CSIS BRIEFS

Mapping the Semiconductor Supply Chain

The Critical Role of the Indo-Pacific Region

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THE ISSUE

The semiconductor industry and its supply chain increasingly rival oil and gas in terms of their importance to international relations, the attention they receive from senior leaders in government and business, and their use as a tool of foreign policy. Across a diverse range of global opportunities and geopolitical challenges, the semiconductor industry supply chain is increasingly at the center of the story. While the semiconductor industry is truly global, the Indo-Pacific is its critical region. Taiwan, Japan, China, and South Korea all play pivotal roles in the Indo-Pacific and the global semiconductor landscape. This paper provides an analysis of the role that the Indo-Pacific region plays in the global semiconductor industry across the various stages of the semiconductor supply chain. Since the United States is a critical Pacific power and a leader in the global semiconductor industry, this analysis also includes the United States when referring to key semiconductor players in the Indo-Pacific region.

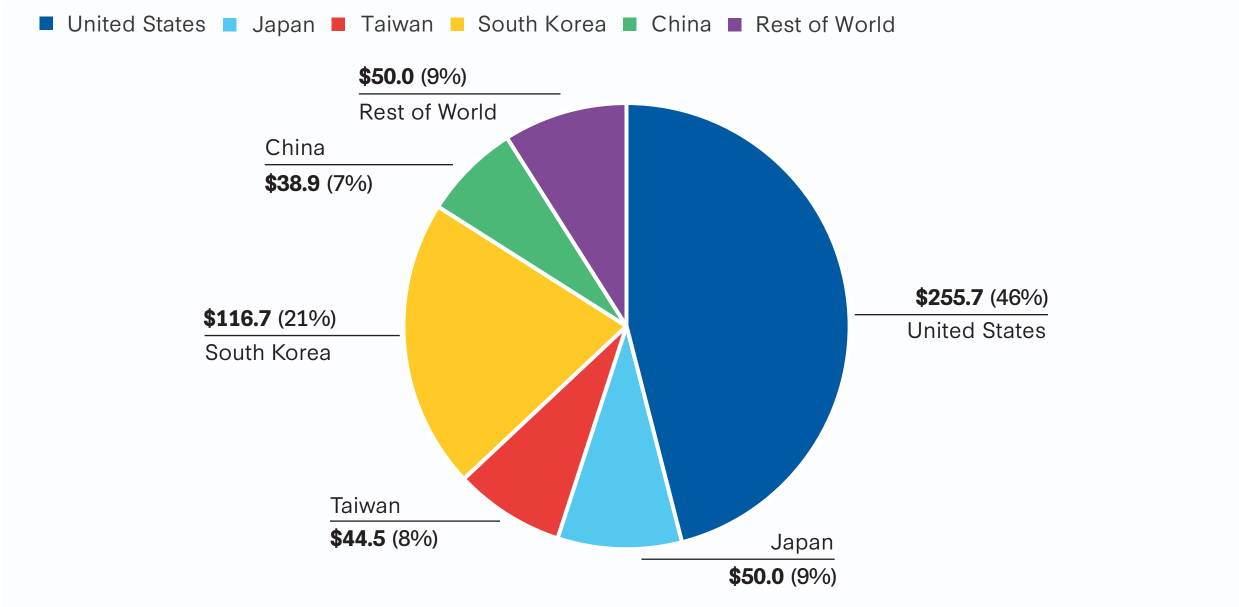
This report is part of a collaborative project between CSIS's Asia Program, Wadhwani Center for AI and Advanced Technologies, and Scholl Chair in International Business. This is one of two reports in a series that maps semiconductor supply chains and opportunities for cooperation in the Indo-Pacific region. The accompanying report, "Semiconductor Supply Chains in the Indo-Pacific Economic Framework for Prosperity: Squaring the Circle on Deeper Cooperation," can be found ***here****.*

THE SIZE OF THE SEMICONDUCTOR INDUSTRY

Today, the word "semiconductors" most commonly refers to integrated circuits (aka "computer chips"), and the semiconductor industry is among the most critical sectors of the global economy. Annual sales of semiconductors are staggeringly large: more than half a trillion dollars in 2022.[1] More importantly, however, the semiconductor industry is an irreplaceable enabler of tens of trillions of dollars of annual economic activity worldwide. Semiconductors are found not only in data centers, laptops, and mobile phones, but also in automobiles, washing machines, light bulbs, nuclear missile guidance systems, and electrical grid infrastructure. In the United States, semiconductors account for only 0.3 percent of GDP, but they are an important production input to 12 percent of GDP.[2] The importance of semiconductors is best demonstrated by the drastic economic consequences of the recent semiconductor shortage. Analysis by the U.S. Department of Commerce found that "the [chip] shortage shaved an estimated $240 billion off U.S. GDP in 2021. The auto industry alone produced 7.7 million fewer cars in 2021 due to lack of chips."[3] In other words, U.S. GDP

Figure 1: Semiconductor Sales by Country (2021, in billions)

Total semiconductor sales in 2021: $555.9 billion



Source: "SIA Factbook 2022," Semiconductor Industry Association, May 2022, https://www.semiconductors.org/wp-content/uploads/2022/05/SIA-2022-Factbook_May-2022.pdf.

was a full 1 percent lower than it would have otherwise been had the semiconductor shortage never occurred. For comparison, the average U.S. GDP annual growth rate over the past 10 years has been 2 percent.[4]

THE SEMICONDUCTOR INDUSTRY VALUE CHAIN

A value chain describes the set of processes that are performed in order to transform economic inputs into outputs. Each link in a value chain represents a supplier-customer relationship, whether internally within an organization or between different organizations. In the case of the semiconductor industry, the global supply chain that enables the aforementioned technological progress is remarkably complex. Some companies play a diverse set of roles and others are highly specialized, but no single company—indeed no single country—is currently capable of internally performing all roles in the supply chain for all types of semiconductors required for a modern economy.

