Policy Brief

Sustaining and Growing the U.S. Semiconductor Advantage: A Primer

Author
Owen J. Daniels
Will Hunt

CSET CENTER for SECURITY and EMERGING TECHNOLOGY

June 2022

Introduction

The United States and several allies and partners presently enjoy an advantage over China in collectively producing the advanced semiconductors necessary for artificial intelligence (AI) and other leading-edge computing technologies. This advantage stems from their tight control over many parts of the semiconductor supply chain, including over design and advanced inputs to production like the semiconductor manufacturing equipment (SME) necessary for advanced chips, and it has promoted comparatively safe and ethical technology development. Yet the complexities of the global semiconductor industry do not guarantee a future edge for the United States and other democratic chipmaking leaders amid strategic competition with China.

Despite its advantages in research, equipment, design software, and intellectual property (IP), the United States lacks onshore semiconductor fabrication facilities (fabs) that covert these and other inputs into leading-edge chips. This reality could undermine the country's chip access and its leading role in advanced semiconductor supply chains. The United States overwhelmingly depends on Taiwanese and South Korean manufacturers for leading-edge logic chip imports, exposing its access to geopolitical risk. Meanwhile, China hopes to lessen its long-term dependence on foreign advanced chips by supporting its domestic manufacturers like SMIC and YMTC and, increasingly, by investing across other parts of the semiconductor supply chain. With unfettered access to advanced chips, China could pursue leading-edge computing capabilities in AI and other areas that threaten the interests, values, and security of the United States and its allies.

The United States should therefore work toward two primary objectives when it comes to sustaining and growing its semiconductor advantages over China. **First, protecting the U.S. SME advantage entails preventing China from producing leading-edge chips.** The United States will need to work with its allies and partners to protect SME supply chains from Chinese access and promote their development on friendly shores, safeguarding U.S. economic and military advantages using tools such as export controls and end-use monitoring. Navigating competitive economic dynamics among governments and multinational private sector firms while working toward shared goals may prove challenging, but will be critically important.

Second, the United States needs to limit potential risks to its own semiconductor supply by reshoring chipmaking capacity. It can achieve this goal by prioritizing and allocating incentives to domestic and allied firms through vehicles like CHIPS for America Act funding that, coupled with regulatory reforms that ease burdens on firms, would decrease the attractiveness of offshoring chip manufacturing. This brief

discusses incentive prioritization in terms of leading-edge logic, leading-edge memory, and legacy logic chips. At the same time, exploring legislation to secure access to skilled foreign labor while investing in domestic education and retraining can help build the future U.S. semiconductor workforce. **Holistically approaching the protection and reshoring goals could bolster U.S. control over both the IP behind SME and advanced chips and the physical fabs that produce them.**

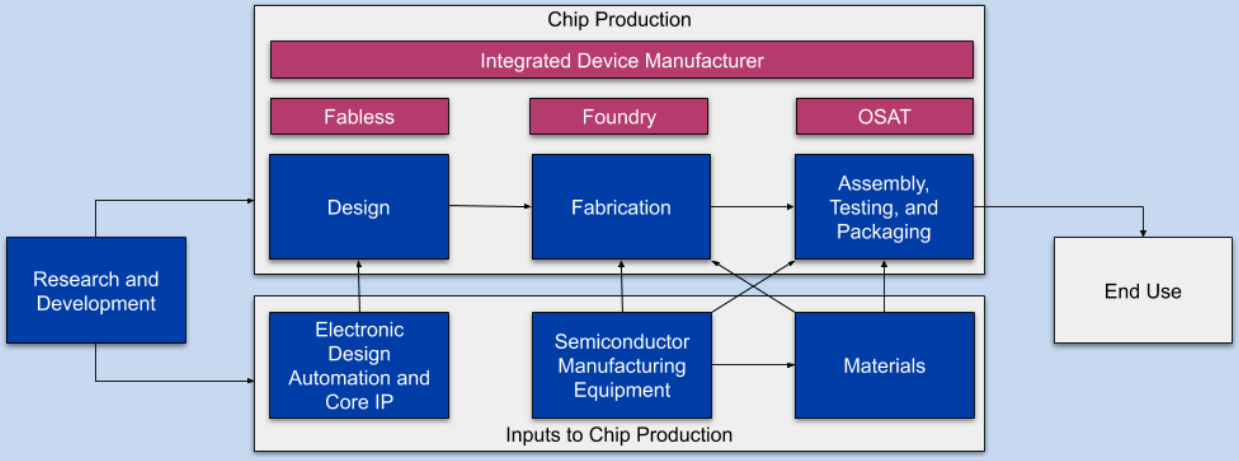
This brief lays out findings from across CSET's work on these issues to help policymakers scope the challenges ahead and identify paths forward.

