production (and the associated cost of capital) to foundries. As a result, fabless companies costs fall largely in two areas: labor and outsourced services. Survey responses indicate these two areas cover over 80 percent of average fabless company costs, with 15 percent devoted to labor, 45 percent to front-end fabrication services (foundries), and 23 percent for test, verification, assembly, and packaging.

Estimated Percent of Costs			
	Fabless	**IDM**	**Foundry**
Labor	15%	18%	24%
Fabrication as a Service (Foundry Services)	45%	12%	5%
Test, Verification, Assembly, and Packaging	23%	14%	1%
Material and Processed Inputs	6%	31%	25%
Utilities	<1%	5%	8%
Equipment, IP, and Other Costs	8%	19%	37%

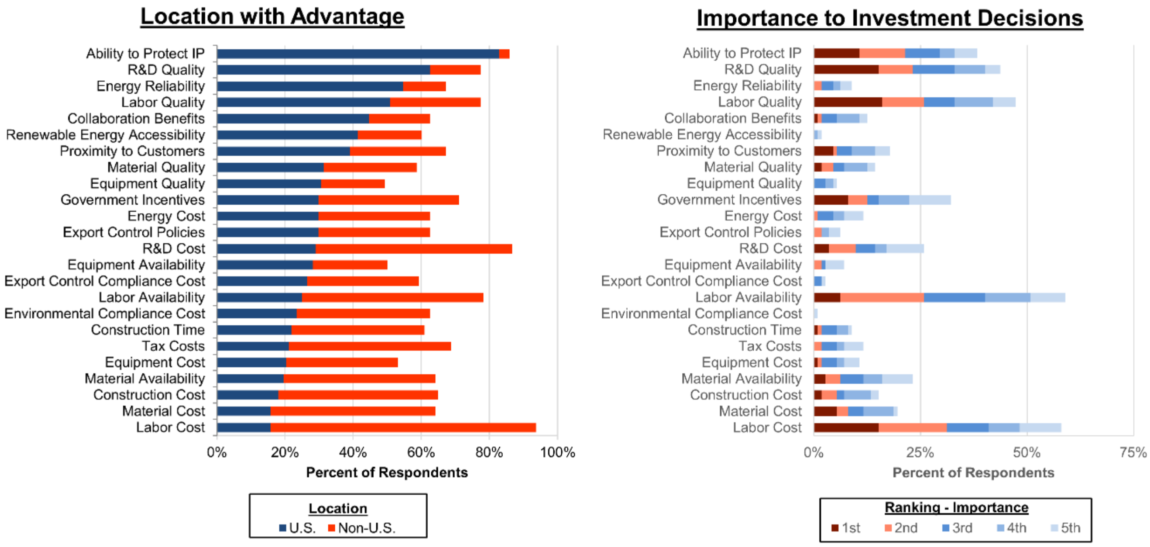
Source: BIS Survey Data

At the other end of the spectrum, foundries also have highly concentrated costs, though necessarily in different areas, with input and equipment covering over half of foundry costs. Foundries are also relatively labor-intensive, with nearly one-quarter of costs attributable to labor. IDMs, spanning both design and fabrication, fall between fabless and foundry costs by category. The exception from BIS survey data is in material and input costs, where IDMs appear to have outsized expenses; this is largely due to companies producing optoelectronics, sensors, and discretes, which have higher shares of material and input costs and lower shares in test, verification, assembly, and packaging.

International Comparisons

Costs are a key factor in investment decisions, but not the only factor. BIS polled survey respondents on the most important factors when deciding on a location to invest in the expansion or construction of facilities, providing a list of 24 factors and asking for a selection of the five most important. In addition, for each factor BIS asked respondents to indicate whether they believed the United States or another country had a greater competitive advantage.

Five factors were selected by at least one-third of respondents: Labor Availability, Labor Cost, Labor Quality, R&D Quality, and Ability to Protect Intellectual Property. Of these most important factors in making investment decisions, respondents believed the United States had advantages compared to the rest of the world in the latter three, while perceived advantages in Labor Cost and Labor Availability lay largely outside the United States.



Source: BIS survey data

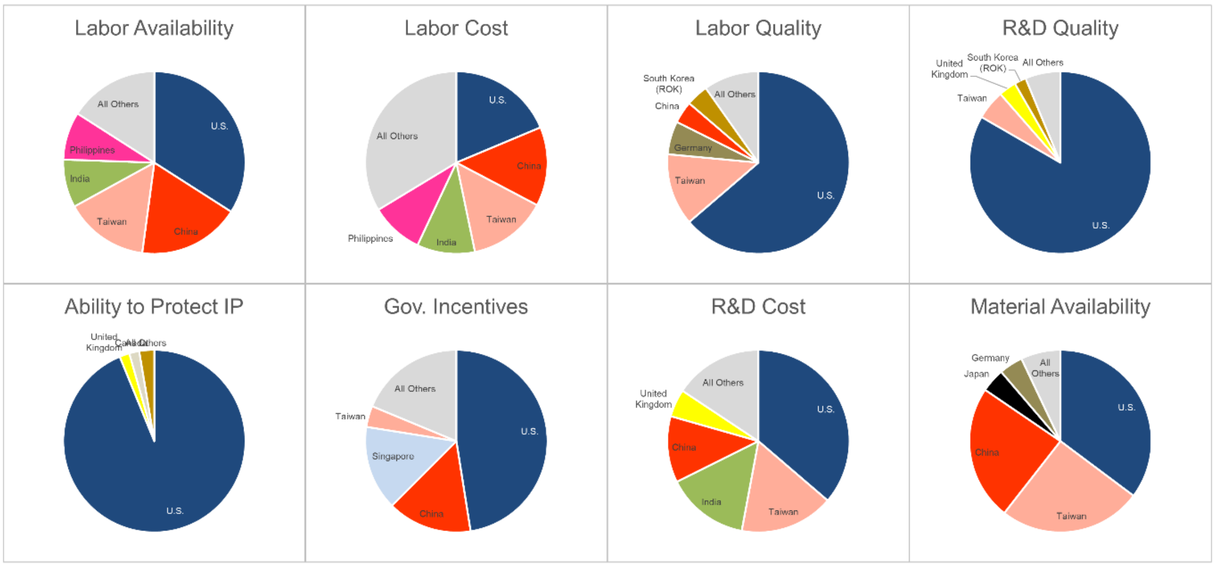
Labor Cost and Availability

More than 80 percent of respondents identified either labor cost or labor availability as one of the five most important factors affecting their decision on where to locate facilities, with 35 percent ranking both items. Most respondents believed that non-U.S. locations provided a greater competitive advantage for both factors, with China, Taiwan, India, and the Philippines most frequently identified as the locations outside of the United States with advantages.

Several respondents indicated that because labor costs were their single largest expense, it was crucial to their competitiveness to minimize labor costs. Several also noted that the more concentrated semiconductor ecosystems in East Asia meant it was easier to find workers in those locations. One respondent indicated that they were able to find workers of equivalent skill outside the United States at 30 percent of the cost.

Respondents indicating they believed the United States held an advantage in labor availability or cost tended to focus on the country's production of top-tier R&D talent, with one respondent writing "Because of our focus on innovation and advanced R&D, we believe that hiring and training Americans constitute a competitive factor in our innovation-oriented work force strategy."

Most Important Factors in Deciding Where to Locate Facilities: Countries With Perceived Advantages



Source: BIS survey data

Labor Quality and R&D Quality

Indeed, labor quality and R&D quality were the next most frequently ranked factors affecting investment decisions, with respondents viewing the United States as dominant in both. For both factors Taiwan was the next most frequently identified location with an advantage, though by many times fewer respondents.

Many respondents pointed to the university system in the United States, writing that the "quality of engineering graduates from [local] colleges and universities is top class," that "U.S. engineering candidates are of higher caliber," and that the "deep/broad R&D infrastructure setup in the U.S. (Universities, National Labs, industry support) provides for a rich pool to draw from."

Respondents identifying non-U.S. locations for labor quality and R&D quality were significantly more focused on the manufacturing ecosystem, which they believed to be more mature outside of the United States. Several respondents indicated that locations outside of the United States provided workforces that were "more consistent and reliable," "stable," and "committed."