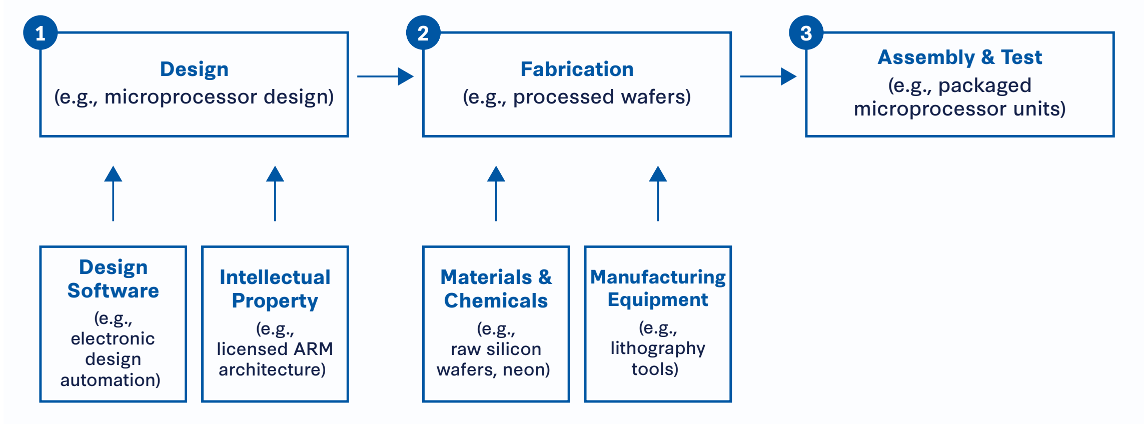
Individual integrated circuit (IC) chips, with millions or even billions of transistors squeezed onto a square inch or less of silicon, underpin nearly all facets of contemporary technology. The intricacy of semiconductors extends to their production process, which takes four to six months and involves more than 500 discrete stages, ranging from specialized design software to fabrication plants and dedicated test facilities.[5] Consequently, the semiconductor supply chain is remarkably complex, segmented, and international. According to estimates by Accenture, a consulting firm, the various inputs to a typical IC chip must cross more than 70 international borders before a final product can be delivered to consumers.[6] Leading chip sellers routinely have tens of thousands of suppliers distributed around the world, and some suppliers are the only companies in the world that possess their technological capabilities at specific performance levels.

Understanding the structure of the global semiconductor manufacturing landscape is critical for policymakers as they aim to navigate shifting supply chains.

DESIGN

The semiconductor manufacturing process begins in design, where a blueprint of a chip's architecture is sketched out to optimize for certain parameters, including cost, power consumption, and capacity, based on the needs of the chip in question. Originally, chip designs were hand-drawn on individual sheets of paper. But as the number of transistors on a single semiconductor grew to hundreds of thousands, and eventually hundreds of billions, highly specialized

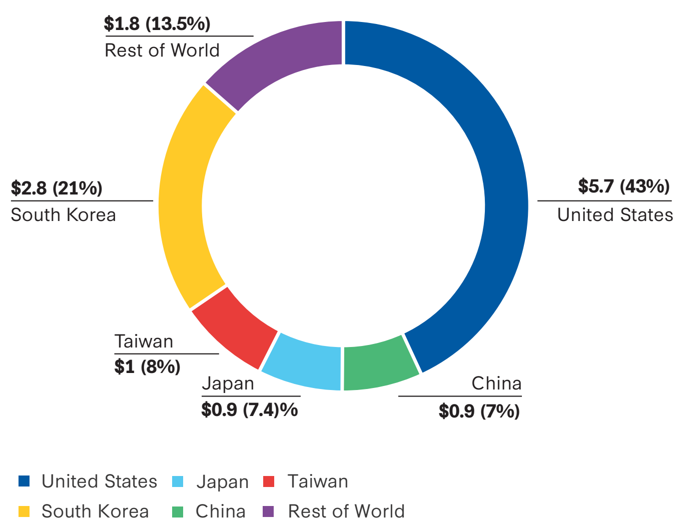
Figure 2: Simplified Depiction of the Semiconductor Value Chain



Source: Authors' own creation.

software became necessary to manage the resulting set of complex interactions and layers. Certain portions of a chip's design are built using reusable pieces of intellectual property (IP), called core IP, that firms license to lessen the burden of the design process. The design segment includes precompetitive research, design automation software known as electronic design automation (EDA), and core IP.

Figure 3: Global IC Design Revenue by Country (2021, in billions)



Note: Figure 3 shows global IC design revenue by region but does not capture the design value created and used solely within the same firm (i.e., the IP created by and used by a firm that does not get licensed out to other firms).
Source: Authors' own research and analysis based on multiple sources; see the endnotes for complete citations.[7]

The United States leads in the semiconductor design segment, with U.S. firms capturing more than 40 percent of global IC design market share, which includes EDA, semiconductor IP, and design services revenue.[8] The United States also leads in chip design work done by companies that do not license designs, but market their chips directly. This is captured by semiconductor sales in Figure 1, but not by the values in Figure 3. According to Georgetown's Center for Security and Emerging Technologies (CSET), U.S. firms controlled more than half of the 2019 market share in core IP.[9]

DESIGN SOFTWARE

Table 1: Select EDA Firms

Select Firms	Company Headquarters
Altium Limited	United States; Australia
Altair	United States
ANSYS	United States
Arteris	United States
Cadence Design Systems Inc.	United States
Keysight Technologies Inc.	United States
PDF Solutions	United States
Synopsys Inc.	United States
CEVA Inc.	United States
Shrodinger Inc.	United States
Mentor Graphics (subsidiary of Siemens EDA)	United States
Zuken	Japan
Empyrean	China
Primarius Technologies	China
Semitronix	China

The global EDA market totaled $8.27 billion in revenue in 2021.[10] The United States also holds the lead in EDA. U.S. firms are the exclusive providers of software that features the full-spectrum capabilities required to design cutting-edge chips.[11] As of 2021, three firms—U.S.-based Cadence, Synopsys, and Mentor Graphics (a U.S.-based subsidiary of the German firm Siemens)—reportedly make up 70 percent of the EDA market.[12]

Chip design software is highly concentrated and plays a critical role in the value chain. Without the latest software, designing leading-edge chips is impossible. In 2021, the U.S. Department of Commerce included certain types of EDA software in a set of export controls, restricting Chinese firms' access to U.S. EDA technology.[13] This is particularly damaging because China's EDA industry is significantly less technologically advanced. The chairman of Empyrean, one of China's more competitive EDA firms, estimated that Chinese EDA tools account for only 2 percent of the global market.[14] However, China's heavily subsidized EDA industry is steadily growing, and U.S. restrictions have spurred Chinese EDA firms to offer their services below market rates to bridge their now growing R&D and technology gap. This strategy won Empyrean a position as a partner with Samsung's Advanced Foundry Ecosystem, and following recent announcements of new partnerships with domestic companies, including Huawei, Empyrean's stock has jumped by 7 percent.[15]

Huawei is working to develop China's indigenous design capacity.[16] The company has reportedly built over 78 design tool products to replace the gap left by the restrictions on EDA software sales to China.[17] In March 2023, Huawei chairman Eric Xu claimed that Huawei had developed an EDA tool suitable for designing logic chips at the 14-nanometer (nm) technology node.[18] Other noteworthy China-based EDA companies include Primarius, X-Epic Corp., Cellixsoft Corp., Semitronix, and Xpedic Technology.