Context

Strategic competition with China and the global chip shortage recently have highlighted the challenges to U.S. semiconductor leadership. Though China remains roughly a decade behind the United States and its allies like the Netherlands, South Korea, Taiwan, and the United Kingdom (among others) in leading-edge semiconductor supply chains, it is nonetheless projected to become the world's largest semiconductor manufacturer overall (including legacy chips) by 2030.[1] While China presently depends on foreign SME from the United States and its allies to produce chips, in time China could threaten U.S. dominance in semiconductor supply chains and manufacturing not only from the IP and economic perspectives, but also in terms of the physical supply chains themselves.

First, China is making concerted efforts both to acquire foreign SME technology and to develop its own SME capabilities. China heavily subsidizes its indigenous semiconductor industry to buy foreign SME technology and related components, as well as efforts to obtain SME IP and know-how in an effort to boost its leading-edge chip production abilities. If successful in producing state-of-the-art chips, China would be free to field technologies and weapons dependent on such chips, like AI, autonomous systems, or advanced hypersonics, in ways that present risks to human rights or international security. It has already deployed surveillance technologies containing GPUs and CPUs made by U.S. firms to alarming ends in monitoring its Muslim Uyghur population in Xinjiang province.[2] Though unlikely for the foreseeable future, China could one day challenge established innovative and resilient global supply chains with brittle, Chinese controlled ones.[3] **The U.S. interest therefore lies in continuing to prevent China from manufacturing leading-edge chips, maintaining its dependence on democratic supply chains.**

The Semiconductor Supply Chain



Note: Blue: Supply chain segment; Red: Business model for production

Source: Saif Khan, Dahlia Peterson, and Alexander Mann, "The Semiconductor Supply Chain: Assessing National Competitiveness" (Center for Security and Emerging Technology, January 2021).

The highly complex semiconductor supply chain is multinational and can be broken down into seven sectors comprising research and development, chip production, and inputs to chip production. Steps in chip production include design, fabrication, and assembly, testing, and packaging (ATP), with inputs feeding each step. Chip production can be completed either by a single integrated device manufacturer (e.g., Intel) or across separate firms that specialize in particular steps, including fabless firms specializing in design, foundries that exclusively produce chips, and outsourced semiconductor assembly and test (OSAT) firms focused on ATP.

CSET research has found that the United States has a significant lead over China in many segments of the semiconductor supply chain, including the research and development, design, and fabrication steps, and inputs like electronic design automation, core IP, and SME. The United States benefits significantly from supply chain integration with allies in areas where it lags, for instance in lithography and assembly, and in package tools. However, the United States notably lacks leading-edge logic foundries that can produce AI chips for third-party customers, and it relies heavily on Taiwan and South Korea for its own leading-edge chips. Disruptions to imports from these countries would therefore harm U.S. advanced semiconductor access and supply chains.

Second, the possibility of conflict involving China and its neighbors threatens the physical security of U.S. advanced semiconductor supply chains. These supply chains are highly globalized, and the U.S. economy, public and private sectors alike, rely extensively on stable semiconductor access from the automotive industry to the defense and intelligence communities. While the United States leads in areas critical to pushing the leading-edge like SME, IP, and design software, China, South Korea, and Taiwan dominate physical chipmaking. Much of the world's semiconductor manufacturing has resided in East Asia since the 1990s. Taiwan manufactures roughly 85 percent of global leading-edge logic chips, and China and Taiwan together produce 63 percent of legacy logic chips. By contrast, the United States has zero onshore leading-edge capacity and only 8 percent of global legacy logic capacity. A Chinese invasion of Taiwan would massively disrupt U.S. access to leading-edge logic chips and threaten U.S. logic consumption for sensitive applications like AI, data centers, automotives, and the military. Similarly, disruptions to South Korean manufacturing and exports from either a North Korean invasion or other contingencies would hamstring U.S. access to dynamic random-access memory (DRAM) chips.[4] **It is therefore in the U.S. interest to secure American access to critical semiconductors by reshoring semiconductor manufacturing in the United States**.