Ability to Protect Intellectual Property

Respondents were nearly unanimous that the United States provided the world's best location for protection of intellectual property. As noted in the General Business Challenges section above, issues related to information security—cybersecurity, foreign industrial espionage, and intellectual property/patent infringement—were areas of increased focus for companies, and innovating and protecting designs are crucial to companies in the United States.

One respondent noted the United States has "robust patent and trade secret [protection], as well as good criminal enforcement," while another wrote that "most startups and small companies stress the advantage of IP protection in U.S."

Additional Areas of Note

Respondents were split on whether the United States or other locations provided a greater advantage in providing government incentives. Nearly all respondents providing comments on the benefit of U.S. incentives mentioned the CHIPS Act, summarized by one respondent: "If the CHIPS Act pans out, it may well tilt the playing field in favor of the U.S."

Other respondents pointed to the significantly longer history of other countries, particularly in Asia, providing incentives to offset high capital costs. Notable comments include:

- *"Global competition is anything but free or fair ... U.S. Government incentives are necessary for competitive U.S. factories."*
- *"Now that all attractive manufacturing locations offer meaningful government incentives, this factor has become slightly less critical. … The U.S. CHIPS Act could close the cost gap with East Asia if grants … are awarded at or near the statutory maximum for projects and applicants also are able to take advantage of the Advanced Manufacturing Investment Credit."*
- *"Incentives and abatements can have a profound impact on the start-up and running costs. To date, Asian countries have been superior to the U.S. regarding incentives and abatements."*
- *"This is a global economic fight. Companies tend to go where the incentives and overall costs are best. The US is unaccustomed to competing for business to locate in its borders. For decades other factors (like currency stability, resources, talent, infrastructure, IP protection, political stability) permitted the US to effectively have no international competition. The world has changed and the playing field of global economics is much more competitive. Our failure to recognize the change has led us to fall behind and watch manufacturing leave the US for foreign offered advantages."*

Several of the remaining highly ranked factors can be grouped together as related to broader production ecosystems: material availability, proximity to customers, material quality, and collaboration benefits. Across these areas, respondents pointed to the importance of secure and ongoing access to partners and materials.

Respondents providing chips used in displays, computers, and mobile devices frequently noted that their customers' manufacturing base was largely based in Asia, providing incentives to have operations there. As noted in the Sales section above, China serves as the shipping location for more chips than any other country, a factor that serves to draw U.S. chip companies to operate in the region.

The production and processing of many of the materials used in semiconductors are also concentrated in China. Several respondents noted that this reliance has caused supply chain challenges, particularly over the last several years.

In addition to the 24 factors provided by BIS—which covered 97 percent of respondent answers—13 respondents indicated that an unlisted item was a key factor. The bulk of these related to the value of an existing microelectronics ecosystem—proximity to designers and to existing facilities, the presence of foundries, and customer base. Several respondents also noted the importance of factors related to security, including classification and participation in the U.S. Department of Defense Trusted Foundry program. Other identified factors include concerns about the availability and cost of land, and the presence of adequate infrastructure.

- *"It is critical to have land that is sufficiently large, has access to adequate infrastructure, and is in a location that is not prone to natural disasters or other environmental conditions that could interfere with very sensitive manufacturing operations (e.g., vibration from railroad tracks, low water quality or weather extremes)."*

5.3 Regulatory Hurdles

For companies interested in constructing, expanding, or modernizing facilities in the United States, regulations designed to protect national security, the environment, or local character can be barriers to investment. One-quarter of IDMs and foundries planning to expand or modernize their facilities in the next ten years indicated that regulations inhibit their organization from constructing, expanding or modernizing in the United States. This figure rises to 34 percent of IDMs and foundries planning on using the investment tax credit included as part of the CHIPS Act, and 46 percent of those planning on making eligible investments of over $100 million.

These respondents identified environmental regulations and/or restrictions (64 percent), export controls (21 percent), local regulations pertaining to permitting or zoning (18 percent), and financial regulations such as foreign direct investment and tax laws (9 percent), as their primary inhibitors. Other inhibitors reported include general regulatory burden, immigration law, and tariffs. Several respondents indicated that while their own organizations were not inhibited from making investments, largely because they operate on a fabless model, they believe there are obstacles impacting the industry as a whole.

Overall, respondents are predominantly concerned about the significant delays anticipated ahead of fab construction due to regulatory compliance. Respondents specifically refer to the National Environmental Policy Act (NEPA), which governs the process through which federal agencies must evaluate the environmental impact of major federal actions. The Council on Environmental Quality reports that the average timeline for completion of the review process between 2010 and 2018 was 4.5 years.[139]

Semiconductor facilities funded under the CHIPS Incentive program currently qualify as major federal actions that must undergo the NEPA review process, which includes the preparation of an Environmental Assessment (EA) and a more detailed Environmental Impact Statement (EIS) document, which is subject to a public comment period. Until the public comments are considered, the EIS finalized, and a record of decision (ROD) issued, the actions under review cannot be implemented. CHIPS Incentive program applicants must also obtain all other necessary permits under the environmental review process and may need to complete a separate environmental review for certain states.[140]

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[139] https://ceq.doe.gov/docs/nepa-practice/CEQ_EIS_Timeline_Report_2020-6-12.pdf
[140] https://www.nist.gov/system/files/documents/2023/04/20/3.18.23-CHIPS for America Overview of NEPA and Environmental Reviews.pdf

Respondents noted the importance of regulations, but focused on the delays imposed by regulatory reviews and permitting, highlighting the value of being able to build quickly:

- *"Delays in semiconductor fab construction will only impede chip production, supply chain resilience, innovation, and economic growth. In order for a semiconductor fab construction project to proceed without any disruption, there must be no significant regulatory delays that can postpone fab construction and operation. Specifically, if the NEPA review takes an unduly long period, this could push out the incentive disbursement, which could jeopardize fab operation."*
- *"We do not own or operate foundries to produce silicon wafers from which our integrated circuits are made. Our business and operations could be adversely affected to the extent our current and potential manufacturing foundry suppliers in the U.S. are inhibited from constructing, expanding, or modernizing their US facilities."*
- *"Regulations, like export, environmental, health and safety, and employment laws do increase the costs in the US compared to other jurisdictions where [our company] manufactures, but it will not inhibit [us] from building … in the US. Regulations and permitting is welcome but needs to move at the speed of business."*
- *"As the government makes historic investments in a domestic manufacturing ecosystem, it must also pursue policies that ensure United States companies are able to maintain preeminence in design and that the vast majority of R&D continues to happen in the United States. The strategy must include both an intentional deployment of funding to foster a long-term domestic talent pipeline, and new policies that can help alleviate short-term labor challenges. The last key factor is the geographical location of our main suppliers and customers."*

5.4 Geopolitical Concerns and Technology Transfer

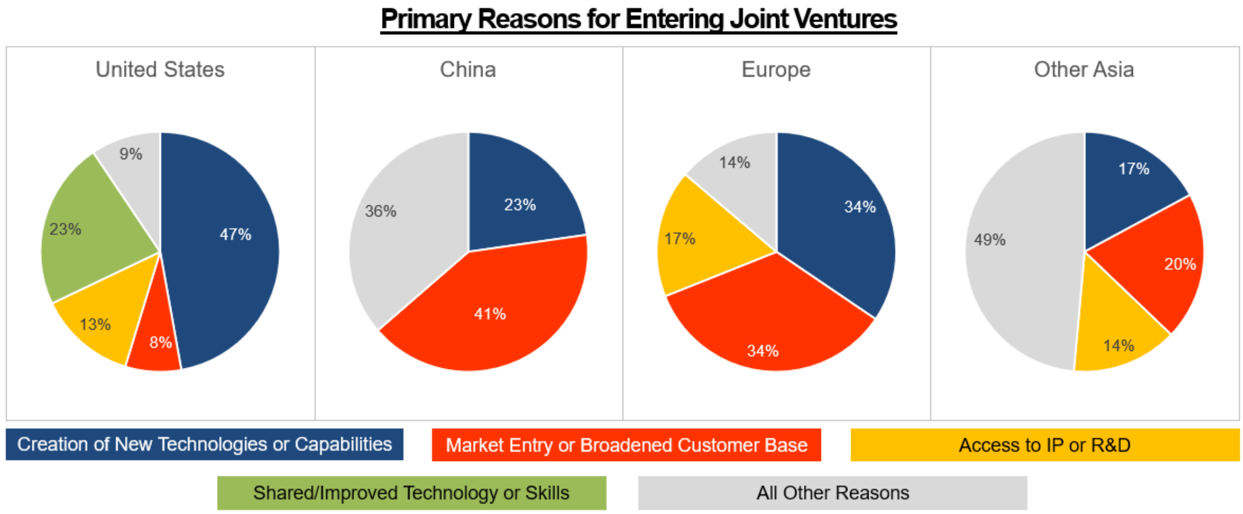
Joint Ventures and Technology Transfer

The semiconductor industry is highly competitive and globally integrated. While U.S.-based companies have expressed the vital importance of protecting their intellectual property, and rising concerns related to information security, less than 30 percent of U.S.-based company chip sales are to users in the United States. International engagement, cooperation, and partnership are necessary for the success of both individual companies and the industry as a whole.