CORE INTELLECTUAL PROPERTY

Similar to EDA software, the United States is also a leader in the production and licensing of core IP. Firms that opt not to build fully customizable chip designs from scratch rely on reusable design blocks built by others. U.S. and UK firms, such as Intel, Cadence, and ARM, are leaders in core IP. According to an estimate by Georgetown CSET, the United States and United Kingdom combined were responsible for over 90 percent of the core IP market in 2019.[19] The core IP market totaled to $5 billion in 2021.[20]

Table 2: Select Core IP Firms

Select Firms	Company Headquarters
ARM Ltd. (Softbank Group Corp.)	United Kingdom; Japan
Imagination Technologies	United Kingdom; China
Alphawave Semi	United Kingdom
Synopsys Inc.	United States
Cadence Design Systems Inc.	United States
SST (Microchip Technology Inc.)	United States
CEVA Inc.	United States
Achronix Semiconductor Corp.	United States
Rambus Inc.	United States
eMemory Technology	Taiwan
Verisilicon Microelectronics Co. Ltd.	China

FABRICATION

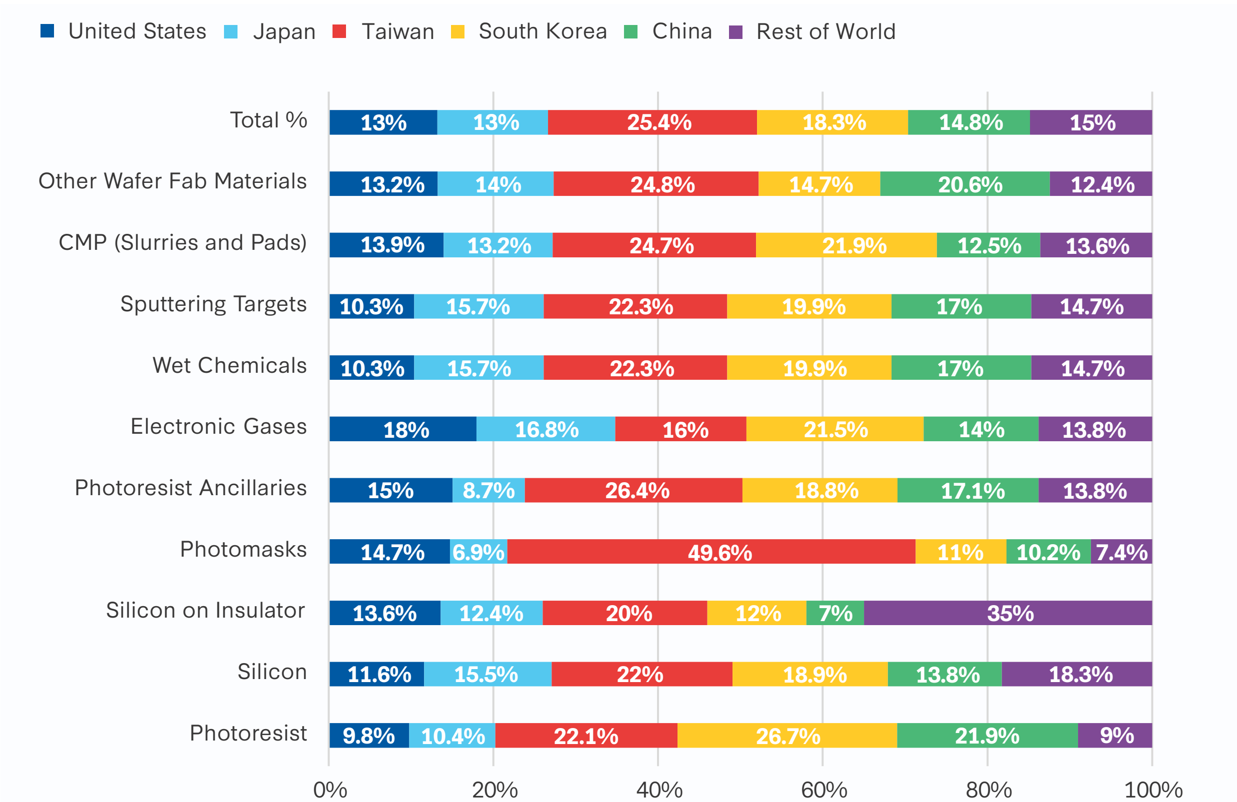
MATERIALS AND CHEMICALS

Raw and manufactured materials, such as silicon wafers, photomasks, and photoresists, along with certain chemicals, are necessary inputs across the semiconductor manufacturing process. The market for fabrication materials exceeded $40 billion in 2021 and is concentrated in the United States, Germany, Japan, Taiwan, South Korea, and China.[21] In 2021, Taiwan captured the largest slice of the market, with a quarter of global materials market share by sales. On the other end of the spectrum, Europe (9 percent) and China (15 percent) enjoy the smallest shares of the market.[22] Although small by measure of total sales volume, Europe occupies a critical space in the materials supply chain, particularly in the supply of chemicals. China holds a much stronger position in the supply of raw materials, particularly in low-grade gallium, tungsten, and magnesium, than in manufactured materials.[23]

Silicon wafers make up the largest portion of the materials market and a third of total semiconductor materials sales in 2021. Silicon wafers are the most common type of semiconductor wafer and are produced in a range of sizes. The market for silicon wafer suppliers has become increasingly concentrated over the last 20 years.[24] The number of firms supplying the critical input

Figure 4: Wafer Fabrication Materials Market Share of Sales by Country (2022)

Total materials market share in 2022: $44.7 billion



Source: "Materials Market Data Subscription (MMDS)," SEMI, March 21, 2023, https://www.semi.org/en/products-services/market-data/mmds.