Ensuring that the United States can achieve these two goals—maintaining its advanced chip leadership over China and minimizing risks from disrupted supply chains for a wide range of semiconductor needs—is essential. It will require cementing the U.S. and allied lead in advanced SME components and semiconductor supply chains with well-coordinated export policies, augmented by chip fabs located on American shores to mitigate global disruptions. It will also require skilled labor—domestic and foreign—to work these fabs, and a permissive regulatory environment that does not deter domestic and foreign firms or workers from laying down roots in the United States.

The next section of this paper offers insights and recommendations from CSET's research for tackling these two broad goals and navigating the complex array of specific policy issues that underpin them.

Sustaining and Growing the U.S. Lead

1. Maintaining Chinese Dependence on Democratic Supply Chains

Presently, China is investing tens of billions of dollars per year in its efforts to catch up to the leading edge in producing advanced chips. But manufacturing leading-edge semiconductors requires access to a wide range of highly sophisticated equipment and materials in the semiconductor supply chain, which are produced exclusively by the United States and a handful of allies. In an effort to increase its domestic advanced manufacturing capacity, China subsidizes its chip designers' and factories' purchases of foreign equipment and materials—to the tune of $15 billion a year in 2018.[5] But in some cases, these nations are not selling the leading-edge versions to China or Chinese companies. Most notably, the Netherlands currently does not allow exports of EUV photolithography equipment to China, which will likely prevent China from reaching the leading edge in advanced microprocessor manufacturing for the foreseeable future.

In order to sustain their advantage, the United States and its allies should adopt "protect" and "promote" policies that undercut China's attempts to join advanced semiconductor manufacturing leaders. "Protect" policies should aim to maintain China's dependence on foreign imports at the chokepoints mentioned above through export controls on software, advanced materials like photomasks and photoresists, and advanced SME, particularly extreme ultraviolet (EUV) photolithography and argon fluoride (ArF) immersion photolithography tools. Monitoring end-uses and end-users of advanced chip exports will also be important for ensuring that chips are used in compliance with international standards and norms without disrupting sales to China for peaceful, commercial uses.[6]

On the "promote" side of the ledger, advanced semiconductor leaders should aim to retain key supply chain sectors on friendly shores. The United States and its allies have a number of mechanisms to accomplish this goal. Funding public-private partnerships, reducing unnecessary trade barriers, negotiating against Chinese semiconductor subsidies, and screening investments for risks of unwanted technology transfers can all help bolster the effectiveness of export controls. Working in concert with Japan, the Netherlands, Taiwan, South Korea, the UK, and Germany will be important to success.

Maintaining Chinese dependence on these countries for advanced SME and leading-edge chips is a first step toward sustaining the United States' incumbent advantage over China in advanced chip manufacturing and keeping China at least two generations behind in semiconductor manufacturing.

2. Reshoring Leading-Edge Chipmaking in the United States

Use Incentives to Make U.S. Reshoring More Attractive

Congress's passage of the CHIPS for America Act was central to the goal of reshoring U.S. domestic capacity in order to limit risks from offshore disruptions. The bill, which became law at the start of 2021, authorized the Department of Commerce to administer about $37 billion in incentives for chipmakers to build fabs on American soil, with dozens of domestic and foreign firms likely to compete for funding.[*] Legislation to appropriate these funds has not yet become law. Ensuring that manufacturing incentives target the chipmaking capacity most necessary to U.S. economic and national security will be key. Policymakers need to strike the right balance in distributing incentives among leading-edge logic, DRAM, and legacy logic chips in order to best serve U.S. interests.

