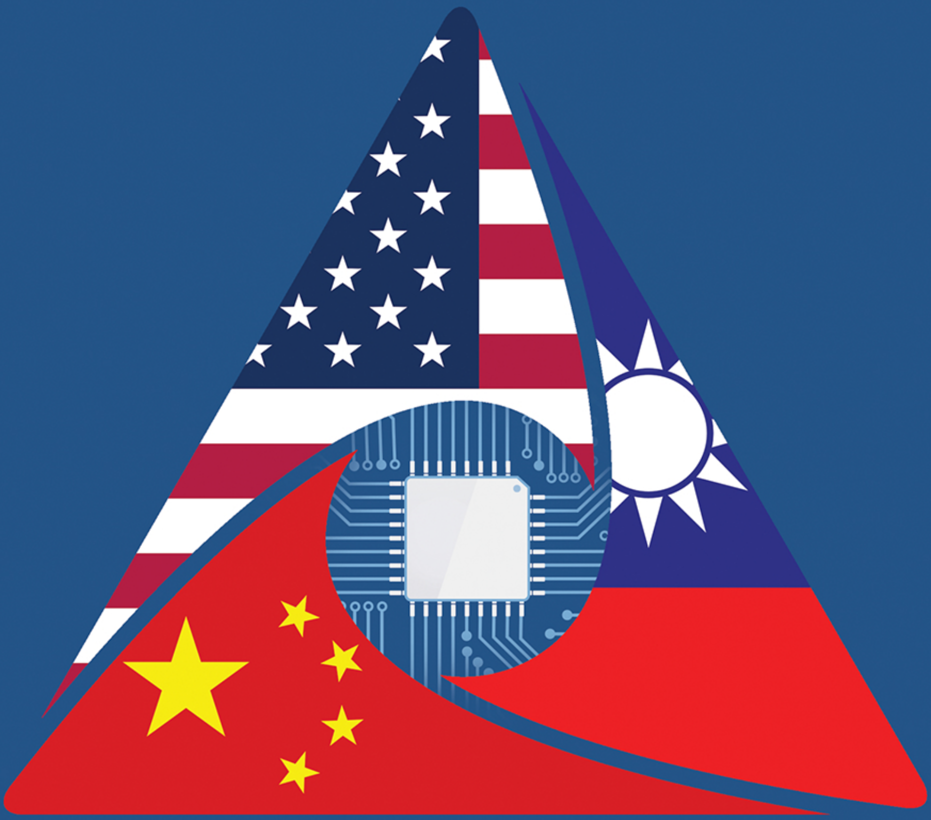

# Silicon Triangle

## The United States, Taiwan, China, and Global Semiconductor Security

Edited by Larry Diamond, James O. Ellis Jr., and Orville Schell

CHAPTER SIX

# US Allies, Partners, and Friends

**DAVID J. TEECE AND GREG LINDEN**

If the world shifts toward more balkanized flows of goods, investment, expertise, people, and ideas, the continued prosperity of liberal democracies will increasingly depend on their ability to collectively sustain technological superiority in fields such as semiconductors and other critical technologies. Meeting this challenge will require those who share common values and interests—as well as those with strong positions in the global semiconductor supply chain—to diminish their dependency on threatening authoritarian states and increase interdependence among themselves.

As the world continues to experience significant changes in global trade relations, the United States should aim not only to advance its position in the microprocessor supply chain but also to engender closer and more collaborative partnerships with like-minded countries—ones that, instead of threatening our supply chains with punitive economic actions or even war, can be relied on as trustworthy collaborators.

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The United States is not alone in its renewed drive for near- to mid-term domestic supply chain resilience and longer-term global technological leadership in semiconductors. The shocks caused by the COVID-19 pandemic and increasingly fraught geopolitical relationships are context-agnostic "driving forces" (see chapter 1) that have changed the terms of the game for the United States and global partners. Using the parlance of the strategic scenario planning of chapter 1, our partners at least perceive the potential for a "westward" shift as flows of goods, capital, intellectual property (IP), and human talent become increasingly decoupled—and thus, they are pursuing self-reliance as a way to insulate against the uncertainty of a less-flat world. This concentration is already reflected in the impressive array of investments and policy instruments now being undertaken by the United States and its partners in the semiconductor sphere.

The lesson of our scenario-planning analysis, however, is more subtle than a simple reversion to self-reliance. The "context-dependent" business and policy responses of our partners illustrate how each country must use its starting position, historical strengths, and social priorities to filter those common driving forces. Purely domestic onshoring is economically inefficient: in a flat "eastern" world, economic growth comes from a focus on specialization and comparative advantage. And in a more balkanized "western" world, meanwhile, autarky is very costly. In a move toward a "western" world of more intensive trade among fewer partners, trade networks with the least friction among participants will be best able to prosper in a deglobalized environment. A shift "westward," then, would not call for further raising of barriers, but rather for selectively lowering them among those nations with shared values and interests.

Developing new strategies for economically and technologically repositioning ourselves to prosper in a deglobalized world is perhaps the key policy challenge of the coming decade. As one considers the pathways now being pursued by US partners in the semiconductor supply chain (partners other than Taiwan, which is the focus of the preceding chapter), our goal should be to identify opportunities to increase commerce and exchange as a way to offset the cost of potentially decoupling from China in the microchip field and other critical-technology fields. This selective opening is an underappreciated requirement for longer-term allied unity on, for example, semiconductor technology export controls; if cooperation on that front is just an ongoing cost to partner-country firms that do business with China, it will not be sustained. China, on its own, represents a substantial market with a skilled workforce and an impressive innovation infrastructure.

So how are our partners looking at and responding to this changing geopolitical landscape?

## Japan

### *Key Laws and Policies*

Japan is a good example of a country that, like the United States, has only recently begun to wake up to its semiconductor supply chain vulnerabilities.

According to Japan's Ministry of Economy, Trade, and Industry (METI), the country's automotive, electronics, and manufacturing technology sectors depend heavily on a reliable supply of semiconductors—the "rice of the industry."[1] Nevertheless, according to Yoichi Funabashi of Japan's Asia Pacific Initiative, before semiconductor shortages in early 2021 the Japanese government did not have sufficient understanding of supply chains, nor did it even have the authority to research them.[2] Disruptions in manufacturing due to COVID-19 not only helped upset US-China relations but also raised attention within Japan to the critical role semiconductors play in its broader economic and military security.

In June 2021, METI released a semiconductor strategy document suggesting that, if nothing was done, Japan's share of global production could fall from 10 percent to as low as zero by 2030. The main force driving toward this outcome was the resurgence of industrial policy in the United States. METI feared that the United States would not only rebuild its share of chip production, but in doing so also attract away Japan's prized chip manufacturing material supply firms.[3]

In October 2021, Japan's parliament elected Fumio Kishida, an experienced and moderate politician, as prime minister. His administration proposed a "new capitalism" policy framework, which included some major new growth strategies such as promoting science and technology and supporting startups, a field that has been a perennial weak spot in Japan's economy. Another element of the plan focused on "economic security," which included reducing Japan's dependence on China for strategic materials and parts as well as countering the misappropriation of IP used in the production of semiconductors.

In November 2021, the government approved a ¥774 billion ($6.8 billion) package for semiconductor investments in Japan. It was allocated as follows:[4]

- ¥47 billion for legacy production, such as analog and power management chips
- ¥110 billion for the research and development of next-generation chip technologies
- Up to ¥476 billion (50 percent of the projected capital cost) for a Sony–Taiwan Semiconductor Manufacturing Company (TSMC) manufacturing joint venture[5]
- At least ¥140 billion for other forms of advanced production, ¥92.9 billion of which was later allocated to a joint venture by memory producers Kioxia (Japan) and Western Digital (US).[6]

The government's aim was to increase the value of Japan's domestic chip production to match or exceed the growth of the global industry (i.e., remain near 10 percent of world output). To achieve that objective, the government seeks to triple its domestic semiconductor revenue to over ¥13 trillion ($114 billion) by 2030.[7] Later, in May 2022, the National Diet passed an economic security bill that was expected to designate semiconductors as a class of "specific important materials," making them eligible for further subsidies.[8]

The new TSMC joint venture factory in Japan's Kumamoto Prefecture is also a part of this package. That factory is expected to produce chips from 20nm to 10nm, making it Japan's most advanced-logic manufacturing facility ("fab"). (A fab belonging to US firm Micron and fabs belonging to Toshiba's Kioxia unit produce DRAM [dynamic random access memory] and NAND Flash memory chips, respectively, at similarly small nanometer ranges.) Construction began in April 2022, and shipments are likely to begin by 2025. TSMC is committed to producing chips in this new plant for at least ten years.[9]

Earlier in 2021, the Japanese government approved a ¥19 billion (about $140 million) subsidy for TSMC's new research and development (R&D) center focused on developing three-dimensional advanced semiconductor packaging capabilities (referred to as "3D IC," or integrated circuits, as described in chapter 2). The Japanese government subsidy was about half the cost of the total facility, which is located inside the existing National Institute of Advanced Industrial Science and Technology (AIST), a large public Japanese research organization that collaborates with industry across a range of fields.[10]