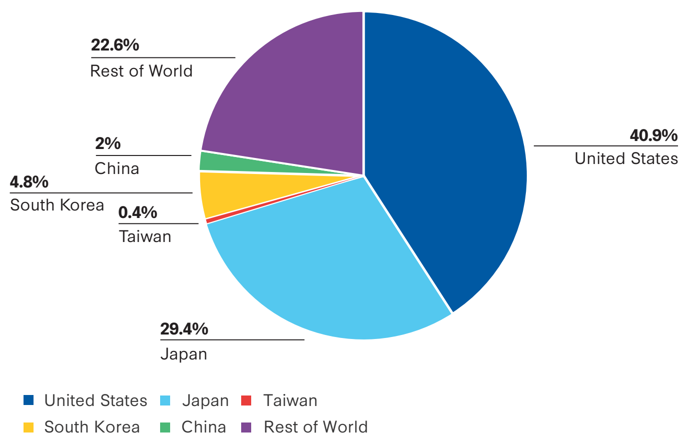
decreased from more than 20 major players in 1990 to 5 companies with control of roughly 95 percent of the market in 2020.[25] Silicon wafers with a diameter of 300 millimeters (roughly equivalent to 12 inches) are the standard input for leading-edge chips and are supplied by firms headquartered in Japan, Taiwan, Germany, and South Korea. Shin-Etsu, a Japanese company, holds the title for the largest silicon wafer manufacturer, with 29.4 percent of global market share in 2020. [26] Sumco (Japan), GlobalWafers (United States), Siltronic (Germany), SK Siltron (South Korea), and Soitec (France) collectively make up 65 percent of the global silicon wafer market. Despite the prevalence of Chinese companies such as Okmetic, JRH, Gritek, MCL, and Simgui, Chinese firms have limited (although fast growing) ability to produce 300 mm/12-inch silicon wafers, which greatly reduces China's importance within the materials supply chain.[27] This gap in domestic supply presents a potential bottleneck to Chinese front-end manufacturing, and many Chinese silicon and equipment suppliers are investing heavily in 300 mm wafer production. The supply of photomasks and photoresists is dominated by Japanese, Taiwanese, and South Korean firms. The market for photomasks topped $5.5 billion in 2021, and photoresists hit $2.7 billion.[28] China cannot produce state-of-the-art photomasks, and its ability to produce advanced photoresists is similarly limited. However, this is an area where China has been investing significantly.[29]

MANUFACTURING EQUIPMENT

Fabrication facilities (fabs) print integrated circuits by layering transistor elements (whose sizes are measured in atoms) onto raw silicon wafers. Doing so requires extensive control over the process with highly specialized and sensitive equipment; the degree of precision required by semiconductor fabs is the most demanding of any manufacturing industry worldwide. Semiconductor manufacturing equipment (SME) that facilitates the precision, scale, speed, purity, and dependability required to sustainably produce semiconductors is expensive and extremely difficult to make. As such, its supply is highly concentrated in key companies and regions. SME includes wafer fabrication

Figure 5: Semiconductor Manufacturing Equipment Market Share by Company Headquarters (2021)

Total semiconductor manufacturing equipment market in 2021: $108.5 billion



Source: "Semiconductor Equipment Database," TechInsights, 2023, https://www.techinsights.com/blog/techinsights-semiconductor-equipment-report.

on the front end as well as semiconductor assembly, test, and packaging equipment for back-end fabrication.

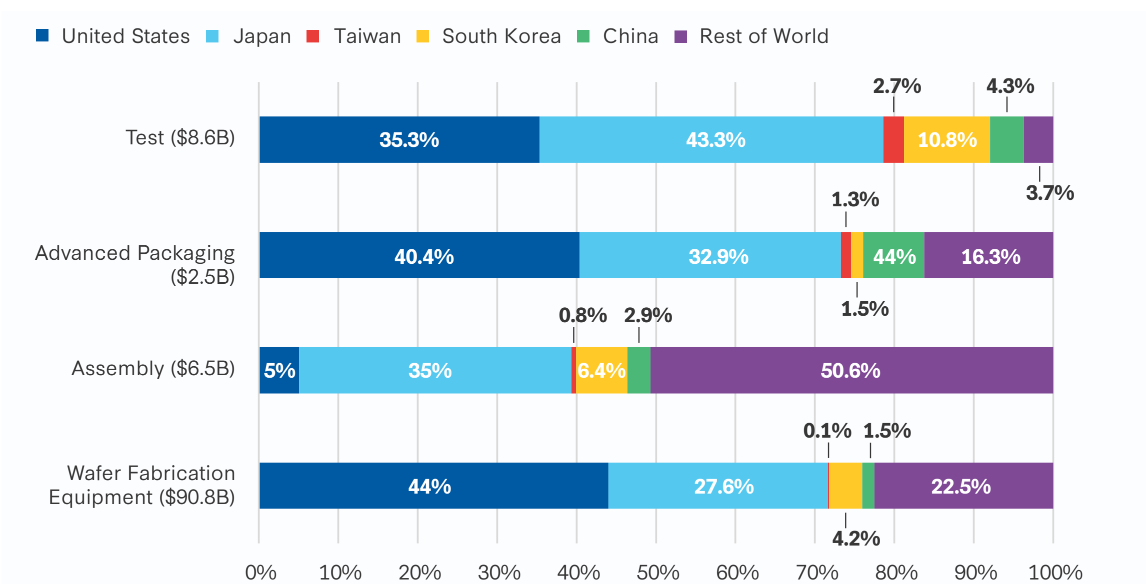
The market in the Indo-Pacific for SME is large. Most of the world's fabs are located in the region and the United States, and equipment suppliers headquartered in Indo-Pacific countries capture 77 percent of the global SME market share by sales.[30] Additionally, the firms in the region are also the largest purchasers: collectively, the region purchased over $104 billion worth of wafer fabrication, assembly, and test equipment in 2021. Note that the $104 billion does not include advanced packaging equipment purchases. The analysis of the semiconductor manufacturing equipment supply chain segment is largely based off data collected by TechInsights.