Leading-edge logic manufacturing should receive the highest proportion of CHIPS Act incentives based on its strategic importance and disruption risks to foreign imports. Leading-edge chips are predominantly used in servers and consumer electronics like tablets, smartphones, and PCs. Incentives totaling $23 billion for leading-edge logic would potentially reshore enough manufacturing capacity to meet the entire U.S. demand through 2027.

This incentive amount would be sufficient to support the development of four new chip fabs among the firms that meet nearly all demand for U.S. leading-logic: Intel (25 percent of demand), Samsung (20), and TSMC (55 percent). By distributing incentives proportionally, the United States could meet nearly all of its leading-edge logic demand with two TSMC fabs and one each for Intel and Samsung. Helping these chipmakers cement plans for new American advanced logic fabs will boost a U.S. firm—Intel—and guard against supply disruptions to Taiwanese TSMC and South Korean Samsung, both of which are critical to U.S. industry.

Leading-edge DRAM manufacturing should be the second priority for CHIPS Act incentive allocation. Attracting a memory chip manufacturer would boost the United States' capacity from near-zero and reduce some reliance on East Asian manufacturing, predominantly from South Korea. By providing $5-10 billion in federal incentives, the

[*] $37 billion represents the amount most likely to be appropriated for non-DOD manufacturing incentives. This section does not address the separate $2 billion set aside for the manufacture of trusted chips for highly sensitive or military applications under the U.S. Innovation and Competition Act, which has passed the Senate. See Hunt, "Sustaining U.S. Competitiveness in Semiconductor Manufacturing," 6-10.

United States could persuade a firm to develop a new American fab that would be likely to remain near the leading edge for years to come. As the only U.S.-headquartered DRAM manufacturer, Micron would be a strong candidate for reshoring incentives to build a new 100,000 wafer per month fab. Because of the economies of scale necessary for DRAM investments and their long-term nature, any incentive recipient should maintain a demonstrated strategy for long-term viability and commitment to production in the United States; these factors also mean that additional future incentives may be necessary.

Legacy logic chips are the third priority and should receive any remaining CHIPS Act incentives. These chips have wide-ranging and important applications for which leading-edge logic is unnecessary, including some military and sensitive applications and in the automotive industry, where modern vehicles incorporate thousands of cheap semiconductors. While the United States has some onshore legacy capacity, incentives could be deployed to cheaply build two to five additional legacy logic fabs or to upgrade existing fabs and equipment with $4-9 billion in incentives—the most sensitive demand for U.S. legacy logic could be met with two fabs.[7]

Reshoring leading-edge logic will be key to maintaining U.S. semiconductor competitiveness with China and building future chip and supply chain resilience. But increasing U.S. production capacity involves more than building new fabs. Limiting the risk of offshoring will also require creating a regulatory environment that is not overly burdensome compared to competitors and ensuring that chipmakers can access the talent they need.

Remove Obstacles to Fab Manufacturing through Regulatory Reform

In addition to providing reshoring incentives for leading-edge logic, the United States needs to take steps to limit the relative attractiveness of offshoring, or manufacturing abroad. A first step would involve broadly evaluating ways to make the U.S. regulatory environment more conducive to fab development. Fab building entails complex interactions with federal, state, and local regulators given fabs' unique infrastructure requirements, and the United States currently builds fabs far more slowly than its competitors.* From 2010 to 2020, the United States not only undertook fewer total new fab projects than China (95 vs. 22), but it produced them at a slower rate (2.5 compared to 1.85 years). China and U.S. allies Japan, South Korea, and Taiwan heavily

* Chip fab infrastructure requirements include large plots of land; seismic stability; reliable and stable supplies of water and electricity; workforce talent; transportation infrastructure, and nearby land for co-location with key suppliers. See John VerWey, "No Permits, No Fabs: The Importance of Regulatory Reform for Semiconductor Manufacturing," (CSET, October 2021), 10-13.

subsidize and offer incentives to help attract semiconductor companies to their shores, exacerbating domestic challenges by attracting American companies like Micron and GlobalFoundries to build fabs abroad.[8]