In July 2022, just a few days shy of a "two-plus-two" dialogue with the United States involving both foreign and industry ministers, the government announced up to ¥92.9 billion ($678 million) to support Kioxia and Western Digital's new flash memory production facility in Mie Prefecture. The subsidy reportedly will cover a third of the project's capital expenditure.[11] The first phase of "Fab 7," intended to produce 162-layer NAND Flash memory, was opened in November 2022.[12]

With these and other new and expanding production facilities, Japan faces a problem shared with seemingly every other jurisdiction seeking to grow its activities: increased demand for talent met, at least in the short term, by meager supply. The number of Japanese twenty-five- to forty-year-olds working in electronic components and circuits manufacturing has decreased from 380,000 to 240,000 in the past ten years, while an industry association called for thirty-five thousand additional semiconductor workers needed by 2032.[13] In response, talent development programs, in partnership with universities and industries, are being formed by local governments in the Kyushu (Japan's "silicon island"), Tohoku, and Chugoku regions.[14]

### *Japan's Production and Consumption*

Japan's share of world chip production, which reached 50 percent in 1990, has fallen steadily to about 10 percent currently.[15] Much of this decline is attributable to Japan's memory producers, which, apart from Toshiba, have been outcompeted by rivals in South Korea. Meanwhile, Japan's vertically integrated logic chip producers also proved less nimble than the US-based fabless startup ecosystem, which, like its

European counterparts, opted to focus on specialty processes instead of keeping up with the leading edge of technology.

In the late 1990s, the Japanese government helped bring about mergers of several producers' diminished chip divisions. Their record of success, however, is mixed. Elpida, which combined the memory business of NEC, Hitachi, and Mitsubishi, struggled for over a decade until it was bought out of bankruptcy by US-based Micron. Renesas, which combined the logic divisions of the same three companies that formed Elpida, fared better and is now a leading provider of microcontrollers to the automotive and industrial segments. Sony, which produces analog chips, is a major supplier of image sensors to the consumer, industrial, and automotive markets. But neither Renesas, Sony, nor Toshiba's memory division Kioxia currently ranks as a top-ten global chip firm overall.

US semiconductor producers are actually quite active in Japan.[16] US-based ON Semiconductor (onsemi) manufactures analog chips in Japan, as does Texas Instruments (in a 200mm wafer size fab it acquired in 2010). Micron, which has been making memory chips in Japan since acquiring Elpida in 2012, announced plans in 2021 for a new fab in Japan at a cost of up to $7 billion.

Whereas Japan's share of chip output has fallen, its role as a supplier of key inputs to chip manufacturing processes remains strong. In materials, for example, most of the world's supply of photoresist coatings, essential for photolithography, is made by Japan-based companies. And Japan's firms also have market shares of 60 percent or more of the global market for another seventy advanced materials used in semiconductor manufacturing.[17] Two Japanese companies, Shin-Etsu Chemical and SUMCO, together control roughly 60 percent of the global market for silicon wafers. In terms of overall materials used in manufacturing processes, Japan's market share is significant, about 30 percent.[18]

To secure necessary materials for semiconductor production (such as tantalum, germanium, and gallium), Japan's government works through the Japan Organization for Metals and Energy Security (JOGMEC), which was formerly known as Japan Oil, Gas and Metals National Corporation, to conduct overseas exploration projects. These efforts include joint ventures with businesses, aiding the Japanese company in acquiring buying rights that insulate them from market fluctuations.[19]

Japan also has significant strengths in semiconductor manufacturing equipment—a 32 percent market share in 2019.[20] Tokyo Electron, which makes machines for the deposition and etching process in chip fabrication, is the third-largest maker of fabrication equipment after Europe's ASML and US-based Applied Materials.[21]

Japan's position in other parts of the semiconductor value chain—including electronic design automation (EDA) software, chip assembly, and fabless chip design—is negligible. The lack of fabless chip companies of any significance—a long-standing point of strength in the United States' venture-backed landscape—is in large part a reflection of Japan's weak startup ecosystem.

On the consumption side, Japan's market for semiconductors was worth about $36.5 billion in 2021, or about 6 percent of the world's total demand.

### *Diplomatic Trends and Issues*

On May 4, 2022, US Commerce Secretary Gina Raimondo met with Japan's minister of economy, trade, and industry, Koichi Hagiuda. This meeting followed Hagiuda's visit to IBM at the Albany NanoTech Complex, an advanced-semiconductor research facility involving Tokyo Electron, among other corporate partners, to discuss US-Japan semiconductor cooperation.[22] That meeting constituted "the first Cabinet-level meeting of the Japan-US Commercial and Industrial Partnership (JUCIP) . . . since its launch in November 2021."[23]

In June 2022, the United States and Japan agreed to jointly pursue 2nm production, aiming to start prototype production between 2025 and 2027.[24] This announcement came a year after AIST also began a research consortium for advanced-semiconductor manufacturing, including 2nm, with external support from Intel and IBM, plus an additional ¥42 billion ($319 million) in funding from METI.[25]

When President Biden met Prime Minister Kishida later that month, the press in Japan reported that they agreed to launch a joint task force to explore the development of next-generation computer chips.[26] And in late July, the two countries held a "two-plus-two" dialogue, in which they reaffirmed the commitment to the task force and promised broader supply chain partnerships under the new JUCIP. They also announced the creation of a new research facility in Japan with talent and equipment from the US National Semiconductor Technology Center to research 2nm, 5G, and quantum computing.[27] From these discussions, along with Japan's recent emphasis on economic security, it appears that Japan's government is eager to partner with the United States on semiconductors and supply chains at large, and this should serve as a good model for other future transnational collaborations.

It is also important to note that Japan, like Taiwan, has historically made extensive investments in chip manufacturing in China. In the 1980s, for example, Japan's chipmakers transferred technology to China for some of its first fabrication efforts. Direct investments in the semiconductor sector, however, were limited, and several unwound as Japan's chip firms reorganized. According to the Organisation for Economic Co-operation and Development (OECD), Japan's reliance on China for its final demand hovered around 10 percent for sectors encompassing semiconductor inputs in 2015 and higher than 3.6 percent for all industries.[28] Japan's current footprint in China appears to consist of one or two assembly plants belonging to Renesas and a handful of chip design centers.

Although Japan doesn't appear to be ready to burn its bridges with China, it has recently shown a greater willingness to resist Chinese pressure. For example, its latest defense white paper treats Taiwan separately from China, triggering China to register a formal objection. Japan, along with Taiwan, was also quick to accept the United States' proposed "Chip 4" alliance in March 2022—compared to initial hesitancy from South Korea in light of its own substantial commercial interests in China.[29]

US observers are aware of tensions between Japan and South Korea that date to Japan's colonial rule during the first half of the twentieth century. For example, in 2019 the Japanese government expressed displeasure over a South Korean court decision about forced labor during

World War II and placed restrictions on exports to South Korea of photoresist, hydrogen fluoride, and fluorine polyimide—all essential to the manufacture of chips and displays. Even so, some Japanese firms—such as Tokyo Ohka Kogyo (photoresist), Daikin (specialty gases), and Showa Denko (wafer polishers)—have nonetheless subsequently invested in new plants inside South Korea to circumvent the restrictions.[30] South Korea also responded by encouraging local firms to displace the need for Japan-based supply, an initiative that is apparently making some progress.[31] In March 2023, Japan announced its intention to lift the export curbs (but with no end date given) as part of a rapprochement with South Korea over historical differences.[32]

### *Chip Industry Trends*

Japan companies are being compelled to recognize "decoupling" pressures with respect to US and China supply chains. In a survey of one hundred companies critical to Japan's economic security, the majority saw China as a significant medium- to long-term risk due to government sanctions by China, rising competition, and talent and knowledge outflow. And yet, none planned to reduce their share of overall sales to China. Rather, US trade barriers were a more immediate concern to them, as many companies were feeling the impact of US-China tensions. Of the Japanese companies, 59.5 percent reported cost increases from US quotas, as opposed to 33.8 percent from China. Some commentators in Japan argue that, sandwiched between US and China sanctions (and the Japanese government's evolving national security policies), they find it difficult to know which way to run.[33]

There have also been some instances of Japan's semiconductor companies expressing caution about US partnerships. In the same survey, referring to the US Department of Commerce's fall 2021 semiconductor supply chain request for information, one industry leader expressed frustration with the US government for asking for what he felt to be his company's trade secrets. He blamed Japan's government for not taking a clearer stance.[34] There are also hints in this survey that the trade tensions with the United States in the 1980s are still seen as the cause of Japan's semiconductor industry downfall. One business leader commented, "The United States always comes knocking politically when a foreign company exceeds a certain size."[35] Another said, "As the United States strengthens its economic security, Japan is likely to become its target. There's a need to revisit the lessons from the 1980s."[36]

Japan's industries seem to respond to geopolitical tensions by reshoring or relocating factories; 14.2 percent of firms responded that they would like to receive government subsidies for shifting existing production within China back to Japan or to other countries.[37] For overseas factories, Japanese companies have increased their presence in the United States, South Korea, and Southeast Asian countries such as Vietnam and Malaysia. Indeed, since the anti-Japanese movement in China in the early 2010s and production disruptions due to COVID-19, Japan's government has been intent on broadly reducing reliance on China through its "China Plus One" diversification strategy.[38] In 2020, METI began implementing the Overseas Supply Chain Diversification Support Program, which finalized its fifth application process in June 2022. The project grants subsidies to Japanese companies for projects in Southeast Asia, and of the 103 successful grantees, 6 were explicitly related to semiconductors[39]—which implies that Japan's government is deeply concerned about its chip supply chains.