The U.S. and Japanese SME industries are the largest, with U.S. firms alone occupying more than 40 percent of global SME market share, followed by Japanese companies at 29 percent. Together with the Netherlands, the three countries dominate the supply of SME. Taiwan and China do not have strong domestic SME suppliers. Taiwan has the smallest SME industry among the major manufacturing countries in the Indo-Pacific, and China produces less than 2 percent of the global supply of SME. South Korea has a small but technologically sophisticated SME industry, responsible for 4.8 percent of global sales.

Within SME, the United States leads in wafer fab and advanced packaging equipment, and Japan leads in assembly and test equipment. Together, the United States and Japan supply over 70 percent of the world's wafer fab equipment. With 4.2 percent of global market share, South Korea plays a smaller but still significant role.

Figure 6: SME Market Share by Company Headquarters (2021)

By SME category



Source: CSIS analysis; "Semiconductor Equipment Database," TechInsights.

Figure 7: Total Semiconductor Manufacturing Equipment Sales and Purchases (2021, in billions)

Note: Please see Appendix 1 for diagrams broken out by SME subcategory. For interactive functionality, see the web-based version of this brief on CSIS.org. The total value in this figure sums to $104 billion, which represents the portion of the SME market for which firm-level data was available. Refer to Figure 5 for the SME market size ($108.5 billion)
Source: CSIS analysis; "Semiconductor Equipment Database," TechInsights.

In assembly equipment, Japan's strength is exceeded only by European industry. Japan leads in test equipment, with around 43 percent of global market share. The United States and South Korea, providing 35.3 percent and 10.8 percent, respectively, also contribute substantially to the test equipment market.

The connections between equipment manufacturers and fab managers do not end at the point of purchase. SME, especially wafer fabrication equipment, generally requires constant post-sales support, including through operational troubleshooting, software updates, spare parts, and maintenance. A significant portion of equipment manufacturer revenue comes from service and support activities. LAM Research, a major U.S.-based equipment provider, drew in over $2 billion in 2021 revenue from servicing alone.[31] The relationships between SME suppliers and purchasers matter, and Figure 7 and Appendix 1 describe the flow and connections of SME from producers to buyers in the Indo-Pacific.

The United States and Japan, the leading producers of SME in the region, primarily supply other Indo-Pacific players; 90 percent of U.S. and Japanese SME sales come from the Indo-Pacific. Meanwhile, Chinese and South Korean equipment manufacturers generally serve their respective domestic markets. Although low in sales volume, Chinese SME manufacturers sell 98 percent of their supply within China. South Korean SME manufacturers sell around 73 percent of their supply to South Korean companies (some of which have production facilities located outside of South Korea). Leading South Korean SME manufacturers include SEMES, Wonik IPS, PSK, and Eugene Tech.

In recent years, China has been the largest market for SME in the Indo-Pacific, purchasing more than $28 billion of equipment in 2021. Notably, 30 percent, 29 percent, and 20 percent of all U.S., Japanese, and South Korean SME sales, respectively, go to customers in China. Conversely, China buys 45 percent of its total SME stock from the United States, and 28 percent from Japan. In 2023, South Korea is expected to overtake China as the top market for SME.[32] Please see Appendix 1 for a breakdown of SME sales and purchases by subcategory.

Wafer Fab Equipment

The United States makes up 44 percent of global market share by sales for wafer fab equipment (WFE). Chinese firms are the largest buyers for U.S. WFE, followed by South Korea and Taiwan. Over half of Chinese fabs' WFE comes from the United States, most of which is sourced from three companies: Applied Materials, Lam Research, and KLA Tencor.[33] An overwhelming portion of U.S. WFE sales in China is composed of deposition and related tools, etching and cleaning tools, and process diagnostic equipment. U.S. WFE suppliers have nearly tripled their revenue in China over the last five years, from $3.7 billion in 2017 to $12.4 billion in 2021.

After China, South Korea and Taiwan are the next-largest importers of WFE in the region, each spending over $20 billion on WFE in 2021, with 42 percent and 40 percent, respectively, coming from the United States. Japan is similarly reliant on the United States, specifically for 48 percent of its supply, though it has lower levels of spending on WFE, totaling just $7.9 billion in 2021.

Japan is a major producer of microlithography and masking equipment, etching and cleaning tools, and deposition and related tools. The Dutch company ASML is the sole provider of the latest generation of photolithography scanner equipment (extreme ultraviolet, or EUV, lithography machines), but Japan's Nikon and Canon provide non-EUV photolithography stepper and scanner equipment. Behind the Netherlands, Japan is the second-largest supplier of microlithography and masking equipment to China. Sales of microlithography equipment to China mainly come from ASML and Japanese firms and have more than tripled from 2017 to 2021.

Japanese WFE manufacturers also have a heavy presence in South Korea ($4.6 billion sold in 2021) and Taiwan ($4.5 billion sold in 2021) but have minimal presence in non-Indo-Pacific countries (under $2 billion sold collectively in 2021). Of the token amount of WFE produced in South Korea, over 75 percent ends up in domestic fabs.

Assembly, Test, and Packaging Equipment

The back end of semiconductor manufacturing–assembly, test, and packaging (ATP)–is generally less capital intensive than wafer fabrication. The size of the ATP equipment market is correspondingly much smaller, totaling $15.2 billion in 2021 compared to $90.8 billion for WFE.

Japan is the largest supplier of assembly equipment in the Indo-Pacific, moving over $2 billion worth in 2021. The country produces 66 percent of its domestic stock of assembly equipment and supplies considerable portions of other countries' demand, such as Taiwan (40 percent), the United States (24 percent), China (29 percent), and South Korea (29 percent). Major Japanese producers include DISCO Corporation, TOWA Corporation, and Accretech (Tokyo Seimitsu).

Japan's position is similarly strong in the market for test equipment. China and Taiwan hold the bulk of the world's ATP facilities, the majority of which are equipped with Japanese tools produced by Advantest, Tokyo Electron, and Accretech. Japan produces 47 percent of Taiwan's total stock of test equipment, 53 percent of China's, and 35 percent of South Korea's.

The United States, with 35 percent of the global test equipment market share, trails Japan's lead, and South Korea comes in third at just under 11 percent.