To increase U.S. attractiveness, governments at federal, state, and local levels need to better match peer semiconductor producers when it comes to offering incentives and undertaking regulatory reforms. An important starting point would be to implement fully several key recommendations from the 2017 report on ensuring long-term U.S. leadership in semiconductors by the President's Council of Advisors on Science and Technology. Efforts should include finding and eliminating redundancies between state and federal permitting regulations for high-tech facilities by streamlining environmental, health, and safety regulations. For example, federal agencies such as the Environmental Protection Agency could explore tailoring semiconductor industry-specific permits that help accelerate new fab construction or existing fab re-tooling. Regulatory reforms should be complemented with infrastructure investments targeting utilities, transportation, and supply chain networks to attract semiconductor manufacturers.[9]

At the nation-to-nation level, the United States should engage allies and partners to coordinate domestic manufacturing incentives and build global supply chain resilience. Preventing undercutting among friendly states could help counter heavy Chinese subsidization. Establishing the extent to which Taiwan and South Korea presently subsidize their domestic industries would be the first step toward understanding what a U.S. negotiating position would look like. Analyzing global semiconductor supply chains and quantifying demand for key inputs can help clarify competition risks to address with partners and boost resilience to ensure U.S. fabs can access the raw materials necessary for chipmaking.[10]

Help Firms Meet New Demand for Both Foreign and Domestic Talent

To fulfill the reshoring potential made possible by CHIPS Act funding and further bolster against offshoring, the semiconductor industry must address immediate and long-term labor force challenges. Based on reshoring estimates for the roughly eight advanced leading-edge logic, DRAM, and legacy logic fabs it could generate, CHIPS Act funding could create about 27,000 new jobs over the next decade in the semiconductor and related component manufacturing industries.[11] The current U.S. labor market is insufficient to meet all of this demand, so fully maximizing the potential of the CHIPS Act will likely require a mix of domestic and foreign workers. The U.S. government therefore needs to help create a regulatory environment that not only

incentivizes firms to locate in the United States but also allows them easy access to the workers they need.

The semiconductor industry will likely need to draw from three primary labor sources. To satisfy short-term demand as the U.S. workforce catches up to requirements, some foreign workers with tacit knowledge of high-skill occupations will be required to staff new fabs. The industry will likely need at least 3,500 highly skilled foreign workers with prior expertise. Ideally, these workers would have experience working at firms like TSMC or Samsung, bringing tacit engineering knowledge to leading-edge chipmaking in the United States and transferring some of this knowledge to American workers.

The second labor source comprises domestic workers of different skill levels from other related U.S. industries and master's and doctoral students at U.S. universities. Certain lower-skilled roles at new fabs, like inspectors, testers, sorters, samplers, and weighers, may be able to attract all the talent they need from other U.S. industries.

The third labor source includes highly skilled American workers with relevant master's and doctoral degrees. However, sourcing higher-skilled U.S. labor may prove challenging in the short term given the semiconductor industry's high demand for such workers and the necessary retraining required for specialized work. In addition, drawing engineers from relevant talent pools like engineering services or the aerospace industry could reduce their availability in other sectors relevant to national security. With cost- and time-intensive training, U.S. master's and doctoral students can also help boost the semiconductor labor force.[12]

In the short term, the United States should explore creating highly skilled work visa programs for Taiwanese and South Korean workers to benefit from their tacit knowledge and ultimately help bolster the success of CHIPS Act-funded fabs. Precedents for such programs already exist, often as part of trade agreements, and the Partner with Korea Act, introduced in the House of Representatives and Senate in 2021, could create 15,000 E-4 highly-skilled work visas for South Koreans. Passing this bill or a similar measure that includes Taiwanese workers would help with the immediate labor needs created by the spending of CHIPS Act funds. **Long-term investments to boost the pipeline of U.S.-born talent in semiconductor-related fields, particularly in STEM education and engineering graduate study, should complement these programs**.[13]

Conclusion

Sustaining and even growing the United States' semiconductor advantage over China will be no small feat. China has the potential to greatly disrupt global SME or chip supply chains, and attracting chipmakers to build new American fabs and developing the U.S. talent pool will take great effort. However, as the CSET work referenced in this paper illustrates, the United States can make progress toward maintaining its semiconductor leadership and mitigating supply chain risks through a combination of legislative work, incentives to key firms, regulatory reforms, and cooperation with allies and partners.