## South Korea

### *Key Laws and Policies*

Chip-related government policies in South Korea have been relatively modest compared with industry-driven business strategies led by the powerful Korean conglomerates, namely Samsung and SK hynix.

Korea is a powerhouse in memory chip production, accounting for 59 percent of global industry value added.[40] But the story is not the same in logic chips, which involve a different set of design and marketing skills. In April 2019, the government launched the System Semiconductor Vision and Strategy, the latest in a series of (so far unsuccessful) public and private efforts to boost logic chip design. This initiative aims to boost the fabless-foundry ecosystem through skills training and investment, and is backed by an investment of ₩1 trillion (about $830 million) over ten years.[41]

Later in 2019, following a dispute with Japan that led to a cutoff of several of Japan's chip-related exports to Korea, the government announced several measures to improve Korea's chip supply base for materials and equipment. These measures included funds of at least ₩2.5 trillion in grants and tax deductions to support mergers and acquisitions (M&A) of foreign suppliers. Meanwhile, foreign suppliers of targeted technologies that invest in manufacturing in Korea were offered cost-sharing grants equal to 40 percent of total investment, and a program for the fast-tracking of applications and infrastructure provision was implemented.[42]

In May 2021, following similar responses by the United States, Europe, and China, Korea's government also announced a "K-Semiconductor Strategy." This strategy consisted of investment commitments by Korea's chipmakers totaling more than ₩500 trillion (about $450 billion) before 2030 to stimulate domestic semiconductor production, with promises by the government for tax incentives and infrastructure, including assured access to water and power. Leading the group of 153 companies, Samsung said it would increase previous investment plans by ₩38 trillion ($33.6 billion) to ₩171 trillion ($151 billion) through 2030 in both its system large-scale integration (LSI; Samsung's fabless division) and foundry businesses. At the same time, SK hynix pledged it would spend ₩125 trillion ($97 billion) on expanding existing foundry facilities, in addition to a previously pledged ₩140 trillion ($106 billion) on four new plants.[43] The plan envisioned a "K-Chip Belt" that sought to connect a group of cities involved in the semiconductor value chain more closely. The government also established a "semiconductor facility investment special fund"—worth over ₩1 trillion—to support facility investment through favorable interest rates. The government also promised to fund the training of thirty-six thousand semiconductor experts and said it would spend ₩1.5 trillion ($1.3 billion) on semiconductor R&D.[44]

In January 2022, Korea's Chips Act advanced in the legislature, with the final version passing easily in March 2023.[45] While the initial language of the Act was less ambitious than that of its US counterpart, some of its measures were strengthened in response to industry feedback. In particular, large firms (such as Samsung and SK hynix) that invested in "core strategy technology" would qualify for tax breaks of 30 to 40 percent on R&D expenses and 15 to 25 percent for facility investment. Small firms would qualify for a deduction of up to 25 percent for investments in facilities (up from 16 percent) and 50 percent for research.[46] The first major investment announcement under the Act came in March 2023: Samsung committed to building five fabs at a cost of roughly $228 billion through 2042 in a new industrial complex near Seoul; the government hoped these Samsung fabs would bring on as many as 150 materials, component, and chip design firms.[47]

While there were some concerns about whether the originally proposed Act would survive the change in presidential administrations, President Yoon Suk-yeol has only doubled down on President Moon Jae-in's semiconductor ambitions. In fact, in late July 2022 the Yoon administration announced plans to make Korea a semiconductor superpower by locally sourcing 50 percent of its semiconductor materials, components, and equipment by 2030—up from 30 percent today. Among other regulatory relaxations and incentives, Korea's road map includes expected industry-related infrastructure investments of ₩340 trillion by 2026; increased tax incentives for equipment and research investments; and a public-private investment of ₩300 billion for small-business innovation and M&A of chip design firms. It also renewed focus on "system semiconductors"—a Korean term for non–memory chip production—with a goal of increasing its current market share of 3 percent to 10 percent by 2030. From 2024 to 2030, the government will also invest ₩950 billion in feasibility studies on semiconductors used in the electrical power and automobile sectors; ₩1.25 trillion in artificial intelligence (AI) semiconductors; and ₩1.5 trillion to support thirty new fabless companies.[48]

The strategy also sought to address Korea's anxieties—shared with other countries—around building its own talent pool. Indeed, an industry organization had forecast that Korea's chip workforce needs would grow from 177,000 in 2021 to 304,000 by 2031. Accordingly, the government detailed plans to train over 150,000 engineers over the coming ten years through university programs and private-led "semiconductor academies." The government will also establish a public-private R&D consortium modeled on the US Semiconductor Research Corporation (dubbed the "Korean SRC") with ₩350 billion appropriated over the next ten years to train talented master's and PhD students in the field.[49]

In August 2022, Yoon pardoned Samsung vice chairman Jay Y. Lee—the de facto head of the Samsung group who had been convicted in early 2017 for bribery—to help overcome a "national economic crisis." So concerned was Korea with its chip supply chains that while on parole, Lee had been allowed to be present in a May 2022 meeting between Yoon and President Biden on Samsung's Pyeongtaek campus and to meet the Netherlands' powerful ASML CEO, Peter Wennink, regarding chip manufacturing equipment.[50]

### *Korea's Production and Consumption*

Semiconductors are a major industry in Korea, accounting for 9.6 percent of manufacturing in the country and 17.3 percent of Korean exports in 2019.[51] In total, Korea's firms now produce 18.4 percent of global chips, which are being manufactured in some of the world's most advanced fabs.

In particular, Korea's firms were able to bootstrap themselves into the memory chip industry, starting in the 1980s with the help of short-term Japanese business partnerships. Because large Korean conglomerates, such as Samsung, had the financial resources to undertake the necessary investments, they became industry leaders. SK hynix, for example, was created in 2012 when the SK conglomerate invested in Hyundai's memory business, which had been struggling since the 2008 financial crisis.[52] By 2019, Korea's two largest chip producers, Samsung and SK hynix, accounted for nearly 60 percent of global memory chip production.[53]

Memory production features strong economies of scale because one chip design that meets industry standards can be replicated over and over. Because similar parts from different producers are nearly interchangeable, memory chips are considered a near commodity, with commodity-like rises and declines in profitability as the global economy fluctuates.

Logic chips, on the other hand, require a more application-specific approach, often customized to each particular end product. This specialization requires a very different set of skills compared to those for memory, ranging from design to marketing. Despite numerous attempts over the years to cultivate the logic business, however, Korea's firms have remained relatively minor players, with only about 3 percent of the global market for digital logic chips in 2019. Even Korea's auto sector relies mostly on imported chips—Korea's chip imports in 2020 were worth about $50 billion, roughly 11 percent of global chip production.[54]

Samsung is, of course, an exception. It began offering foundry services using its advanced processes in 2005, and has attracted major customers such as Apple and Qualcomm. Korea is the world's second-largest foundry provider, with a roughly 20 percent market share.[55] Even so, Samsung has struggled in recent years to keep pace with TSMC in advanced-logic chips: low yields at Samsung's 3nm and 4nm foundries have driven chip designer Qualcomm to shift production of its leading-edge chips entirely to TSMC, which now commands around a 50 percent market share.[56]

As in Japan, Korea's chip sector is dominated by large commercial groups, with fewer new startups. One consequence is a near absence of fabless chip design firms (apart from a recent spin-off firm called LX Semicon). One purpose of the country's "K-Chip Belt" strategy, mentioned above, is therefore to create a more supportive ecosystem for startups.