Thirty-five respondents reported having a combined total of 136 joint ventures in 2022, 61 percent of which involved organizations outside of the United States. The most frequently identified non-U.S. location for joint venture partnerships was China, with 22—one-quarter of the non-U.S. joint ventures. Other locations across Asia—primarily Taiwan, Japan, and Singapore—accounted for an additional 40 percent of non-U.S. joint ventures, with the remaining one-third focused in Europe.

Primary reasons for entering these joint ventures varied significantly by region. Nearly half of the joint ventures located in the United States were primarily focused on the creation of new technologies or capabilities. Another quarter targeted shared/improved technology or skills—a category identified for no joint ventures outside the United States.

Joint ventures in China were heavily focused on market access, with 41 percent having a primary reason of market entry or broadened customer base. Less than one-quarter of joint ventures in China were focused on the creation of new technology or capabilities. No remaining factor accounted for a significant portion of responses.



Nearly all European joint ventures were aimed at the creation of new technology or capabilities, market entry or broadened customer base, or access to IP or R&D. The share of respondents creating joint ventures for the purpose of market entry or broadened customer base was similar to those in China. For no joint ventures in either region did any respondent indicate they had pursued the joint venture as a required condition of gaining market access.

BIS asked respondents whether their organization had felt coerced to share technology with a joint venture partner or government. No applicable cases were identified by respondents.

BIS also asked respondents to identify whether they had lost control of or transferred intellectual property to any entities whose primary beneficiary was (or was suspected to be) a foreign government or affiliated with a foreign government. Respondents identified a total of 17 such cases, with sharing carried out through research collaborations, licensing agreements, or joint ventures. The majority of the identifications involved the use of licensed IP to carry out joint research. Only one case indicated a detrimental loss of intellectual property.

Respondents identified a total of 27 occurrences of unauthorized transfer of intellectual property since 2017. Half of the unauthorized transfers were carried out by former employees or contractors, with the remaining cases split between disclosures by contractors, suppliers, or business partners, network intrusions, or phishing. In most cases, respondents were unable to identify—or did not believe there was—a country benefitting from the unauthorized transfer. Among those that were identified, China was the only country listed.

Subsidies

Investments in the semiconductor industry have long been driven by government support. The global level of subsidies offered has significantly increased since 2020, with the combination of increased manufacturing concentration in China and Taiwan and microelectronics-driven supply chain disruptions highlighting the need for more resilient production. By some estimates, the 2021 chip shortage cost the auto industry alone more than $210 billion in lost sales based on a chip shortfall of $10 billion.[141]

Since 2020, hundreds of billions of dollars in government subsidies have been approved. The United States CHIPS and Science Act provides for $39 billion in manufacturing incentives and $13 billion in R&D and workforce development. The law also includes an advanced manufacturing tax credit of 25 percent, providing additional incentives worth an estimated $24 billion.[142]

Across the world, many countries have created or are exploring significant new incentives to attract or retain semiconductor production capabilities, with tax credits often used as a primary method of government support. The European Chips Act provides incentives of $46 billion.[143] India plans to spend $10 billion on semiconductor incentives, providing as much as half of project value.[144] Japan has announced plans to invest nearly $7 billion between newly-formed Rapidus and TSMC.[145] South Korea hopes to draw $450 billion in investment via a 20 percent tax credit, providing support equivalent to $90 billion.[146] Taiwan approved in 2023 an increase in its R&D tax credit to 25 percent.[147] Singapore, recognized by survey respondents (alongside China) as the top location outside of the United States to receive government incentives, provides benefits collectively estimated to lower the cost of fab ownership by 25 to 30 percent.[148]

While many of these incentives are newly announced, China has offered large semiconductor incentives for the past decade, launching the National Integrated Circuit Investment Fund (or Big Fund) in 2014 with $21 billion and adding an additional $35 billion in 2019 and reported $41 billion in 2023.[149] This investment fund is supplemented by local funds, tax breaks, and loans,

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141 https://www2.deloitte.com/za/en/pages/technology-media-and-telecommunications/articles/semiconductor-industry-outlook.html

142 Based on Congressional Budget Office estimates (https://www.cbo.gov/system/files/2022-07/hr4346_chip.pdf). Survey respondents indicated they expected $109 billion worth of investments would be eligible for the tax credit, a value of $27 billion. Additional investments by companies outside the scope of this survey (e.g. providers of semiconductor manufacturing equipment) will likely apply.

143 https://www.consilium.europa.eu/en/press/press-releases/2023/07/25/chips-act-council-gives-its-final-approval/

144 https://www.reuters.com/world/china/india-unveils-10-bln-plan-woo-semiconductor-display-makers-2021-12-15/

145 https://www.reuters.com/markets/deals/japan-add-23-bln-subsidy-rapidus-chitose-chip-plant-media-2023-04-10/

146 https://www.bloomberg.com/news/articles/2021-05-13/korea-unveils-450-billion-push-to-seize-global-chipmaking-crown

147 https://www.bloomberg.com/news/articles/2023-01-09/taiwan-passes-its-chips-act-offers-tax-credits-to-chipmakers

148 https://www.whitehouse.gov/wp-content/uploads/2021/06/100-day-supply-chain-review-report.pdf

149 https://www.csis.org/analysis/chinas-new-strategy-waging-microchip-tech-war

with the total Chinese government semiconductor industry investment estimated to be over $190 billion.[150]

This investment has come alongside a massive expansion in Chinese fabrication capacity, rising from an estimated 12 percent of global capacity in 2014 to a forecast 23 percent in 2025.[151] A review of semiconductor startup data from the SemiEngineering website found more startups were funded in China from 2020-2022 than in the rest of the world combined, with China-based startups accounting for 20 of the 25 highest-funded startups.[152] According to a 2019 OECD report, Chinese government involvement was "especially large" in global context for the 2014 to 2018 period.[153]

Altogether, global subsidies aimed at the semiconductor industry total approximately $400 billion, much of which will be disbursed between 2023 and 2027.[154]

5.5 Perspectives on Areas for U.S. Government Support

In addition to information on their capabilities, supply chains, challenges, and areas of concern, BIS solicited feedback from survey respondents on areas that U.S. government policy or support could enhance the long-term competitiveness of their companies, the industry as a whole, and associated sectors of the U.S. economy. Respondents provided 874 comments on these areas with a wide variety of suggestions.