This analysis is derived from several existing CSET papers that address these topics in greater detail. Please see these reports for additional details and author information.

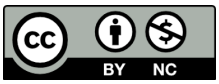
- Securing Semiconductor Supply Chains, by Saif Khan
- The Semiconductor Supply Chain: Assessing National Competitiveness, by Saif M. Khan, Alexander Mann, Dahlia Peterson
- Sustaining U.S. Competitiveness in Semiconductor Manufacturing: Priorities for CHIPS Act Incentives, by Will Hunt
- No Permits, No Fabs: The Importance of Regulatory Reform for Semiconductor Manufacturing, by John VerWey
- Reshoring Chipmaking Capacity Requires High-Skilled Foreign Talent: Estimating the Labor Demand Generated by CHIPS Act Incentives, by Will Hunt
- Preserving the Chokepoints: Reducing the Risks of Offshoring Among U.S. Semiconductor Manufacturing Equipment Firms, by Andre Barbe and Will Hunt

Authors

Owen J. Daniels is a policy communications specialist and Will Hunt is a research fellow at the Center for Security and Emerging Technology.

Acknowledgments

For their helpful feedback and editorial assistance, we would like to thank Igor Mikolic-Torreira, Margarita Konaev, Amy Chao, Lynne Weil, Danny Hague, Jessica Shao, and Adrienne Thompson.



CSET Product ID #: 20220006

Document Identifier: doi: 10.51593/20220006

Endnotes

[1] Saif Khan, Dahlia Peterson, and Alexander Mann, "The Semiconductor Supply Chain: Assessing National Competitiveness" (Center for Security and Emerging Technology, January 2021), 8, https://cset.georgetown.edu/publication/the-semiconductor-supply-chain/.

[2] James Millward and Dahlia Peterson, "China's System of Oppression in Xinjiang: How It Developed and How to Curb It," (Brookings Institution, September 2020), https://www.brookings.edu/research/chinas-system-of-oppression-in-xinjiang-how-it-developed-and-how-to-curb-it/.

[3] Saif Khan, "Securing Semiconductor Supply Chains," (Center for Security and Emerging Technology, January 2021), 10-11, https://cset.georgetown.edu/publication/securing-semiconductor-supply-chains/.

[4] Will Hunt, "Sustaining U.S. Competitiveness in Semiconductor Manufacturing: Priorities for CHIPS Act Incentives," (Center for Security and Emerging Technology, January 2022), 2-6, https://cset.georgetown.edu/publication/sustaining-u-s-competitiveness-in-semiconductor-manufacturing/.

[5] Khan, "Securing Semiconductor Supply Chains," 9.

[6] Khan, "Securing Semiconductor Supply Chains," 4-5.

[7] Hunt, "Sustaining U.S. Competitiveness in Semiconductor Manufacturing," 8-15.

[8] John VerWey, "No Permits, No Fabs: The Importance of Regulatory Reform for Semiconductor Manufacturing," (Center for Security and Emerging Technology, October 2021), 4-17, https://cset.georgetown.edu/publication/no-permits-no-fabs/.

[9] VerWey, "No Permits, No Fabs," 2-18.

[10] VerWey, "No Permits, No Fabs," 25-26.

[11] Will Hunt, "Reshoring Chipmaking Capacity Requires High-Skilled Foreign Talent: Estimating the Labor Demand Generated by CHIPS Act Incentives," (Center for Security and Emerging Technology, February 2022), 3, https://cset.georgetown.edu/publication/reshoring-chipmaking-capacity-requires-high-skilled-foreign-talent/.

[12] Hunt, "Reshoring Chipmaking Capacity Requires High-Skilled Foreign Talent," 4-9.

[13] Hunt, "Reshoring Chipmaking Capacity Requires High-Skilled Foreign Talent," 11-13.