Finally, while Korea has hundreds of firms in its semiconductor supply chain, it is still dependent on imports for many chip manufacturing inputs. For example, its only wafer supplier, SK Siltron, accounts for only about 10 percent of the world's supply. And for materials overall, the market share of Korea suppliers was 16 percent as of 2019, while Korea firms accounted for only 4 percent of chipmaking equipment, 11 percent of chip assembly activity, and a negligible portion of chip design software (EDA).[57]

### *Diplomatic Trends and Issues*

Unlike Japan, which has been more amenable to embracing the opportunities to partner with the United States, Korea has been more wary of teaming up with the United States, especially given concerns over competition for market share. In memory chips, Micron arguably overtook Samsung and SK hynix in technology (with its 176-layer NAND and 1-alpha DRAM chips) and in profit margins in 2021. And since Intel is now attempting to catch up to Samsung in chip manufacturing, there are some competitive issues that make collaboration more difficult.[58] As noted in the discussion in chapter 3 on improving global supply chain information, the United States triggered controversy when it requested supply chain data from Korea's chipmakers, who feared that such data could be used for commercial advantage.[59]

Korea has also been unwilling to fully endorse various US efforts to counter China because the latter absorbs about a third of Korea's exports.[60] Korea's chip firms have also invested billions of dollars in China-based manufacturing, which accounts for a substantial share of their output. For example, SK hynix opened a major DRAM fab in Wuxi in 2006 (initially a joint venture with Europe's STMicroelectronics, which SK hynix later bought out) that now produces 47 percent of SK hynix's DRAM memory chips. At the same time, Samsung has a flash memory fab in Xi'an that produces 42 percent of Samsung's total NAND Flash output.

Making the US-Korea chips ecology even more complex, in November 2021 the United States prevented SK hynix from importing ASML's extreme ultraviolet (EUV) machines to upgrade its Wuxi plant because of concerns that the technology could be used to benefit China's military.[61] Although the companies have not made official statements, SK hynix and Samsung officials are worried that further export controls by the Biden administration could hurt their operations in China while effectively advantaging their American memory chip rival, Micron, whose only manufacturing in China is for module assembly.[62] To ease this concern, the Biden administration's October 2022 export controls included preemptive one-year licenses for Samsung's and SK hynix's memory operations in China. After one year, however, both firms will need a "plan B" unless further exemptions are forthcoming.[63]

To be sure, some progress has been made between the United States and Korea. In December 2021, the two nations held the first (virtual) meeting of a new Semiconductor Partnership Dialogue to deepen ties in technology development, personnel exchanges, and investment.[64] And President Yoon has been in favor of a broader "technological alliance" with the United States, including in the semiconductor sector. Unlike his predecessor Moon Jae-in, Yoon has been much more closely aligned with the United States on security issues: he abandoned Moon's "three noes" policy with China, became the first South Korean president to attend a NATO summit, embraced the Indo-Pacific Economic Framework for Prosperity (IPEF),[65] and has even expressed interest in joining the "Quad" of the United States, Australia, India, and Japan. Just after taking office, he met President Biden at the Samsung Pyeongtaek semiconductor complex, where they pledged the continuation of the Semiconductor Partnership Dialogue and a "global comprehensive strategic alliance."[66]

Korea's large semiconductor firms have largely followed Yoon's footsteps in partnering with the United States. As described in chapter 3, in November 2021 Samsung announced a $17 billion fab in Taylor, Texas, near its existing US manufacturing facility in Austin. In July, Samsung followed up with plans to build as many as ten more fabs between Taylor and Austin over the next twenty years, for a total of $200 billion in investments.[67] In the same month, SK hynix committed $15 billion from its next round of investment in the United States to benefit its semiconductor ecosystem, including R&D collaboration with universities, investment in materials, and "restoration" of advanced-chip packaging.[68]

Even so, Korea has been more wary in committing to the March 2022 US proposal for a "Chip 4" alliance that would bring together the United States, Japan, Korea, and Taiwan. The issue, of course, has attracted the attention of China, which still needs its fabs from Korea to pursue self-sufficiency.[69] And, when editorials in China's *Global Times* warned of unspecified "countermeasures against South Korea" if Korea sides with the United States, Seoul was listening. In early August, Korea finally agreed to participate in the preliminary US meeting, but insisted that the group be called a “consultative body” not aimed at excluding China.[70] Other suggested regional foreign policy moves by Korea included Foreign Minister Park Jin’s meeting with Chinese foreign minister Wang Yi in August of that same year (amid China’s live-fire drills in the Taiwan Strait), as well as the snubbing of US House Speaker Nancy Pelosi when President Yoon failed to meet with her during her visit to Korea earlier that month.[71]

For Korea, the trade-off between cooperating with the United States or with China appears to be, as one semiconductor official put it, a competition between technology versus markets.[72] A researcher at the Korea Institute of Industrial Economics and Trade (KIET), a government-funded research operation, said that “receiving US support is very important [for Korea] in terms of building a high-level chip ecosystem from wafer fabrication to software and semiconductor equipment,” and “it’s very possible for the United States to grant access for the use of US technologies exclusively to its allies.”[73] On the other hand, Korea has fabs in China, even though it has to be careful to monitor for technology leaks by tracking its chip engineers’ travels as part of its intellectual property protection strategy.[74]

Potential technology benefits for Korea also extend to partnerships with Japan and the Netherlands. Top semiconductor equipment companies from those countries have set up or recently expanded R&D centers in Gyeonggi province.[75] A KIET report warns, however, that Western partnership upsides for Korea could be short-lived. Written in July 2022, it alleges that the United States and European Union (EU) are using Korea as crutches to increase domestic production and fade out reliance on Taiwan (and Asia at large) in the long run. And unlike the United States and Japan—which maintain advantages in fabless design and chip materials, respectively—Korea’s industry profitability, which is based on commodity memory production, is expected to deteriorate around 2025 due to an oversupply of chips.[76]

Finally, President Yoon’s administration has emphasized rekindling better relations with Japan, which could aid a strong trilateral partnership with the United States. Japanese and Korean foreign ministers met often throughout 2022, while Biden, Yoon, and Kishida also held a trilateral meeting at the NATO summit in late June of 2022. And in a March 2023 Korean independence day speech, Yoon declared, "Japan has transformed from a militaristic aggressor of the past into a partner that shares the same universal values with us."[77] To be sure, President Yoon will have to balance his desire to improve relations with Japan with his low domestic approval ratings and the opposition-led National Assembly.[78]

## Europe

### *Key Laws and Policies*

Commercial activities of the semiconductor industry in Europe and the EU, much like those in the United States, were not a policy priority until the pandemic-era chip shortage. Before then, government support in Europe had been directed primarily toward research projects.

In 2014, for example, the European Commission (EC)—the executive body of the EU—launched the research-oriented Electronic Components and Systems for European Leadership (ECSEL) initiative. From 2014 to 2020, €2.4 billion (roughly $2.7 billion at 2020 exchange rates) in public spending was split equally between the Commission itself and EU member states. Funding was matched by industry, research organizations, and universities to support research in areas such as CMOS (complementary metal-oxide semiconductor) technology, digital-analog mixed-signal and sensor technologies, power technologies, and fully depleted silicon-on-insulator (FDSOI) process technology that could be an alternative to conventional CMOS chip architectures for low-power devices.[79]

The ECSEL was renewed in 2021 for another six years under the auspices of the Key Digital Technologies Joint Undertaking (KDTJU), with €1.8 billion in additional funding from the EU's Horizon Europe research program and comparable amounts from member states and private industry.[80] And if the EU Chips Act (discussed below) is also enacted as originally proposed in February 2022, the KDTJU will become the Chips Joint Undertaking.

In 2018 came the start of a program called the Important Projects of Common European Interest (IPCEI) on microelectronics, another part of the European Union's push for greater "component sovereignty" in key domains such as defense, aerospace, and critical infrastructure.[81] The program involves thirty-two companies and research organizations from France, Germany, Italy, Austria, and the United Kingdom working across five technology fields: energy-efficient chips, power semiconductors, sensors, advanced optical equipment, and compound materials.[82] But IPCEI funding can finance only pilot production lines, not high-volume fabs. Moreover, its funding stems from the participating countries themselves, not the EU budget. Despite these program limitations, however, IPCEI supported the development of Bosch's 300mm fab, inaugurated in June 2021 in Germany, providing €200 million of an initial €1 billion investment.[83]

But while the EU has supported research, it has done less to stimulate high-volume production. Political attitudes are now shifting. In particular, technological "sovereignty" has become an issue. In recognition of the changing global landscape, the Commission has set an ambitious goal of accounting for 20 percent of global chip production by 2030, double its current level.[84]

Europe has work to do to attract foreign commercial interest. In 2021, Thierry Breton, the European Commissioner for the Internal Market, met with Intel, TSMC, and Samsung to discuss possible fab investments.[85] While Intel was clearly interested, Samsung made no public announcement, and TSMC let it be known it was not planning any Europe investment.[86]

In early 2022 the Commission proposed a European Chips Act, featuring €43 billion (about $45.2 billion) in spending. The European Parliament and member states, following extensive debate, provisionally agreed to the Act in April 2023.[87] The compromise agreement is split across three "pillars," and expected sources of funding are mixed: the Paris-based Institut Montaigne estimates that roughly €7 billion may come from existing EU semiconductor-related R&D funds such as Horizon Europe.[88] The remainder, including any money for building fabs, will have to come from national governments and private investment.