Need for Long-Term Solutions

One dominant theme was that while the CHIPS and Science Act was sorely needed to enable investment in domestic manufacturing, longer term support is necessary to fully level the playing field for U.S. businesses and to foster a robust domestic workforce. As one respondent noted, "Foreign incentives and lower operating costs have created a 30-45% cost differential of manufacturing in the U.S., and U.S. incentives and the investment tax credit are absolutely essential in closing this gap and ensuring the long-term competitiveness of our organization and the broader U.S. semiconductor ecosystem." Similar cost differentials were cited by other respondents, with consistent public reports from TSMC, Boston Consulting Group, and the Semiconductor Industry Association.[155]

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[150] https://www.semiconductors.org/wp-content/uploads/2021/07/Taking-Stock-of-China%E2%80%99s-Semiconductor-Industry_final.pdf, including additional $41 billion in 2023

[151] https://www.semi.org/en/blogs/business-markets/china-surges-past-the-americas-and-japan-in-ic-capacity, https://www.eetasia.com/semi-global-300mm-chip-fab-capacity-forecast-to-reach-new-high-in-2025/

[152] https://www.stiftung-nv.de/sites/default/files/snv_semiconductor_startup_funding_activities.pdf

[153] https://read.oecd-ilibrary.org/trade/measuring-distortions-in-international-markets_8fe4491d-en

[154] This figure aligns with that reported by Applied Materials in their May 18, 2023 earnings call

[155] TSMC founder Morris Chang indicated the cost of fab operation in the United States was 50% higher than in Taiwan, echoed by TSMC Chairman Mark Liu on the company's July 2023 earnings call https://investor.tsmc.com/english/quarterly-results/2023/q2. BCG report indicates ten-year total cost of fab ownership in the United States is 30% higher than in Taiwan, Korea, or Singapore and 50% higher than in China, with 40-70% of this difference stemming from government incentives https://www.bcg.com/publications/2020/incentives-and-competitiveness-in-semiconductor-manufacturing. Another BCG report finds that the share of semiconductor R&D funded by public investment outside the United

Respondents indicated that one of the most impactful ways the U.S. government can support domestic industry is through the creation of a large and capable domestic workforce across all processes of the semiconductor ecosystem. In addition to direct support for education and training, a robust domestic workforce requires long term and consistent investment in manufacturing facilities. As identified above, the minimal levels of new fab construction in the United States over the past two decades has resulted in companies now building fabs reporting difficulty finding enough workers with direct applicable experience.

Nearly two-thirds of the comments respondents provided in response to "what can the U.S. government do to promote higher and more effective investment in microelectronics manufacturing in the United States" addressed the implementation of CHIPS Act incentives or the need for additional, longer term incentives. Many of these comments indicated there was a need to level the playing field or counteract the incentives and protections in place in other countries.

Select comments include:

- *"Incentives such as the Chips Act and FABS act go a long way to leveling the playing field."*
- *"The government should explore other long-term mechanisms (e.g., special economic zones, etc.) to maintain a healthy overall domestic semiconductor industry, as well as looking at ways to stimulate and assure demand over the long term."*
- *"Establish long term policies and incentives. Microelectronics is capital intensive and this drives much of the location decision. Policies need to make long term investment a better option."*
- *"Markets that require very large capital with long payback is not supported by Wall Street. … If supported by Chips Act type investment although 'with 30 year payback requirement' will help US investment in such infrastructure, foundries and factories."*
- *"Incentives need to focus not only on the one-time cost of constructing or locating operations in the United States, but also on the long-term, ongoing operational costs of operating, maintaining and modernizing operations in the United States."*
- *"The CHIPS & Science Act was a great first step, but without a long-term plan, there will be hesitation to move supply chains to the U.S."*
- *"Programs under the CHIPS Act are well-positioned to bridge the gap between private market investment incentives and the far broader public interest benefits served by investment in long-term R&D for semiconductor design and manufacturing."*
- *"The semiconductor manufacturing business is incredibly capital intensive, and as a result, requires steady and large-scale investments over a prolonged period of time. Therefore, policies that encourage investment, such as incentive grants and tax credits, should be made permanent."*

States is more than twice that inside the United States. https://www.bcg.com/publications/2022/the-challenges-of-semiconductor-design-space

- *"The CHIPS Act, especially the Investment Tax Credit and grant program, was a significant step to promote more effective investment, and continued efforts in developing technical talent in the US and relaxed or expanded immigration for technical industries like semiconductors will help."*

These comments were not entirely self-serving; a significantly smaller share of respondents indicated that incentives were most crucial for the long-term competitiveness of *their organization* than needed for the domestic microelectronics industry as a whole. Regarding their organization's long-term competitiveness, respondents most frequently commented on workforce development—which was also the second-most frequently identified category of responses for the promotion of the broader domestic microelectronics industry.

As identified above, the three most frequently cited factors determining the location of company's semiconductor investment decisions were related to labor cost, availability, and quality. Respondents are highly optimistic on the quality of U.S. university education but see a need to expand the number of graduates of these programs, as well as to better enable U.S. companies to attract and retain top talent from around the world. Companies generally saw education and workforce development support as a necessary long-term pillar of support for the U.S. microelectronics industry, but also have an immediate need for experienced workers. Drawing in talented workers from around the world further concentrates the skilled workforce in the United States and enhances the competitiveness of U.S. businesses.

Support for Increased Collaboration

Investments in workforces and facilities are enhanced by collaborations with universities and local economic development organizations. Respondent comments on ways the U.S. government can support these collaborations revealed that while broader partnerships are in place at many leading U.S. companies, smaller organizations often lack the resources, structure, and knowledge to form and maintain these collaborations. Many respondents indicated that government facilitation of R&D partnerships and interactions with local economic development organizations would be highly beneficial for their organizations.

U.S. Government initiatives underway through the CHIPS Act, such as the National Semiconductor Technology Center (NSTC) and the Department of Defense-led Microelectronics Commons program, are examples of the types of programs that aim to address these types of concerns. Both have a goal of accelerating the commercialization process through increased collaboration between academic institutions, researchers, and businesses.

For R&D partnerships with universities, several respondents noted the precompetitive R&D space was "critical for maintaining industry technology leadership in the medium- and long-term," but expressed concerns about their experiences with university ownership and licensing of intellectual property. Representative comments on this topic include:

- *"Currently, top research universities end up filing patents on innovations resulting from collaboration with industry and end up taxing industry with royalties and lawsuits based on such patents. This behavior by many top research universities is a huge detriment to collaboration between industry and universities."*

- *"Reform the current practice that makes universities competitors to industry funders for rights to exploit jointly developed or industry funded IP (for example: Create/encourage efficient models whereby industry is able to exploit IP developed at universities with industry funding)."*
- *"The U.S. government can convene and incentivize novel partnership models for R&D that include industry, academia, start-ups, and non-profits."*
- *"IP must be appropriately handled to both facilitate moving new technology to commercialization via a shared model but also allow for independent owned IP exploration in a private manner."*

On the topic of coordinating with local economic development organizations, nearly all comments focused on their need for assistance in identifying the relevant contacts. Several large organizations noted that they have extensive and ongoing partnerships with local economic development organizations, but smaller organizations often indicated they did not have the same types of government relations departments, and that in addition to lacking the resources to maintain ongoing contacts, they often struggled to find these contacts in the first place. Several respondents suggested a role for the U.S. government in fostering these relationships:

- *"Having a [single] source of data (website?) for what local and state government programs are available to support semiconductor manufacturing [would be helpful]. Many smaller and mid-sized companies do not have the resources to search out and evaluate all investment opportunities [and learn if] supplement opportunities exist. These types of programs drive companies to co-invest and drive technology to the market faster."*
- *"Incentivize or otherwise encourage city, state, and county governments to create consolidated (shared across multiple local government entities) incentive application processes specifically targeted at semiconductor manufacturing."*
- *"It is difficult for small companies to navigate and be informed of potential funding sources and application processes; the existing process benefits larger companies that have resources solely dedicated to such activities."*
- *"A more centralized or systematic process to facilitate conversations and manage the investment process."*
- *"Enhancing the methods by which organizations are able to coordinate with local economic development organizations, and not just one locality but many localities at once (to ease site selection lead times), and keeping minimal or at least consistent the terms and conditions of local incentives, will help facilitate investment."*

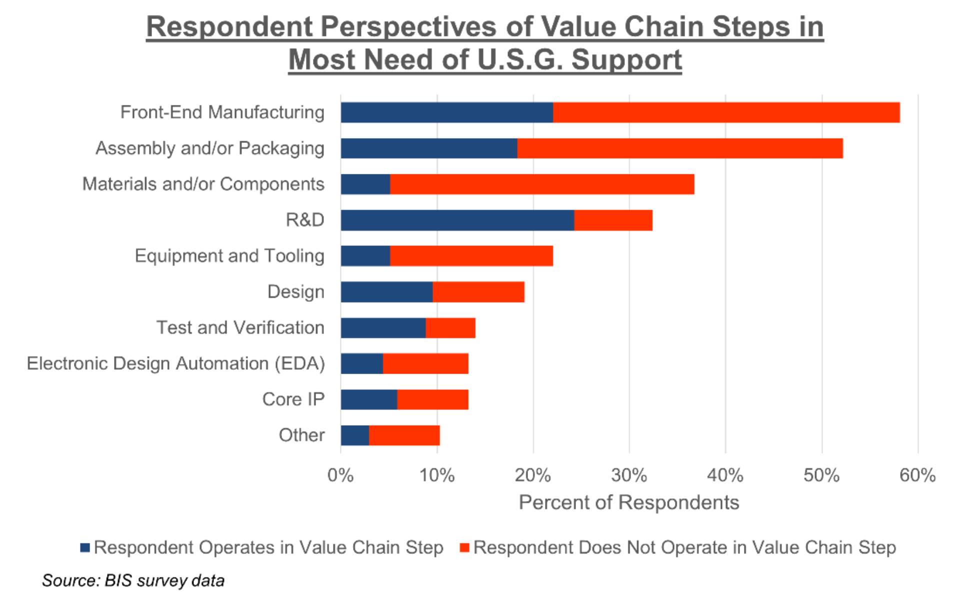
Even among larger organizations that have significant experience with local economic development organizations, respondents suggested that there is space for the U.S. government to help organize and streamline these experiences. Among the suggestions were increased education by the federal government to local organizations on best practices, available resources, and coordination of regulatory requirements:

- *“When the company selects a site to build a semiconductor facility, a key factor is the "one stop shop" process which such organizations offer to coordinate state and local resources across issues such as zoning, infrastructure, and incentives. One area for potential assistance would be for the federal government to help promote, scale, and replicate best practices for successful investment programs across the country, including areas like workforce development; transportation, energy, and water infrastructure support; and state and local financial incentives packages.”*
- *“Having the USG set up programs to educate EDOs [economic development organizations] on the funds available under federal legislation, such as the Inflation Reduction Act, will help to promote better programs at the state and local levels. The USG can also provide a central website with contact information for EDOs or equivalent organizations at the state and local levels.”*
- *“We've found that States with a centralized "one stop shop" coordinating state and local incentives are easier to deal with. This approach would be helpful if more states adopted it.”*
- *“When engaging with state and local governments, it can often be unclear how their regulatory requirements align (or do not align) with federal government requirements. One example of these is with regard to how federal environmental reviews and state environmental reviews might be duplicative of one another--adding to timelines and the regulatory burden.”*

Broader Areas of Investment

In addition to gathering their perspectives on ways in which the U.S. government can support their businesses, domestic microelectronics manufacturing, and collaboration, BIS asked respondents to identify which portions of the microelectronics value chain were most in need of government incentives, as well as which additional economic clusters outside of microelectronics should be supported to help strengthen the U.S. semiconductor industry.

Within the microelectronics sector, more than half of respondents indicated that front-end manufacturing and assembly and/or packaging warranted government incentives. These responses were not purely motivated by direct financial interest, as less than 40 percent of each category was made up of respondents operating within that value chain step. Respondents were also strongly supportive of providers of materials and/or components receiving incentives, with 37 percent of respondents listing that value chain step despite few of them operating within the category.



Select comments:

- Front-End Manufacturing:
  - *"This segment is the most subsidized by foreign countries and therefore where the greatest cost-disadvantage exists, so should benefit from the most government incentives to offset. As evidenced by the chip shortage, limited front end fab capacity is a critically important source of risk to customers and end-users. As the anchor of the chip supply chain, investing in fabs drives follow on investment across suppliers to the semiconductor ecosystem. Front end manufacturers also must procure expensive tools for leading-edge semiconductor manufacturing (up to $100-250 million each), so significant incentives for front-end manufacturing are needed to offset."*
  - *"Without government incentives, it is very difficult for US manufacturing compete foreign governments / entities"*
  - *"Wafer front end manufacturing is very costly to build up and maintain. Other countries are already subsidizing this value chain segment through large incentives and abatements. The US needs to level the playing field and make it financially competitive to build and operate a fab in the US."*
  - *"The lack of foundries in the US represents a risk for the defense industry."*
  - *"Investments in advanced fabs are extremely expensive, with most now in Asia because of government assistance. The US need to offer similar assistance to compete."*
- Assembly and/or Packaging
  - *"Packaging is the forefront of advances in semiconductor technology. All of the major packaging houses are foreign. Providing incentives to for packaging houses to work on cutting-edge technologies is fundamental to the continued progress of semiconductor technologies in the US."*

- *"Little to no onshore packaging to support the ecosystem. With the transition to [heterogeneous integration], capital is needed to develop the manufacturing capability."*
- *"Investment in new equipment/materials is required for the introduction of advanced packaging (Chiplet, 2.5D, 3DIC, etc.) in support of shrinkage in semiconductor process. In the past, assembly & package-related technology cycles were long so the amount of investment was relatively small; this is gradually increasing. Assembly & package support in conjunction with front-end manufacturing is also important. If the production volume of semiconductor manufacturing plants in the US increases, the demand for assembly & package processing from wafer to chip will also increase."*
- *"Advanced packaging is the future of microelectronics. There is opportunity to be a world leader in this, and failure to do so will mean losing the next generation of semiconductors to foreign competitors."*

- <u>Materials and/or Components</u>
    - *"Most of the materials, gases, and components for microelectronics are sourced outside of the U.S. co-locating materials, gases, and components in or near the U.S. would make the U.S. more competitive and less dependent on other nations and to reduce overall costs."*
    - *"Materials innovation is the back bone of all technologies. Need to invest in R&D of materials and their use in new components and new capabilities."*
    - *"The industry's main weakness is the dependencies on raw materials, including substrates, and access to critical minerals and materials from non-US allies."*
    - *"In the future, the microelectronics industry will broaden materials and devices well beyond traditional silicon device manufacturing to continue to advance industry performance roadmaps. This creates the opportunity to benefit from this inflection or the chance to fall further behind off shore competition who are investing in these areas."*
    - *"Most of the material needed for production of microelectronics come from Asia and represent a risk to US defense and industry."*

Responses on which investments in areas outside of microelectronics would best strengthen the U.S. semiconductor industry painted a similar picture, with investments in materials identified more than twice as frequently as any other area. In addition to the above identified concerns about availability and sourcing of a wide array of key materials, many respondents also pointed to the broad benefits of advances in materials science.

Also frequently highlighted was the need for downstream demand for semiconductors. In prior sections of the survey respondents noted that lack of domestic electronics production in several semiconductor-heavy segments—notably displays, mobile devices, personal computers—limited the viability of domestic production of semiconductors for those markets. For the future, many respondents highlighted the increased intensity of semiconductor usage driven by automation, artificial intelligence (AI), and the Internet of things (IoT) as areas that the United States should focus on to ensure domestic demand for semiconductors.

Artificial Intelligence is rapidly increasing in importance to the microelectronics industry, both as an end use and through incorporation in the R&D, design, and production process. Market-leading providers of IP and Electronic Design Automation (EDA) tools are highlighting the immense value of AI in the design process. Synopsys reported in May 2023 that they are "embedding AI in everything we do,"[156] and Cadence Design Systems noted in July 2023 that AI-enabled design can provide a greater benefit than would be achieved by moving to a more advanced node.[157] On the end use side, providers of leading-edge chips expect AI uses and demand to grow massively over the next decade. Qualcomm reported expectations for significant increases in uses of edge and on-device AI,[158] and Intel has noted they see AI in everything from data centers to hearing aids.[159] For data center AI accelerators, market leaders are making plans for explosive growth. AMD and TSMC both indicated in second quarter 2023 earnings calls that they expect AI demand to grow at 50 percent per year through 2027 and NVIDIA noted they expect $1 trillion in data center value to be upgraded to use AI accelerators by 2032 and that data center workload "soon will be predominately generative AI."[160]

Thirty-two percent of survey respondents indicated they expect AI will be one of the top three emerging technologies that most impact the semiconductor industry in the next five to 10 years, noting both the increased demand and improvements in semiconductor design. Respondents also noted that further AI advancement was tied to successful semiconductor material, capability, and process advancements:

- *"AI not only creates a massive market for the semiconductor industry, but also impacts how semiconductors are built. AI will be deployed in the design of semiconductors and semiconductor adjacent technologies."*
- *"AI's ability to parse and interpret big data allows for new semiconductor materials with very specific desired properties to be formulated, and new device designs and optimization to be engineered."*
- *"AI requires a significant amount of computing/processing power, which will become a hindrance to further development if advancements are not made in semiconductor capabilities."*