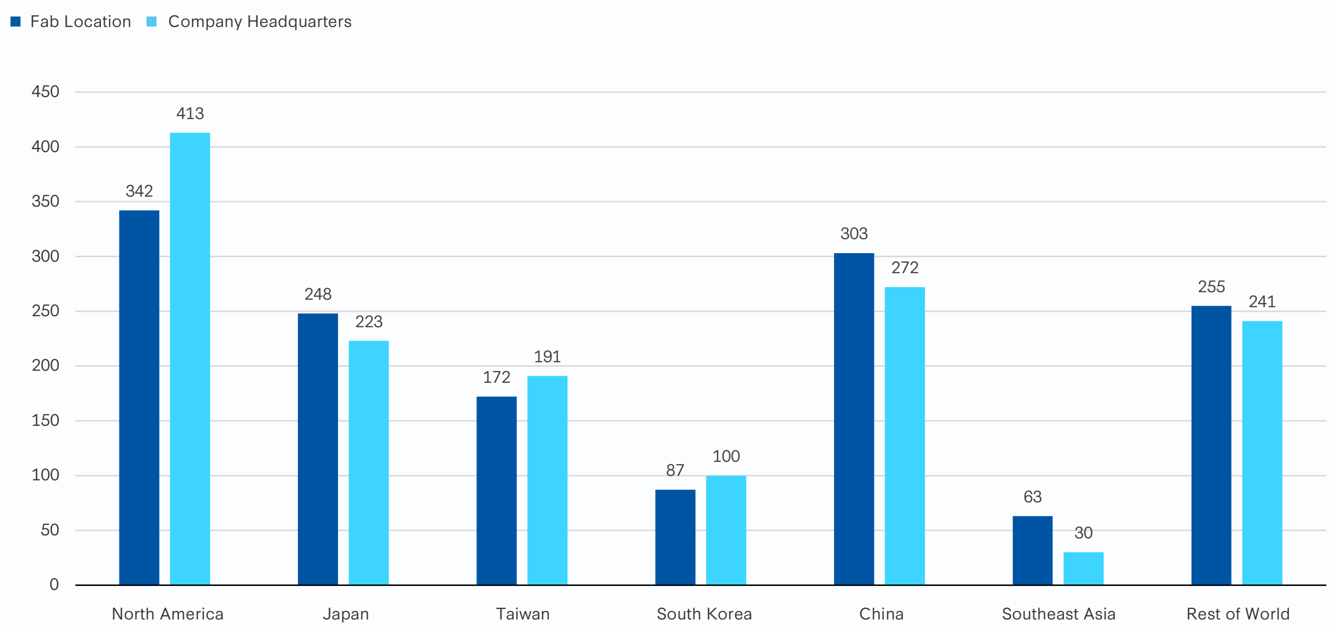
ATP equipment manufacturing has reportedly been China's most competitive segment within the SME market, largely due to the presence of a single firm, ASM Pacific.[34] However, ASM Pacific has since moved its headquarters to Singapore and for the purposes of this data set is no longer classified as a Chinese company.[35] The company retains a large presence in China and Hong Kong and is a steady partner for many Chinese ATP facilities.

WAFER FABRICATION FACILITIES

Semiconductor fabrication, especially for advanced nodes, can be an extremely difficult task. Producing firms are usually split between integrated device managers

Figure 8: Number of Wafer Fabs by Fab Location and Company Headquarters

Total wafer fab facilities counted: 1,470



Source: CSIS analysis; "World Fab Forecast," SEMI, March 14, 2023, https://www.semi.org/en/products-services/market-data/world-fab-forecast.

(IDMs), fabless design firms, foundry managers, and outsourced semiconductor assembly and test (OSAT) firms. IDMs control every step of the semiconductor manufacturing process, including design, fabrication, and ATP. Fabless and foundry firms specialize in either designing or fabricating semiconductor chips and often outsource ATP to OSAT providers.

The advance of Moore's law has made the process of etching advanced chips increasingly difficult and expensive. The Taiwan Semiconductor Manufacturing Company (TSMC) estimates that a 3 nm fab, the most advanced model at the time of writing, costs more than $20 billion.[36] Housing billions worth of manufacturing equipment, these fabrication facilities are incredibly valuable and reflect years of investment and iterative learning before operating at full capacity.

The Indo-Pacific (also including the United States) holds the vast majority of the world's semiconductor wafer fabrication facilities. Out of 1,470 confirmed wafer fabrication facilities worldwide, 1,215 are located within the Indo-Pacific, and 1,229 are operated by companies headquartered in the Indo-Pacific, including North America. Analysis on wafer fabrication facilities is based off data collected by SEMI.[37]

The largest pushes in terms of announced fab facilities are in the United States, China, and Taiwan, respectively with 24, 19, and 17 new fabs aiming to start construction before December 2024. China, having poured substantial amounts of government incentives and subsidies into building a domestic chip sector long before the United States and allies, is predicted to have 28 new fabs begin operations before December 2024.

Not all fabs are created equal, and only a few have the capabilities and infrastructure necessary to manufacture the most advanced semiconductors. Legacy chips are sufficient and, due to cost and complexity, preferred for some applications in the automotive industry, certain types of defense technology, aircrafts, and consumer electronics.[38] However, for advanced applications in artificial intelligence, quantum and high-performance computing, and other critical and compute-heavy technologies, advanced-node chips (16 nm or smaller) are essential. Over the course of the history of the semiconductor industry, wafer diameter size has increased as transistor sizes have shrunk. This is because it is more economical to produce more chips per wafer during production. Accordingly, wafer diameter size is a rough proxy for the technological sophistication of a given production facility. Newer facilities with more

Table 3: Number of Wafer Fabs by Capabilities and Fab Location

Wafer Size (in)	United States	Japan	Taiwan	South Korea	China	Total
2	10	5	19	2	49	85
3	20	4	3	0	9	36
4	63	36	19	8	57	183
5	5	15	3	2	14	39
6	84	74	30	9	64	261
8 (200 mm)	61	53	26	12	36	188
12 (300 mm)	33	29	44	32	41	179
Total	**276**	**216**	**144**	**65**	**270**	**971**

Note: Eight inches is roughly equivalent to 200 nm, and the two are often used interchangeably when referring to silicon wafer diameter size. Twelve inches is roughly equivalent to 300 nm, and the two are often used interchangeably when referring to silicon wafer diameter size.
Source: CSIS analysis; "World Fab Forecast," SEMI, March 14, 2023, https://www.semi.org/en/products-services/market-data/world-fab-forecast.

modern equipment almost always produce chips using larger diameter wafers at smaller transistor sizes.