While the EU Chips Act aims to facilitate funding for large-scale manufacturing, fabs must still qualify as a "first-of-a-kind" facility in the EU in some product dimension (such as technology node or substrate material) and have a "funding gap" such that they would not be commercially viable without state aid.[89] But at least two projects appear likely to benefit if a package of state aid can be put together by Germany and approved by the Commission: an expansion by GlobalFoundries in Dresden and two new factories from Intel in Magdeburg. In September 2021, the German economy minister announced a €3 billion plan to stimulate production all along the microelectronics value chain.[90] Intel, meanwhile, was hoping for subsidies of €8 billion for its new investment plan, and it is reportedly asking for billions more by 2023, noting that its costs of doing business in Europe are rising.[91]

The Act also introduces tools for anticipating and responding to semiconductor shortages. These include a European Semiconductor Board with member-state representatives engaging in information sharing on interlocking supply chains. In addition, the Act empowers the Commission to impose "priority-rated orders" on facilities that benefit from subsidies and to act as a "central purchasing body" for "public procurement" on behalf of member states when crises arise.[92]

### *Europe's Production and Consumption*

Since the late 1990s, Europe has been home to three large chip producers—STMicroelectronics, Infineon, and NXP—all of which were spun off from diversified electronics producers in France, Germany, and the Netherlands. They all produce chips primarily with specialty processes that give them some differentiation, and they are leaders in the fields of microcontrollers, sensors, and power electronics; they work closely with EU industrial firms, especially in the automotive sector. None of their fabs, however, are at the cutting edge of chip manufacturing technology. Since roughly 2015, the value of their production has rested at less than 10 percent of global chip output.[93]

Europe is also home to smaller specialty chip producers, such as Germany's Bosch (an auto industry supplier) and at least one contract foundry (meaning it produces chips for chip design specialists). The foundry, X-FAB, has plants in France, Germany, Malaysia, and the United States. Other fabs in Europe are foreign owned, including the Germany-based foundry fabs of GlobalFoundries and an Italian foundry fab known as LFoundry that, since 2019, has belonged to a China-based company, Wuxi Xichanweixin Semiconductor. Its most advanced production process is 110nm, suitable for analog applications.[94]

The most advanced chip production in the EU takes place at Intel's fab in Ireland, where Intel has invested more than €30 billion since 1989. The fab currently produces 14nm semiconductors. In March 2022, Intel announced that it would invest an additional $36 billion in Europe, including a major expansion of its Ireland fab and two new fabs in Germany.[95]

Europe accounts for about 20 percent of global sales of semiconductor manufacturing equipment. Its crown jewel is the Netherlands' ASML, which makes deep ultraviolet (DUV) and extreme ultraviolet (EUV) chip lithography equipment. Because ASML is the only producer in the world that can produce EUV lithography machines able to make chips at the smallest dimensions (5nm or below), cooperation by the Netherlands with the US embargo on exporting dual-use technology to China has been critical in preventing China chip producers from upgrading to the latest manufacturing processes. Today, ASML's only customers for EUV machines are Samsung and SK hynix in Korea, Intel in the United States, and TSMC in Taiwan. The first commercial application of ASML's EUV technology in the European Union will be at the fab Intel is expanding in Ireland.

European companies produce about 30 percent of nonwafer manufacturing supplies and inputs worldwide. Germany's BASF, the world's largest chemicals producer, is among the top five suppliers of materials to the chip industry.

Europe has recently taken an important place in chip design software. With its 2017 acquisition of the US firm Mentor Graphics, Germany's industrial giant Siemens became one of the top three providers of EDA (chip design) software, accounting for about 25 percent of global sales in this category.

Europe is also home to three leading research centers for nanoelectronics: imec (Belgium), CEA-Leti (France), and Fraunhofer (Germany). Each of these works extensively with international partners from industry and academia—including partners from China.

Europe has relatively few fabless (design-only) chip firms—accounting for only about 3 percent of the global total. For example, ARM (United Kingdom) is the developer of the processor IP core at the heart of most smartphones worldwide. As described in the discussion of industry and technology trends in chapter 2, ARM's IP core is a proprietary chip architecture that ARM licenses to other firms to speed their chip design process, provide access to the ARM ecosystem, and ensure product compatibility. ARM was a listed British company until Japan's SoftBank acquired it in 2016. SoftBank had sought to sell ARM to US-based Nvidia, but regulatory hurdles have complicated that effort, and in March 2023 Softbank announced its intention to relist ARM, this time in New York.

Notably, Europe has no significant chip assembly, test, and packaging sector, so complete chip supply chains invariably flow outside the continent.

On the consumption side, the greater Europe region (Europe, Middle East, and Africa, or EMEA) accounts for roughly 10 percent of global chip demand by systems integrators/original equipment manufacturers (OEMs). The largest sector by value is automobiles, and EMEA accounts for nearly a third of the world's auto chip demand. EMEA demand for general computing chips is nearly as large in value, but its demand is only about 6 percent of the world's total. Next-largest is EMEA chip demand for military and industrial uses; Europe accounts for about 20 percent of world demand. The EMEA region does not account for significant shares of the chip industry's other main markets in the consumer and communications sectors.

### *Diplomatic Trends and Issues*

The European Union has become increasingly aware of China as a potential national security threat. A 2019 report by the European Parliament noted "the need for a common multi-pronged policy response to the systemic competition between the EU's market-based and China's state-capitalist economic models."[96] At the same time, that document forecasted the inevitability of continued engagement, calling China "a cooperation partner, a negotiating partner, an economic competitor, and a systemic rival." There is, of course, an unresolved contradiction implicit in this formulation.

The European Union has so far maintained a high-level dialogue with China on cooperation in the sciences and technology.[97] Even so, a high-level diplomatic summit between China and the EU in April 2022 brought out more areas of disagreement than cooperation.[98]

China's diplomatic support for Russia despite the latter's invasion of Ukraine has put new strain on the relationship. In a March 2023 speech, European Commission President Ursula von der Leyen characterized China as seeking "systemic change of the international order with China at its center."[99] She indicated that the EU is no longer trying to revive its Comprehensive Agreement on Investment with China, and that any military support for Russia would further degrade the relationship.

While the European Union once sought to avoid appearing to be too close to the United States in its efforts to counter China's expansion, it has since demonstrated a growing desire to cooperate. In December 2020, the EU proposed an EU-US Trade and Technology Council (TTC) as part of a revitalized transatlantic partnership,[100] and in June 2021 the US and EU announced the formation of that council, consisting of ten working groups, including ones for technology standards, secure supply chains, and ICT competitiveness.[101] A second Ministerial Meeting was held in May 2022, after which Thierry Breton, EU commissioner for internal markets, referred to "a joint ambition to strengthen supply chain resilience in other areas, from raw materials to semiconductors."[102] It will be important to watch for concrete follow-on coordination from this body given its rhetorical ambitions, especially after French president Macron and EC president von der Leyen's trip to China in April 2023.

Notably, the European Union and its member states, while having no formal relations with Taiwan (except for the Vatican), have recently stepped up their support through parliamentarian visits and by adding Taiwan to their Indo-Pacific strategy as an economic and political partner. In December 2021, the European Parliament adopted its first-ever stand-alone report on expanding EU-Taiwan relations. Lithuania opened a de facto Taiwan embassy in November 2021; Taiwan reciprocated by setting up a $200 million investment fund for semiconductors and biotechnology in Lithuania, as well as a $1 billion credit fund.[103] And in early June of 2022, Taiwan and the European Union strengthened ties by elevating talks on semiconductor collaboration in research and supply chain monitoring from the deputy ministerial level.

Although TSMC in 2022 denied it had plans for a fab in the EU, Taiwan nonetheless was still eager to develop an institutionalized partnership that could promote future investments in Europe.[104] One ongoing challenge to Europe's advanced-semiconductor manufacturing ambitions may be a lack of anchor customers—such as a major integrated smartphone OEM like Apple or a major chip designer like Qualcomm—that would motivate suppliers to colocate in the region.

Europe think tanks have recommended that the EU forge similar bilateral partnerships with other partners such as Japan, South Korea, and Singapore. Institut Montaigne, a think tank in France with large corporate sponsorship, observed that semiconductor alliances are important for early warnings of supply chain problems and can serve as part of a "Western counteroffensive playbook" against aggression.[105]

## Southeast Asia

Southeast Asia has an important role in the semiconductor industry: it is the main destination for assembly, testing, and packaging (ATP) by multinational chip firms as well as outsourced semiconductor assembly and test (OSAT) firms. ATP, which makes up 13 percent of total global semiconductor industry capital expenditures and 6 percent of value added, is less capital-intensive than fabrication. OSAT capital expenditures are typically around 15 percent of their total revenues, compared to foundry companies' 35 percent capital expenditure share. Here, the region's cheaper labor costs (up to 80 percent below US levels) create a competitive advantage.[106] More advanced packaging processes—often colocated with chip fabbing itself—have become a critical part of overall chip performance and energy efficiency. Meanwhile, the traditional OSAT markets in Singapore and Malaysia have declined in the past ten years, with foreign investments and domestic firms diversifying into other parts of the value chain.[107]

With overseas firms looking to diversify their manufacturing bases outside of China, Southeast Asia nations have experienced tremendous growth in foreign investments. Although the region offers possible incentives to bypass Western export controls to China while also remaining close to Chinese customers, so far there has been little formal presence of outbound semiconductor investment from China in the region.[108] The development of multilateral trade agreements—such as the China-driven Regional Comprehensive Economic Partnership (RCEP), Japan-driven Comprehensive and Progressive Agreement for Trans-Pacific Partnership (CPTPP), and US-driven Indo-Pacific Economic Framework for Prosperity (IPEF)—may further stimulate investment and the region's involvement in semiconductor supply chains.