[156] https://s201.q4cdn.com/778493406/files/doc_financials/2023/q2/2023-05-17_SNPS_Q223_Prepared_Remarks.pdf
[157] Cadence Design Systems, Second Quarter 2023 Financial Results Conference Call, July 24, 2023
[158] Qualcomm, Third Quarter 2023 Earnings Webcast, August 2, 2023
[159] Intel, Second Quarter 2023 Earnings Webcast, July 1, 2023
[160] NVIDIA, First Quarter Fiscal 2024 Earnings Webcast, May 24, 2023

6. Findings and Recommendations

Findings

- **Production Capabilities**
  - Nearly all semiconductor design and manufacturing companies are headquartered in eight locales: United States, Taiwan, South Korea, Japan, China (PRC), Germany, Switzerland, and the Netherlands.
  - The BIS survey covers an estimated 63 percent of global semiconductor revenue, with data from respondents operating 3,760 semiconductor-related facilities around the world.
  - Semiconductor companies operating in the United States are global enterprises, with half of their facilities located outside of the United States. China and Taiwan accounted for over one-quarter of non-U.S. facilities identified by survey respondents.
  - The United States is an essential leader of the microelectronics sector. Companies headquartered in the United States accounted for an estimated 53 percent of semiconductor device revenue in 2022.
  - BIS estimates that while half of global semiconductor product revenue is attributable to U.S.-based companies, significant portions of the design and manufacturing process are carried out elsewhere. Estimated global share of semiconductor activities carried out inside the United States:
    - R&D: 47 percent
    - Design: 27 percent
    - Front-End Fabrication: 12 percent
    - Assembly, Test, and Packaging: <2 percent
  - BIS estimates that 85 percent of chips sold by U.S.-based companies are packaged—either in-house or by outsourced semiconductor assembly and test (OSAT) providers—in four locations: Taiwan, China, South Korea, and Malaysia.

- **Inputs and Equipment**
  - Facilities located in the United States are mostly supplied from within the United States, while those outside of the United States are mostly supplied from other countries.
  - Bare wafers are undersupplied in the United States, and with most wafers coming from outside the country, wafers lead the list of materials/inputs that respondents were most concerned about being able to acquire.
  - Availability of gases—particularly helium, nitrogen, hydrogen chloride, neon, nitrogen trifluoride, and hydrogen—was an acute concern for respondents, second only to wafers in overall level of concern, with a higher number of respondents expressing “extreme” or “great” concern about their ability to acquire the necessary gases. The gas supply market was concentrated, with three companies accounting for 60 percent of respondents’ primary supplier identifications.

- Respondents identified 78 unique chemicals of concern, led by sulfuric acid and isopropyl alcohol. The United States has significant import dependence for ultra-high purity forms of both chemicals.
- The United States is largely lacking a supply chain to support assembly, test, and package (AT&P) activities.
- Companies based in the United States, Japan, and the Netherlands account for 90 percent of semiconductor manufacturing equipment market share. This is largely on the strength of several key companies: U.S.-based Applied Materials, Lam Research, and KLA Corporation, Japan-based Tokyo Electron, and Netherlands-based ASML.
- Equipment had extended lead times of one year for all categories except for Assembly, Manufacturing Automation, and Test equipment which averaged about half that time, and lithography equipment for 300mm wafers which approached two years.

- **<u>Workforce</u>**
  - The semiconductor industry directly employs over 200,000 people in the United States, with expectations for 70,000 new jobs by 2032.
  - The semiconductor workforce is highly educated, with three-quarters of jobs requiring a four-year degree. Requirements are more stringent at fabless companies, with 86 percent of jobs requiring at least a four-year degree and nearly half requiring an advanced degree. At foundries, one-third of the positions required no more than a high-school degree.
  - Semiconductor jobs are well paid, with average salaries both for production workers and STEM-focused workers over 30 percent higher than national averages.
  - Respondents identified workforce-related items as both their top business challenges and the most important factors in deciding where to locate a facility.
  - The ability to draw in and retain skilled workers from outside the United States was seen as crucial by semiconductor companies in maintaining the United States' international competitiveness while the country increases focus on domestic education and training initiatives.

- **<u>Sales and Financial Performance</u>**
  - Companies based in the United States account for half of global semiconductor product sales, a figure largely unchanged for the past 30 years.
  - Market share of U.S.-based companies has been bolstered by the growing market share of fabless companies, an area the United States is dominant in.
  - The primary sales location for semiconductors is the Asia/Pacific region—accounting for half of all semiconductor sales—and within that region China, which accounts for an estimated 30-40 percent of semiconductor sales of U.S.-based companies. Sales to locations inside the United States account for approximately one-quarter of the sales of U.S.-based semiconductor companies.

- Two-thirds of semiconductors are used in Information and Communications Technology (ICT) sectors led by personal computers and mobile devices. The primary other end uses were in the Automotive and Industrial sectors, which are driven by heavy use of analog, micro, and O-S-D chips.
- Respondents expect the fastest growth through 2032 in the Aerospace and Defense sectors and Automotive sector. Growth in Mobile Devices and Personal Computers is expected to lag, but still average more than 5 percent per year.
- Mature technology nodes—those over 28 nanometers—represent the majority of respondents products across all product segments. Respondents anticipate this will continue to be the case in 2027 for all segments outside of logic and micro.
- Fabless companies exhibited higher financial risk, higher profit margins, and higher shares of companies with net losses, suggestive of the higher risk/reward profile of the group.
- Capital expenditures among survey respondents have nearly doubled since 2017, with expenditures inside the U.S. growing more quickly—though still lower since 2016 in absolute terms.
- Capital expenditures are largely attributable to several large companies with major leading-edge investments. TSMC accounts for 19 percent of the value of the total industry's property, plant, and equipment (PP&E), and Intel for 17 percent. The memory segment—largely controlled by four companies—accounts for 27 percent.
- Among U.S.-based companies, Intel and Micron together account for three-quarters of the global PP&E owned by U.S.-based companies.
- U.S.-based companies account for three-quarters of global semiconductor provider R&D, devoting an average of 18 percent of their revenue to R&D. Intel alone accounts for 20 percent of all semiconductor provider R&D expenditure.
- Equipment, accounting for half of the cost of a new fab, is the primary capital expenditure priority for respondents. Most planned to expand or modernize their facilities in the next 10 years, with one-quarter of U.S. fabrication facilities expected to be both modernized and expanded within two years.
- With no new large fabs built in the United States in over 30 years, the long gap in major construction of new fabs in the United States has led to limited direct experience for U.S. workers, causing challenges with the construction of new fabs.
- Respondents have plans for over $200 billion in expenditures on capital projects in the United States between 2023 and 2032, 19 percent of which respondents expected would be provided by federal, state, and local funding.

- **Business Challenges and International Comparisons**
  - The three most frequently identified business challenges were worker/skills retention, labor availability/costs, and foreign competition.
  - Input availability presented a challenge unexpected by many respondents, having been expected by 38 percent of respondents in 2017 but experienced by 60

percent of respondents in 2022. These challenges were heavily attributed to shortages during COVID-19 and resulting from the associated surge in demand for electronics, to the war in Ukraine, and to increased international trade disputes.
    - Respondents expressed rising concern related to information security, with increasing expectations of challenges related to cybersecurity, intellectual property and patent infringement, and foreign industrial espionage.
    - IDMs and foundries had increasing expectations of challenges related to environmental regulations and lack of infrastructure, and were significantly more concerned than fabless companies about aging equipment, facilities, and infrastructure.
    - The United States is comparatively strong in three of the five most important factors driving capital investment—Ability to Protect Intellectual Property, R&D Quality, and Labor Quality—but weak among the top two factors: Labor Cost and Labor Availability.
    - Respondents were optimistic about the implementation of the CHIPS Act and see it as crucial to allowing U.S.-based companies to fairly compete.
    - The broader electronics ecosystem—including upstream suppliers of materials and equipment and downstream customers and end users—was highlighted as a major factor in determining location of operations.
    - 25 percent of IDMs and foundries planning to expand or modernize facilities between 2023 and 2032 indicated that regulations inhibit their ability to do so in the United States. Among respondents making investments of over $100 million, this figure reached 46 percent. Major concerns were related to delays associated with environmental regulations, to U.S. export controls, and to local zoning or permitting.
    - Respondents were largely sanguine about their interactions with foreign governments, noting no recent cases of coercion to share technology and limited solicitations. Unauthorized technology transfers were nearly all carried out by former employees or business partners.
    - Global subsidies aimed at the semiconductor industry total approximately $400 billion, most announced since 2020. Incentives provided by China have been more persistent and larger than other countries, with an estimated $150 billion provided to support the Chinese semiconductor industry since 2014.