The number of fabs in a given country is generally a poor measure of production capacity. Each fab varies greatly by important indicators of productivity, including equipment production rates, wafer throughput time, wafer yield or defect density, and process maturity.[39] Effectively indexing the production capacity of each fabrication facility can be difficult to assess with confidence, however, so this paper uses number of facilities as an imperfect proxy for capacity. According to data from SEMI, a semiconductor industry association, U.S. companies hold the lead in owning or operating the largest number of wafer fabrication plants (61) with the ability to process 12-inch/300 mm or wider silicon wafers. Taiwan follows with approximately 44 such fabs in operation.

The picture looks slightly different when measuring by facility location and not by the operating company's country of origin. As of January 2022, U.S.-firms operated 11 fabs located in China, 1 of which has the capacity to operate with 12-inch wafers. South Korean firms, mostly Samsung and SK Hynix, also operate 11 fabs within China, but the majority (7) can function with wafers 12 inches in diameter. Taiwanese fab operators have 13 facilities in China, with relatively less-developed capabilities: 8 can only handle 6-inch wafers or smaller, and 2 have the capacity to handle 8-inch wafers or smaller. Following the announcement of new U.S. semiconductor export controls on October 7, 2022, however, some of the most advanced Chinese fabs in China have slowed or ceased operations. These counts may look different a year on.

Figure 9: Wafer Fabs Starting Operations between Jan 2022 and Dec 2024

Total wafer fab facilities counted: 92

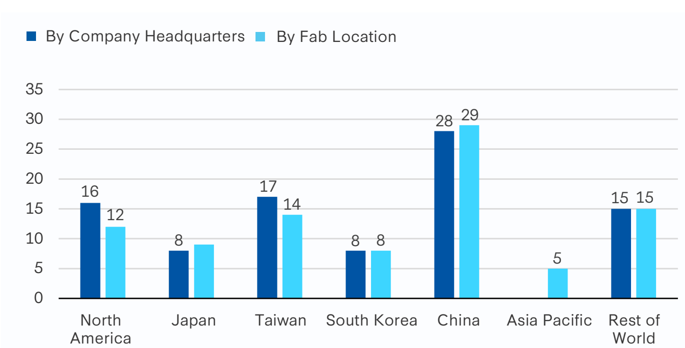
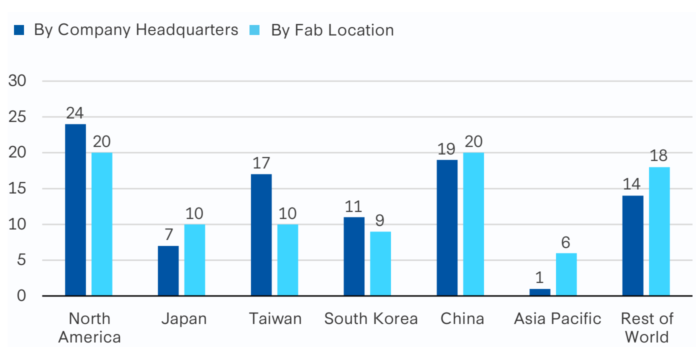


Figure 10: Wafer Fabs Starting Construction between Jan 2022 and Dec 2024

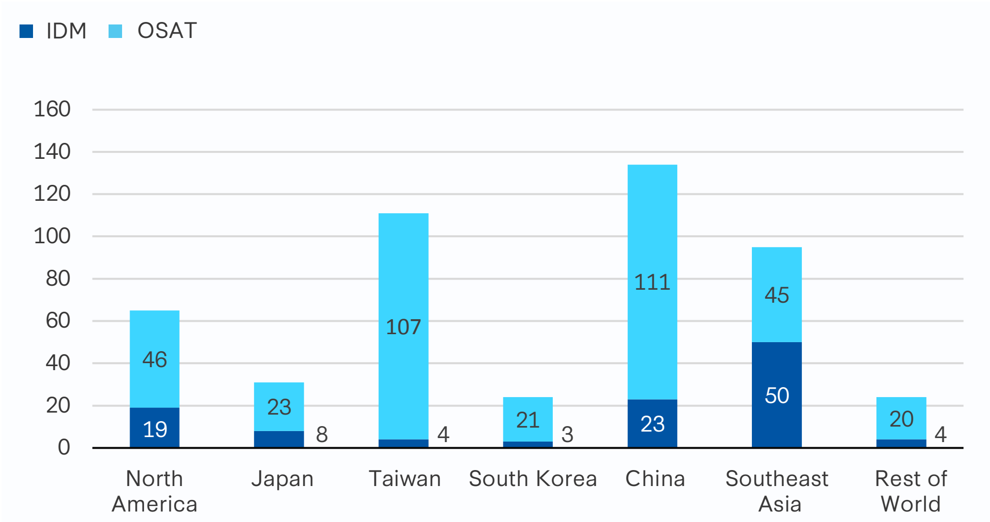
Total wafer fab facilities counted: 93



Note: Projected wafer fabrication counts are not comprehensive and will not necessarily result in built and operated facilities. Chinese proposed wafer fab construction projects have a comparatively higher rate of not coming to fruition.
Source: "World Fab Forecast," SEMI, March 14, 2023, https://www.semi.org/en/products-services/market-data/world-fab-forecast.

Figure 11: Number of ATP Facilities per Country (2021)

Total number of ATP facilities counted: 484



Source: SEMI, "Worldwide Semiconductor Assembly and Test Facility Database Now Tracks Integrated Device Manufacturers, 475 Facilities," Press release, February 23, 2022, https://www.semi.org/en/news-media-press-releases/semi-press-releases/worldwide-semiconductor-assembly-and-test-facility-database-now-tracks-integrated-device-manufacturers-475-facilities.

ASSEMBLY, TEST, AND PACKAGING

Once the fab has completed its process per wafer, individual chips get cut, separated, tested, and assembled for integration into final products. This portion of the supply chain is referred to as ATP. ATP generally involves fewer complex processes and tools than other portions of the semiconductor manufacturing supply chain and is correspondingly more labor intensive. With each successive shrinking of transistor size and density, however, ATP has quickly become more complex.

Today, the vast majority of ATP facilities (above 95 percent) exist in Indo-Pacific countries, with a heavy concentration of OSAT providers in Taiwan, China, and Southeast Asia (particularly in Singapore, Malaysia, Vietnam, and the Philippines). Out of 484 facilities counted by Semiconductor Equipment and Materials International (SEMI) in 2021, 134, or 28 percent, were in China.