Although attitudes across the region are varied, a common refrain heard in the capitals of Southeast Asia countries is: "Don't make us choose between the United States and China." For example, in a recent survey of government, business, and academic leaders in the region, the majority of respondents from Malaysia (57 percent), Singapore (78 percent), and Vietnam (74 percent) believed that Southeast Asia should align with the United States if it had to choose between it and China (with 54 percent overall).[109] At the same time, however, in the same survey China was voted as the most influential economic, political, and strategic power in the region.[110] Interestingly, views in Malaysia and Singapore today favoring alignment with the United States have risen around 20 percentage points from 2020, with Malaysia virtually flipping sides.[111] Commentators in Malaysia, Singapore, and Vietnam believe that the US-China trade war will promote investment and growth in their semiconductor industries, with Malaysia (and possibly Singapore) indicating a growing interest in collaborating with the United States on semiconductors.

## *Malaysia*

### *Industry and Policy*

Although Malaysia has some fabs, its semiconductor activity has been dominated by assembly and testing. A foundry fab opened on the island of Borneo in the late 1990s, but since 2006 it has been owned by Europe-based X-FAB. It currently employs mature node processes down to 130nm.[112] SilTerra, an independent foundry that opened around the same time in a high-tech zone near Penang, was owned by a state-affiliated fund but was sold in 2021 to private Malaysian and Chinese capital; its most advanced node is at 110nm.[113] In 2006, Germany's Infineon opened a fab in Malaysia for power management chip production; and in 2022, Infineon announced an additional €2 billion for its third manufacturing line in wide-bandgap (silicon carbide and gallium nitride) semiconductors.[114]

Malaysia accounts for over 13 percent of the global OSAT market, with approximately 7 percent of the total global semiconductor trade flowing through the country.[115] Eighty percent of Malaysia's back-end output is concentrated in the island state of Penang, dubbed "the Silicon Valley of the East," which has been active in the industry for over fifty years.[116] While the industry has largely been dominated by the "big four" OSAT firms (Amkor Technology, STATS ChipPAC, Siliconware Precision Industries, and ASE Global), domestic automated test manufacturing (ATE) firms have grown rapidly and are catching up in terms of combined market capitalization.[117]

Many multinational electronics firms that consume semiconductors are also present. Over just the past two years, Malaysia has approved a record amount of foreign direct investment (FDI), mainly led by the electrical and electronics sector. In 2021, the country approved ninety-four such projects worth 148 billion Malaysian ringgit (RM)

($35.7 billion) and associated with over twenty-eight thousand jobs.[118] Sectoral exports rose by 18 percent to reach RM 456 billion in 2021, generating 56 percent of Malaysia's trade surplus.[119]

FDI projects include Intel's investment of RM 30 billion ($7.1 billion) over the next ten years into a new packaging and test facility, which is set to create over four thousand jobs at an Intel subsidiary that operates in Penang and in Kedah state. Nexperia, a Netherlands-based firm now owned by China's Wingtech, is investing RM 1.6 billion by 2026 to build automated production facilities for power-management semiconductors used in cars. Other recent investments are wide-ranging, including materials and components, front- and back-end manufacturing, and contract manufacturing from firms based in Austria, Germany, Japan, Taiwan, the United States, and China. Multinational corporations receive tax breaks and are perceived favorably by local enterprises.[120]

With investments pouring in, one concern in Malaysia is its tightening labor market. The Malaysia Semiconductor Industry Association (MSIA) reported that, with plants operating below capacity and threatening the country's competitiveness, its members need thirty thousand new trained workers immediately. To ease the labor shortage, the government lifted its freeze on foreign workers in August of 2022 and deferred a condition that at least 80 percent of electronics sector company workers must be Malaysian.[121]

*Relations with the United States*

Given Malaysia's key role in the back end of the chip manufacturing chain, the United States relies on Malaysia for a stable semiconductor supply.[122] While Malaysia's top import and export partner is China, the United States was Malaysia's number-three destination for exports, and in 2021 it accounted for the highest level of FDI at RM 15.6 billion, compared to China's RM 1.8 billion.[123]

In May 2022, US Secretary of Commerce Gina Raimondo and Malaysia's Senior Minister for International Trade and Industry Mohamed Azmin Ali signed the US-Malaysia Memorandum of Cooperation on Semiconductor Supply Chain Resilience. The memorandum included "guiding principles" to strengthen government-industry partnerships and to promote investments in the supply chain. No monetary commitments were made.[124]

Malaysia's industry views itself as well positioned in the current geopolitical arena. Malaysia Semiconductor Industry Association president Dato' Seri Wong Siew Hai sees China-Taiwan tensions benefiting Malaysia as countries look to manufacture more in Southeast Asia countries to mitigate risks.[125] He also believes that new leading-edge fabs operating in the United States following CHIPS Act funding will stimulate assembly investments in Malaysia, although he also expressed concern that the 15 percent global minimum tax reforms slated for 2023 may dampen such incentives. Malaysia's economists also fear that supply chain disruptions—which may occur given deeper US export controls or sanctions on People's Republic of China (PRC)-based firms, or direct conflict in the Pacific—could slow down growth and outweigh such benefits.[126]

## *Singapore*

### *Industry and Policies*

Singapore accounts for 11 percent of the global semiconductor market and 5 percent of global wafer fabrication capacity. It also holds a 19 percent share of semiconductor manufacturing equipment, including some lithography systems.[127] Since the 1990s, the country has developed four wafer fab parks via the JTC Corporation, a government agency employing over 13,500 people. Its twenty-one wafer plants represent Southeast Asia's most important semiconductor manufacturing base, with fourteen global semiconductor firms employing 18,600 workers.[128] Notably, they are home to Micron's new 176-layer NAND memory chip production, with Micron having invested a total of $15 billion in the country.[129] Other US firms, such as GlobalFoundries (which acquired a Singapore-owned foundry in 2009), also operate in the parks; together they compose Singapore's 18.3 percent share of US-headquartered firms' chip manufacturing capacity in 2021, which was the largest overseas share—even higher than Taiwan's 9.7 percent.[130]

Semiconductor manufacturing has a large presence in Singapore's economy, accounting for 80 percent of electronics sector output and 7 percent of Singapore's gross domestic product (GDP).[131] Singapore's appeal to overseas firms has been its high-skilled workers, modern infrastructure, and favorable tax and regulation policies. Currently, the Singapore government's semiconductor strategy is under its "Manufacturing 2030" vision, which includes a target to grow the country's overall manufacturing industry by 50 percent by 2030.[132] Both Singapore's Ministry of Trade and Industry and the Singapore Semiconductor Industry Association have launched various initiatives to attract and train talent, and two thousand new semiconductor jobs are expected in the next three to five years.[133]

Much of that manufacturing growth is expected to come from foreign investments, in which China is anticipated to have little direct presence. Of the $8.77 billion in manufacturing investments in 2021—42.3 percent of which was for the electronics sector overall—US firms contributed 67.1 percent, compared to China's 1.1 percent. In semiconductors, US/UAE GlobalFoundries announced a $4 billion investment to raise their Singapore production capacity to 1.5 million 300mm wafers annually by early 2024.[134] Other investments include plans by Germany's Infineon to make Singapore its AI innovation hub, Taiwan UMC's $5 billion fab for 22nm and 28nm logic chips, and a joint venture by Germany's Siltronic AG and South Korea's Samsung to build a €2 billion 300mm wafer plant.[135]

Singapore's success in luring foreign investment comes in part from cheap fab operating costs. According to a 2020 Boston Consulting Group report, when estimating ten-year total costs of operation of advanced-memory fabs, with the United States indexed to 100, Singapore came in at a score of 79—higher than China's 73 but lower than Japan's 99 and South Korea's 81.[136] In addition to tax breaks and subsidies for development and land procurement, infrastructure investments into centralized parks and economic zones have lowered the cost of business and shortened construction timelines. Such incentives arguably prompted GlobalFoundries to direct its 2021 investment to Singapore rather than its home, New York. The CHIPS Act, however, may shift the tide back toward reshoring.[137]

Singapore has also historically invested in R&D. The Agency for Science, Technology and Research (A*STAR), established in 1991, conducts joint research programs that include microelectronics with global companies. A*STAR's R&D budget has steadily increased: in 2020 it was allocated $25 billion, a 30 percent increase from the previous iteration.[138] And in December 2021, Applied Materials and A*STAR's Institute of Microelectronics announced a $210 million investment to extend joint research on 3D chip packaging.[139]