- **<u>Perspectives on U.S. Government Support</u>**
    - The cost of manufacturing in the United States is significantly higher than abroad, driven by subsidies and lower operating costs overseas. Respondents see incentives as essential to leveling the playing field for doing business in the United States.
    - Establishment of longer-term incentives that support continued fab construction can drive down the overall costs of incentives and cost of production by maintaining an experienced work force and established supply chain.

- Companies generally saw education and workforce development support as a necessary long-term pillar of support for the U.S. microelectronics industry, but also have an immediate need for experienced workers. Drawing in talented workers from around the world further concentrates the skilled workforce in the United States and enhances the competitiveness of U.S. businesses.
- Respondents primarily believe incentives should be targeted at front-end manufacturing, assembly/packaging, and materials.
- To ensure future domestic demand, many respondents highlighted the increased intensity of semiconductor usage driven by automation, artificial intelligence (AI), and the Internet of things (IoT) as areas that the United States should support.

Recommendations

The risks presented in the Semiconductors 100-Day Report[161] continue to exist, and the recommendations provided in that report continue to be valid. That report presented seven sets of recommendations:

1) Promote investment, transparency, and collaboration, in partnership with industry, to address the semiconductor shortage
2) Fund the Creating Helpful Incentives for Production of Semiconductors (CHIPS) for America provisions in the Fiscal Year 2021 National Defense Authorization Act (NDAA)
3) Strengthen the Domestic Semiconductor Manufacturing Ecosystem
4) Support Manufacturers, Particularly Small and Medium-Size Businesses
5) Build a Diverse and Accessible Talent Pipeline for Jobs in the Semiconductor Industry
6) Engage with Allies and Partners on Semiconductor Supply Chain Resilience
7) Protect U.S. Technological Advantages in Semiconductor Manufacturing and Advanced Packaging

The Department, the broader U.S. government, and the microelectronics industry have made significant progress in implementing these recommendations, though continued focus on the extensive work already underway is essential to sustaining a robust, healthy, and competitive U.S. microelectronics industry.

The data collected and research and analysis carried out for this report support several additional recommendations, many of which overlap with and supplement the above recommendations. These recommendations fall into four broad categories:

1. Level the Playing Field for Semiconductor Manufacturing in the United States

Companies in the United States have for decades faced higher costs than competitors around the globe. BIS survey respondents identified foreign competition as their third greatest organizational challenge, behind only labor availability/costs and worker/skills retention, with the highest share of respondents listing foreign competition as their single greatest organizational challenge. Low-cost production and foreign subsidies were most frequently mentioned in comments on foreign competition.

There is intense global competition to attract semiconductor fabrication facilities, which serve as a foundation for the entire microelectronics ecosystem, attracting both upstream and downstream investments. Survey responses and existing research indicate that between lower operating and construction costs, direct government funding, tax incentives, and additional funding initiatives in other countries, the cost of manufacturing semiconductors in the United States may be some 30 to 45 percent higher than the rest of the world.

[161] https://www.whitehouse.gov/wp-content/uploads/2021/06/100-day-supply-chain-review-report.pdf

For the United States to manufacture its fair share of semiconductors domestically, companies operating in the United States must be able to compete on a level playing field. Recommendations for allowing semiconductor fabrication to thrive in the United States include:

A. *Long-Term Support for Domestic Fabrication Capabilities*

The process of constructing fabrication facilities is a valuable resource in its own right. The consistent construction of fabs in the United States will not only serve to decrease the risks of limited domestic production, but also will lead to knowledge gains, process improvements, and lower construction and operating cost differentials.

The U.S. government should enact permanent provisions that incentivize steady construction and modernization of semiconductor fabrication facilities, such as the investment tax credit scheduled to end in 2027.

The importance of products relying on mature processes must also be recognized. While these products produce less revenue than leading-edge processes, they are essential for national security uses and significant R&D continues to be performed on products using mature processes. Many of these chips are produced using older, and in some cases obsolete, equipment on smaller wafer sizes. Additionally, forecast PRC overcapacity threatens to make these products financially nonviable in the United States and allied economies. *Incentives to support domestic production should include mature technologies and consider ways to support upgrades to ensure long term commercial viability*.

In addition, survey respondents indicated the variety of overlapping incentives and requirements at the federal, state, and local level presented challenges, especially for smaller companies. *The U.S. government should develop a program to help organize and streamline interactions across the federal government, with local authorities, and with economic development organizations and to promote best practices in support of semiconductor facility investments.*

B. *Long-Term Support for Domestic AT&P Capabilities*

The production of semiconductors requires assembly and packaging, as well as front-end fabrication, and the United States currently has minimal assembly and packaging capabilities. The assembly and packaging capabilities of U.S.-based companies—both in-house and outsourced—are highly dependent on operations in Taiwan, China, South Korea, and Malaysia, with nearly half of all chips provided by U.S.-based companies packaged in Taiwan or China.

The U.S. government should provide sufficient incentives to allow for competitive domestic assembly and packaging capabilities. This should include incentives focused on increased automation. The labor-intensive AT&P segment is heavily concentrated in low-wage areas of the world, but automation can bridge the cost gap of providing AT&P in the United States, as well as increase well-paying jobs in equipment manufacturing and servicing.

C. *Continue to Protect U.S. Technology*

Companies and researchers in the U.S. lead the world in semiconductor R&D, design, and development of semiconductor manufacturing equipment. Survey respondents indicated that the protection of their intellectual property was a leading factor in deciding where to make investments, and that the United States led the world in the ability to protect intellectual property.

The U.S. government should continue to focus on these strengths by aggressively protecting intellectual property and through the targeted use of export controls to ensure that technology developed in the United States is not used in ways that harm U.S. economic or national security. This includes increasing resources for law enforcement and U.S. Government agencies to prevent and prosecute semiconductor intellectual property theft and industrial espionage.

D. *Combat Unfair Trade Practices*

China has a track record of subsidizing overcapacity in strategic sectors like solar, steel, and batteries that has decimated foreign competitors. The PRC government has provided its domestic semiconductor industry with an estimated $190 billion in subsidies in the last decade, which is likely to drive below market pricing for legacy semiconductors and create an unlevel global playing field for US and other foreign competitors.

The U.S. government should defend domestic semiconductor investments from PRC nonmarket behavior. Respondents most commonly referenced low-cost Chinese production when noting their concerns about the challenge from foreign competition and suggested the U.S. government take action to combat unfair trade practices, including imposition of tariffs or expansion of export controls.

2. Ensure U.S. Leadership in Advanced Research and Development

In addition to protecting technology developed in the United States, the U.S. government should ensure that the United States remains the world's leading place to carry out advanced semiconductor research and development. Governments around the world are targeting U.S. leadership, with the share of semiconductor R&D and design funded by public investment estimated to be 2.3 times higher in the rest of the world than in the United States, including 3.5 times higher in China.[162]

Continued U.S. leadership in semiconductor R&D relies on education and workforce leadership and protection of technology, but also requires methods to incubate, protect, and commercialize innovative technologies and support for companies developing

[162] https://www.bcg.com/publications/2022/the-challenges-of-semiconductor-design-space

sensitive technologies. Recommendations to support continued U.S. leadership in advanced R&D include:

A. *Support for "Lab-to-Fab" Transition*

Survey respondents highlighted the importance of pre-competitive R&D, broader access to fabrication facilities for research and prototyping, and challenges facing smaller organizations in commercializing research.

The successful implementation of the National Semiconductor Technology Center (NSTC) is a keystone for continued U.S. competitiveness and leadership in semiconductor R&D. As already outlined in the Department's "A Vision and Strategy for the National Semiconductor Technology Center,"[163] the NSTC's three high-level goals are (1) Extend America's leadership in semiconductor technology; (2) Reduce the time and cost of moving from design idea to commercialization; and (3) Build and sustain a semiconductor workforce development ecosystem.