CONCLUSION

Governments, including but not limited to the United States and China, have launched diverse initiatives at the national and multinational levels to reinforce and restructure the semiconductor supply chain to their national security and geopolitical goals. The U.S. CHIPS and Science Act passed in August 2022 and set aside nearly $50 billion in investments to grow U.S. semiconductor manufacturing capacity.[40] South Korea announced major tax cuts for semiconductor companies in a bill known as the "K-Chips Act."[41] Japan, India, and the European Union have also announced similar measures.[42] For the future of the global semiconductor industry, these changes mean that policy is now as important as market forces. The motives behind current and proposed future policies (and related subsidies) range beyond economics to include national security and technological sovereignty. Amid these transformative changes, policymakers should take stock of the critical role that countries in the Indo-Pacific region play in semiconductor supply chains.

As it stands, technological and economic limitations have evolved a semiconductor supply chain that is incredibly complex and specialized. Despite consistent efforts, no country has been able to achieve true self-sufficiency in semiconductor manufacturing to date. To successfully fortify the United States' position along the supply chain and mitigate risk, U.S. policy should aim to grow a healthy and resilient semiconductor ecosystem in which allies and partners continue to play a key role. The Department of Commerce has already stated that this is a key prong of the CHIPS Act implementation strategy. Carried out by the CHIPS office in the Department of Commerce, coordinating investment and incentive programs, promoting knowledge exchanges and collaboration, and facilitating cross-border commerce are all high-priority objectives for CHIPS Act implementation.[43] Continued dialogue with key allies, particularly in the Indo-Pacific, is important to minimize duplicative investments, grow the comparative strengths of each country's domestic industry, and de-risk key dependencies. ■

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APPENDIX 1

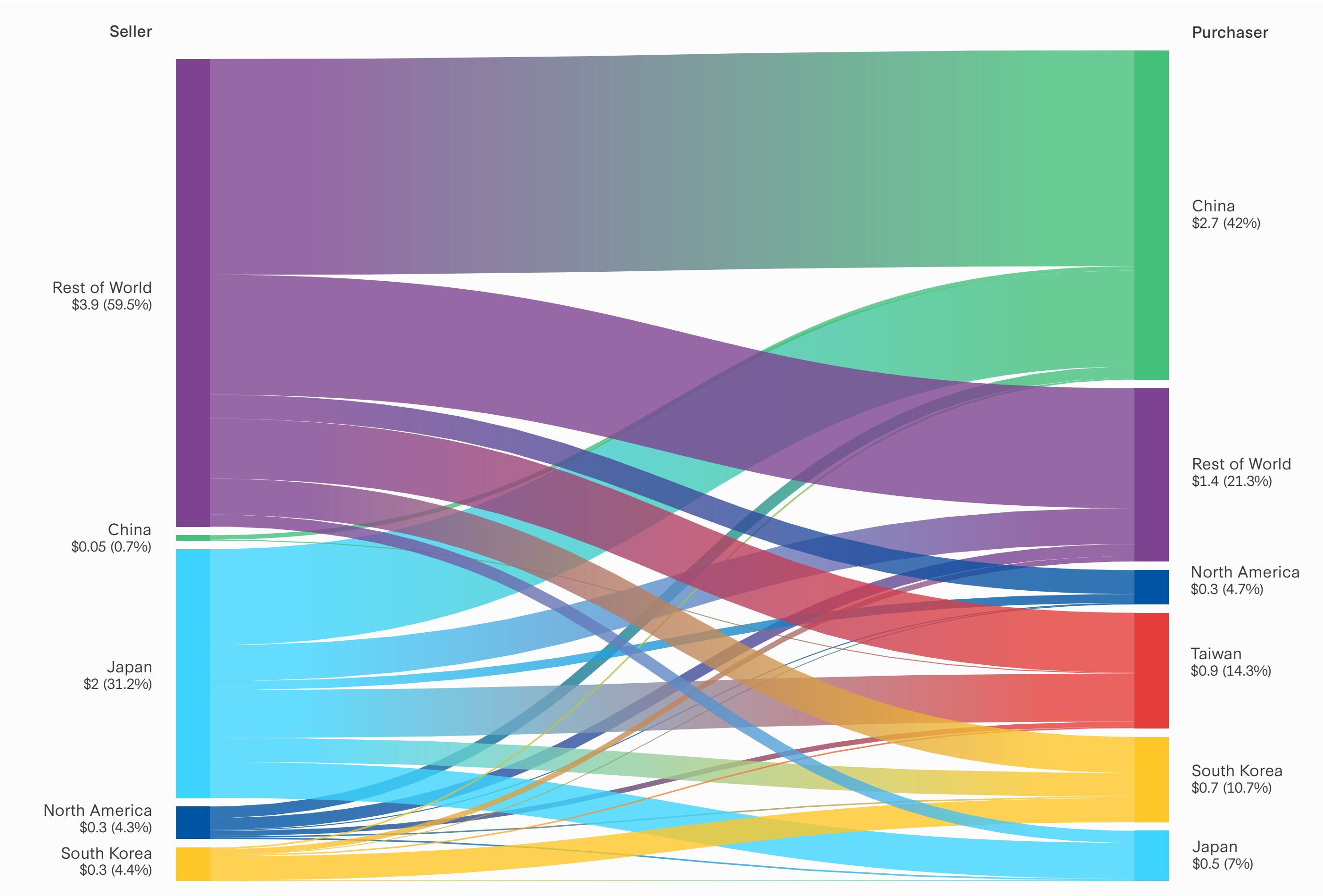
Figure 7-1: Wafer Fabrication Equipment Sales and Purchases (2021, in billions)

Total market size in 2021: $88.9 billion

Source: CSIS analysis; "Semiconductor Equipment Database," TechInsights.

Figure 7-2: Assembly Equipment Sales and Purchases (2021, in billions)

Total market size in 2021: $6.5 billion



Source: CSIS analysis; "Semiconductor Equipment Database," TechInsights.

Figure 7-3: Test Equipment Sales and Purchases (2021, in billions)

Total market size in 2021: $8.6 billion

Source: CSIS analysis; "Semiconductor Equipment Database," TechInsights.

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