### *Relations with the United States*

Singapore has been not only a vital economic partner to the United States but also a security partner—buying US weapons systems and participating in joint training exercises. Even so, Singapore has also had close economic and cultural ties to China and has seen itself at the intersection of these two contending powers. Recently, for example, although Singapore condemned Russia's invasion of Ukraine and imposed sanctions on Moscow, Prime Minister Lee Hsien Loong made explicit that the country was not aligning itself with US stances per se. While visiting the United States in March of 2022 and encouraging US engagement in Southeast Asia, Lee also emphasized that the United States should "give [China] some space to influence the global system" and build trust for cooperation.[140]

So, while Singapore is an important home to US firms' semiconductor manufacturing (especially with Micron's Singapore production base there), China is still its biggest import and export destination (the United States ranks fourth and third, respectively), making Singapore loath to overtly offend China.[141]

## *Vietnam*

### *Industry and Policies*

Compared to Malaysia and Singapore, Vietnam is a relative newcomer to the semiconductor industry. In 2009, the government began investing in semiconductors and set up research and education centers, semiconductor development programs, and labs at its new high-tech parks, catalyzing rapid growth.[142] In fact, between 2000 and 2019 Vietnam had the fastest growth in electric component exports in Southeast Asia, with a compound annual growth rate of 25.5 percent (followed by the Philippines at 7.4 percent and Malaysia at 5.9 percent).[143]

Because of its lower labor costs, Vietnam has attracted substantial foreign investment in back-end ATP. For example, Intel currently houses its largest assembly and testing plant in the country: it invested $1 billion in 2006 and another $475 million in 2021. Other firms with research centers and factories in Vietnam include Qualcomm, Texas Instruments, SK hynix, and NXP Semiconductors.[144]

While further investments in education and infrastructure will still be necessary for Vietnam to move up the value chain, firms have already begun expanding investments in semiconductor materials and components. Samsung, Vietnam's largest single foreign direct investor, announced a $3.3 billion investment to expand its "flip-chip ball grid array" packaging facility by July 2023. South Korea's Amkor plans to invest $1.6 billion for advanced packaging technology. And US OEM supplier Hayward Quartz announced plans to produce chip materials in a new $110 million factory.[145] While Vietnam's indigenous chip industry remains relatively immature, it hosts a growing ecosystem of around twenty domestic chip design firms.[146] Moreover, investment in the semiconductor industry is being incentivized by a zero percent corporate income tax for the first four years, followed by a 5 percent rate during the next nine years and a 10 percent rate over the following fifteen years—as opposed to a standard rate of 20 percent. In addition, semiconductor industrial parks fund 10 to 15 percent of training costs for companies operating within them.[147]

Unlike in other Southeast Asia countries, however, there is notably little US investment in Vietnam. In both 2020 and 2021, Singapore and South Korea topped the list, followed by China, Japan, and Taiwan.[148] Vietnam's biggest export destination overall is the United States (China is second)—though China is Vietnam's largest import partner by far, reflecting its current role as a supply chain intermediary between the two superpowers.[149]

## India

### *Key Laws and Policies*

For decades, India's chip sector was treated clumsily by government policy. India's underdeveloped infrastructure poses significant hurdles for fabrication facilities, which need reliable water, electricity, and transportation—services that Delhi has primarily left to state-level governments. Moreover, historical efforts (including import bans) to ensure that India's electronics OEMs would use only India-produced chips essentially resulted in the development of neither electronics firms nor chip producers.[150] Several private fab projects were floated during the 2000s, with support offered by the states involved—but none made it anywhere near production.[151] Similarly, when the central government announced a fab subsidy program in 2007, only one proposal was submitted, and the project stalled within a year. A renewed government effort in 2011 generated a round of nearly a dozen proposals, of which two were selected for support; both of those plans also failed.[152]

In 2020, alongside a suite of manufacturing-oriented production-linked incentives (PLIs) from the government of Prime Minister Narendra Modi, the central government announced the Scheme for Promotion of Manufacturing of Electronic Components and Semiconductors (SPECS).[153] SPECS offers a 25 percent subsidy on capital costs (excluding building construction).

In December 2021, the Indian cabinet approved a budget of ₹760 billion (about $9 billion) over six years in an ambitious effort to support semiconductor fabrication and assembly (as well as flat-panel display manufacturing).[154] Fabs targeting 28nm-or-less process nodes can receive grants for up to 50 percent of their total capital cost, with support sliding to 30 percent if the targeted process is 45nm to 65nm.[155] Fabs for sensors and other specialty products, as well as chip assembly plants, can also receive a 30 percent subsidy. A separate "design-linked incentive" offered up to 50 percent of covered expenses for the development of new chip designs. These incentives—part of the Program for Development of Semiconductor and Display Manufacturing Ecosystem—are administered by a newly created India Semiconductor Mission.[156]

### *India's Production and Consumption*

India has one integrated circuit fab: the Semi-Conductor Laboratory, a 150mm-wafer fab started in the 1980s that designs and manufactures application-specific chips for India's telecom and space sectors.[157] Its most recent process upgrade was to a 180nm process node. Formerly attached to the Department of Space and the Ministry of Electronics and Information Technology (MeitY), the lab is being converted to a research institute under the India Semiconductor Mission.

Given this shallow base of experience, India's semiconductor manufacturing plans must rely on firms moving into the semiconductor space; industry investment grant proposals are evaluated by a bureaucracy that has similarly limited sectoral experience. Perhaps the most ambitious applicant for a subsidy to build a fab under the government's new scheme was a business group called Vedanta Resources, in partnership with Foxconn (Hon Hai), the Taiwan firm best known in India for its iPhone assembly facilities. A minority partner in the venture, Foxconn is seeking to diversify into chip production for the first time, including through the acquisition of intellectual property for 65nm-to-28nm logic chip production that could be used for domestic market smartphones, consumer electronics, and the auto sector.[158] In September 2022, Vedanta and Foxconn announced a planned investment of ₹1.54 trillion ($20 billion) in the state of Gujarat, pending award of government incentives, declaring that the deal would further India's goals to build a domestic, self-reliant "Silicon Valley" that would be less dependent on China.[159] In part, Gujarat was likely chosen instead of the more likely Maharashtra because of valuable land-related incentives, which beat out Maharashtra's offer of a 30 percent capital subsidy and a power tariff subsidy.[160]

Another applicant for the semiconductor fabrication incentives was ISMC, a joint venture between an Abu Dhabi–based venture fund and

Israel's Tower Semiconductor, which is in the process of being purchased by Intel. Tower has indicated that its role is limited to providing technology and know-how.[161] The proposed 65nm analog chip fab, in line with Tower's commercial experience, was expected to cost $3 billion—and as of mid-2022, the venture had signed a memorandum of understanding with Karnataka state.[162] Pratap Simha, a member of parliament from Mysuru state, which has also courted the investment, described his interest in terms of the local spillover benefits of infrastructure upgrades required for the plant, as well as the clustering effect from colocation of related electronics sector firms.[163]

In 2022, Sahasra—an Indian company that has historically imported and distributed memory modules—announced its intentions to move upstream and open India's first back-end memory chip ATP facility in Rajasthan, with a total planned investment of $94 million.[164] The plant was to receive support under the government's PLI and SPECS schemes, together with a "customized incentive package approval from [the] state government of Rajasthan."[165]

Despite so much focus on manufacturing, India's real chip strength to date actually lies in chip design, with more than one hundred chip design organizations. Most chip design activity takes place within foreign subsidiaries, including those of the top US and European chip companies. In Bangalore, where the majority of India's design centers are located, about two-thirds of the engineers work in these multinational subsidiaries. The first Indian chip subsidiary was opened by Texas Instruments in 1985, followed by others in the 1990s. While these subsidiaries initially focused only on implementing "back office" aspects of the design process (other aspects were then handed off to workers abroad), over time these domestic contributors have taken on more comprehensive responsibilities.

Many of India's large IT services companies—including Wipro, Tata, and Sasken—have also developed sophisticated chip design capabilities, but their focus remains on the low-margin, design-for-hire services rather than the riskier but potentially lucrative own-product business. Surprisingly, given this degree of human capital, there have been relatively few local spin-offs from multinational chip design activities, and chip design startups in India are still uncommon.

India's business conglomerates are generally respected for their quality of execution in a variety of other industrial and consumer-facing sectors, and they are now attempting to make inroads into the semiconductor industry. In 2021, Tata Sons acquired a majority stake in Tejas Networks, a telecom gear maker.[166] This acquisition was followed by the launch of an automotive-oriented chip design collaboration with the Japan-based firm Renesas, which receives about half of its revenue from carmakers (Tata Motors is the largest manufacturer of electric cars in India, and Japan's government owns 20 percent of Renesas's shares).[167] As of late 2022, Reliance Industries was also reported to be evaluating an investment in one of the three PLI applicant firms.[168]

### *Human Capital*

Indians are now the fastest-growing student group in Taiwan, doubling over the last five years, with a majority pursuing postgraduate degrees. The Taiwan government in turn has offered programs to attract Indian students, including paid internships, scholarships for PhD students, language training, and research fellowships. The Indian and Taiwanese governments have jointly sponsored ten engineering projects since 2008, with each receiving up to $40,000 of funding.[169] And when, in April 2022, the All India Council for Technical Education (AICTE) approved the introduction of two semiconductor-related educational programs in integrated circuit manufacturing and in "electronics engineering for very large scale integration design and technology,"[170] they were paired with the introduction of optional East Asian language courses intended to better equip Indian students to pursue internships in the semiconductor industry in Taiwan and South Korea.[171] Such people-to-people programs have become a foundation for collaboration between India and Taiwan, amidst concurrent shared security concerns—tensions on the India-China border and PRC military exercises around Taiwan.