Another key feature of the CHIPS Act is the Department of Defense-led Microelectronics Commons program, which has already begun awarding money to regional hubs to drive "lab-to-fab" innovation and accelerate development and commercialization of new semiconductor technologies.[164]

This report's recommendation is not a new feature, but rather serves to highlight the importance of the NSTC and the Microelectronics Commons, and the broad industry support for their goals.

B. *Increased R&D Incentives*

Government funding as a share of semiconductor R&D is significantly higher outside of the U.S. In addition to working with partners and allies to minimize the impact of non-market actors, *the U.S. government should consider implementing R&D incentives designed to counterbalance the effects of actions required to protect sensitive technologies*. Additionally, export controls, by limiting the size of the addressable market, may reduce revenue opportunities of companies that produce controlled products, in turn reducing funds available for corporate R&D. A supplemental tax credit focused on R&D in areas affected by export controls or related to sensitive technology can help minimize the negative longer-term effects of protecting these technologies.

3. Support the Availability of High-Quality Manufacturing Materials and Inputs

Manufacturing semiconductors requires hundreds of different materials with stringent quality requirements. Maintaining a healthy domestic semiconductor manufacturing base

[163] https://www.nist.gov/document/vision-and-strategy-national-semiconductor-technology-center
[164] https://microelectronicscommons.org/

requires a robust material supply chain that is resilient to regional or company-specific shocks. Manufacturing materials are prone to disruption, with concentrated supply and highly volatile prices.[165] The United States is reliant—and increasingly so—on imports of critical materials; the Department of Defense's 2021 100-Day Review of Critical Minerals and Materials (Critical Materials 100-Day Report) noted that China "dominates the processing of strategic and critical materials, giving it de facto control over the flow of material."[166]

The new construction and expansion of semiconductor manufacturing clusters in the United States is already driving expansion of domestic material and input capabilities. Continued investments in U.S. semiconductor manufacturing will help ensure these domestic capabilities remain healthy and competitive. Nonetheless, the underlying risks of supply chain concentration and vulnerability remain present. Recommendations to support the availability of high-quality semiconductor manufacturing materials and inputs include:

A. Reform and Strengthen U.S. Stockpiles

As identified in the Critical Materials 100-Day Report, "U.S. stockpile authorities and funding have not kept up with needs."[167] That report provides extensive recommendations on strengthening U.S. supply of critical materials, including methods for strengthening U.S. stockpiles. In addition to the recommendations made in that report, *the U.S. government should explore the value of legislation authorizing the stockpile to function as an economic stockpile* above critical inventory levels to help insulate the economy from large price spikes and supply shocks.[168]

B. Work with Allies and Partners to Decrease Vulnerabilities in Global Supply Chains

Also identified in the Critical Materials 100-Day Report, the *U.S. government should continue and increase coordination with allies and partners to strengthen material supply chain diversity and resilience*. This is of particular importance to the semiconductor industry, which has regional reliance both for raw materials and processed materials, as well as supplier concentration in several key materials. In addition, *the U.S. Government should expand work with allies and*

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[165] The standard deviation of monthly changes in the global price of Industrial Materials index (https://fred.stlouisfed.org/series/PINDUINDEXM) is over 11 times that of the U.S. consumer price index (https://fred.stlouisfed.org/series/USACPIALLMINMEI) since 2000

[166] https://www.whitehouse.gov/wp-content/uploads/2021/06/100-day-supply-chain-review-report.pdf

[167] https://www.whitehouse.gov/wp-content/uploads/2021/06/100-day-supply-chain-review-report.pdf

[168] Such assessments have been carried out in the past, including the 1975 Comptroller General's Report to Congress, "Stockpile Objectives of Strategic and Critical Materials Should Be Reconsidered Because of Shortages", and the 1983 Congressional Budget Office "Strategic and Critical Nonfuel Minerals: Problems and Policy Alternatives".

partners to establish industry-wide security standards and vendor evaluation processes to address cybersecurity supply chain vulnerabilities.

C. *Explore Incentives for Supply Chain Diversity*

Given the concentration of key materials and inputs both geographically and within key companies, *both individual companies and the U.S. government should take actions to increase the diversity of supply*.

The U.S. government should consider expanding the advanced manufacturing tax credit included in the CHIPS Act to apply to specialized materials needed for the production of semiconductors, as well as for the printed circuit boards that chips connect to.

Additionally, *the U.S. government should explore ways to incentivize companies to diversify their supply chains*, including through tax incentives for geographically diverse sourcing, development and distribution of supply chain best practices and standards, and studies quantifying the cost of concentrated supply chains.

4. Build a Diverse and Accessible Talent Pipeline for Jobs in the Semiconductor Industry

This category is identical to that of the Semiconductors 100-Day Report to highlight that workforce development is vital, the challenges are ongoing, and the solutions require long-term actions. That report highlighted the need for both immediate increases in the ability of companies in the United States to attract and retain talented workers from around the world and for longer term investments in domestic education. Survey responses have made it clear that workforce challenges are at the forefront of semiconductor industry health and competitiveness, requiring an "all of the above" solution.

Recommendations to ensure that U.S. companies have access to the workforce required to thrive include:

A. *Increase the Ability of Companies in the U.S. to Hire and Retain Highly Skilled Non-U.S. Citizens*

The strength of the U.S. semiconductor industry relies on the strength of its workforce. Survey respondents consistently indicated that their ability to find, hire, and retain highly skilled workers was both of key importance in making business decisions and a major challenge to their operations. Limiting the pool of workers available to companies in the U.S. provides an advantage to foreign competitors. For the U.S. semiconductor industry to continue to lead the world, it needs to be able to hire and retain the greatest talent from around the world.

As identified in the Semiconductors 100-Day Report, *the U.S. government should increase the number of visas available, eliminate country-specific employment-based visas, and exempt highly skilled workers from employment-based visa caps.*

B. *Enhance Pathways for Workers in America to Become American Workers*

In addition to expanding the ability of U.S. companies to attract talented workers from around the world, the U.S. semiconductor industry will benefit from ensuring these workers are able to stay in the country and continue to drive U.S. innovation and competitiveness. *The U.S. government should expand and enhance the ways in which workers who are not currently citizens or permanent residents can stay in the United States in perpetuity.* By providing broader avenues to permanent residency and citizenship, the United States can ensure it not only can attract the world's most talented workforce, but that it can retain it and allow it to participate in and drive the American dream.

C. *Increase Support for U.S.-based Microelectronics Education*

Beyond the immediate increase in the availability and talent of the semiconductor workforce enabled by visa and immigration reform, the United States needs to expand the size and skill of the domestic workforce through investments in U.S. education. Survey respondents noted that interest in and ability to support the U.S. microelectronics industry starts in elementary school.

The U.S. government should invest in hands-on STEM training in elementary, middle, and high school. At higher levels, the U.S. government can help contribute to smooth transitions from school to the workforce by collaborating with educational institutions and industry on curriculum building and standardized credentialing, and by increasing scholarships and grants for higher education in electrical engineering and other crucial microelectronics paths.

D. *Build More Fabs*

The presence of semiconductor fabrication facilities of all sizes serves a key role that not only enables the production of microelectronics, but also provides the foundation that allows the entire microelectronics ecosystem to flourish. In addition to driving investments in the supply chain and knowledge gains through construction and operation of facilities, fabs are crucial for microelectronics education. Survey respondents noted the value of hands-on experience in education and training as well as in sparking initial interest in microelectronics. *The U.S. government should continue to provide the U.S. semiconductor industry with the appropriate incentives and support to ensure that companies and research institutions build and modernize fabs of all types and sizes* to support the future of the U.S. microelectronics industry.

Next Steps in Assessing the U.S. Microelectronics Industrial Base

This report has focused on the portion of the U.S. microelectronics industry dedicated to the design, manufacture, and distribution of semiconductor products. BIS will use this survey and assessment as a foundation for continued analysis of the capabilities and vulnerabilities of the broader U.S. microelectronics industrial base.

Subsequent assessments will address key features of the microelectronics supply chain that support domestic manufacturing of semiconductors, including semiconductor manufacturing equipment and material inputs, as well as identification of critical technology areas that would be impacted by disruptions in microelectronics production and an assessment of the impact of such disruptions. One of the biggest unknowns involves the U.S. government's lack of visibility into China-based dependencies in the defense industrial base and the absence of financial or regulatory incentives for defense customers to track and eliminate these dependencies.