In August of 2022, the India Electronics and Semiconductor Association also announced a "Semiconductor Nation—Campus Connect" initiative to increase awareness of the semiconductor industry among college students. Targeting both undergraduate and postgraduate students in engineering fields, the program aims to increase the number of electronics students in India entering semiconductor-related industries.[172]

### *Diplomatic Trends and Issues*

India is historically a member of the Non-Aligned Movement (NAM), which was established by a group of developing economies in the 1950s and 1960s when tensions were rising between Russia and the United States. Despite being "non-aligned," India turned to the Soviet Union for military support during its 1971 war with Pakistan. More recently, however, India joined the Quad, a partnership with Australia, Japan, and the United States created in 2007 in response to China's rising power. Even so, India, like many NAM members, abstained from the UN vote to condemn Russia's invasion of Ukraine.

Indians are painfully aware of the tech shadow cast by China, and under Prime Minister Modi, Delhi is pursuing a more aggressive policy of technology self-reliance under the moniker "Make in India," which extends from chips to electronic systems.[173] There is inherent tension in the Self-Reliant India (Atmanirbhar Bharat) policy between isolationism and a recognition of the need to engage with the world economy for needed new technologies and markets. Indeed, India has had a fraught relationship with China since the two fought a war in 1962. China's growing support for Pakistan is unwelcome in India, and tensions over disputed border areas in Ladakh, Bhutan, and Arunachal Pradesh have periodically broken into military conflict. The push by India's government for local production has given further reason to scrutinize dependencies on goods or technologies from China. In particular, India began to pressure China's firms after more than a dozen Indian soldiers died in a clash with Chinese forces at a disputed Himalayan border in 2020. India has, for example, banned hundreds of smartphone apps from China, used unofficial means to effectively bar technology firms

Huawei Technologies and ZTE from selling telecom equipment to its wireless carriers, and investigated the financial reporting of China-based smartphone firms Xiaomi and OPPO. Nevertheless, India's government has not completely written off all investment from China—so long as an investment is seen as enabling India-based value chains.[174]

In contrast, the United States is India's largest trading partner and most important export market.[175] The United States hosts the largest Indian diaspora, numbering over four million people; and roughly one-third of all immigrant-founded startups in the United States have Indian founders. The two governments maintain high-level ties on issues of common interest, including security, energy and climate, and finance. India was one of twelve countries to partner with the United States on IPEF, and both countries recently heralded the launch of a bilateral initiative on Critical and Emerging Technology (iCET), which was focused on long-term cooperation across a variety of technology areas, including semiconductors.[176]

In April 2022, the semiconductor trade associations of the United States and India—SIA and India Electronics and Semiconductor Association (IESA), respectively—signed a memorandum of understanding to identify potential opportunities in the semiconductor sector.[177] Dozens of US chip companies, including Intel and Qualcomm, have long-established design subsidiaries in India, centered in the city of Bangalore.

In April 2022, India and the EU also launched the EU-India Trade and Technology Council to address issues of technology, trade, and security as possible areas of cooperation, including a free-trade agreement and cooperation on 5G wireless and artificial intelligence.[178] This additional collaboration would create a more complete technology ecology with Europe's main chip companies (STMicroelectronics, NXP, and Infineon) that have had chip design and software development subsidiaries in India for over twenty years.

Summarizing India's current strategy, Delhi's envoy to Taiwan, Gourangalal Das, has emphasized the need to solidify India's semiconductor supply chain, noting that India's chip demand is growing at twice the global rate and is projected to reach 10 percent of global demand by 2030. The most credible results of India's efforts are likely to be in production of trailing-edge chips ranging from 65nm to 28nm as well as in back-end ATP. To that end, India's current overall subsidy scheme targets not just chipmaking plants but also the electronic systems industry—firms such as phone assembler Foxconn—and adjacent technology supply chains such as telecom, solar photovoltaics, and batteries.[179] As in the United States, execution and longer-term commercial sustainability in these efforts will be led by the private sector and ultimately depend less on government subsidies than on the competitiveness of the overall business and regulatory environment.

## Israel

### *Key Laws and Policies*

While relatively small, Israel's position as a US partner and global technology leader deserves special mention. Since the 1960s, Israel has pursued an industrial policy favoring science-based industry and has incubated an industrial structure composed of small- and medium-sized firms.[180] Israel's military also conducts advanced R&D, which has helped Israel establish a strong talent pipeline to the private sector.

Israel's government has also adopted incentives to persuade multinational technology companies to conduct manufacturing or research in the semiconductor sector—a tradition dating back to Intel's initial research investment in the 1970s. As Intel has invested more, Israel's government has provided tax rebates, grants, and flexibility in planning permissions—and over time, engineers from Intel and other multinationals have spawned a vibrant domestic semiconductor startup sector.

### *Israel's Production and Consumption*

In the 1980s, Intel chose Israel for its first offshore fab. Today, it employs roughly ten thousand employees who work on microprocessor manufacturing and R&D—making Israel Intel's biggest offshore location, and making Intel Israel's largest private employer.[181]

Intel's Fab 28 began operations in the early 2000s and has since been upgraded with the aid of grants and tax breaks from Israel's government. More recently, Intel announced plans to build Fab 38—a 4nm EUV-node production site—in Israel, with operations beginning in 2024.[182] Total investment is expected to be about $10 billion, including as much as $4 billion in grants from Israel's government.[183]

In February 2022, Intel announced that it was acquiring Israel-based Tower Semiconductor for $5.4 billion. Tower provides foundry services for making analog chips and has fabs in Israel, California, Texas, and Japan. In 2017, Tower set up a partnership to build a fab in China, but its partner Tacoma (Nanjing) Semiconductor later went bankrupt, and the project appears to have ended. More recently, Tower has been part of a joint venture proposal to produce analog chips in India.

Israel also has a small but healthy fabless chip design startup ecosystem. Before the COVID-19 pandemic it was adding about a dozen firms a year, with half of their funding coming from Israel sources and about a quarter from US sources.[184] Exit for successful startup firms is often through acquisition by larger multinational firms. Intel, for example, has bought multiple chip startups in Israel. One of its recent acquisitions was Habana Labs, an AI chip designer, which Intel acquired for about $2 billion in December 2019. In 2017, Intel acquired Mobileye, which develops chips and other devices for autonomous driving, for $15.3 billion, the most ever paid for a company based in Israel.

Numerous other technology companies have opened or acquired chip design centers in Israel, including Amazon, Apple, ARM, Microsoft, Nvidia, NXP, Qualcomm, and Samsung. Google opened a design center in 2021, and Facebook is reportedly following suit.[185]

### *Diplomatic Trends and Issues*

Israel has maintained an evolving posture of US strategic alignment, but alongside commercial relationships with China that often include high-tech areas. The degree of technology cooperation with China, however, has been adjusted based upon security considerations. China has reportedly been looking recently to Israel as a potential source of advanced chip design and integration technologies, with Huawei and Xiaomi investing in chip design there.[186] Meanwhile, in the spring of 2023, it was reported that China's financial regulators were slowing their review of

Intel's acquisition of Israel's Tower—a move interpreted to be taken in retaliation for US semiconductor technology export controls on China.[187]

The United States is by far Israel's largest export market (27.7 percent of the total in 2020), with China and Hong Kong a distant second (at 9.1 percent of export value).[188] Nonetheless, semiconductors compose a large part of Israel's exports to China: Israel-based firms sell inspection equipment for chip manufacturing to China-based firms,[189] and Israel's chip exports to China—largely from the Intel subsidiary—rose by 80 percent in 2018 to $2.6 billion.[190]

Under the Trump administration, the United States pressed Israel to further curb China's access to its advanced technologies, as Israel had agreed to do regarding military dual-use technologies during the Clinton administration. In 2019, Israel established a mechanism to vet foreign investment into potentially sensitive industries. Even so, in May 2020, Secretary of State Mike Pompeo warned that engaging with China in sensitive areas such as communications could threaten "the capacity for America to work alongside Israel on important projects."[191]

In this sense, Israel is a symbol of the complex set of conflicting interests that many other American allies, partners, and friends profiled in this chapter are also trying to reconcile. Given every country's increasingly contradictory commercial and strategic imperatives, their abilities to align with the United States in our rapidly changing world will rest not just on the force of arguments on security grounds, but on our ability to offer market and investment alternatives. In that sense, our own economic performance and our openness to business with like-minded partners is key to sustaining our collective national security too.

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