MAINTAINING U.S. LEADERSHIP IN SEMICONDUCTORS AND COUNTERING CHINA'S THREATS

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EXECUTIVE SUMMARY

- China is targeting global leadership in the semiconductor industry and has put some $120 billion of Chinese government money behind this campaign. Chinese domination of the vital semiconductor industry, if achieved, would make the U.S. dependent upon China for these vital components and endanger Americans' security where chips are used for sensitive products and installations.
- Taiwan is a particular exposure for the U.S. One company, TSMC, accounts for over half of global chip foundry revenue, including chips used in almost every 4G and 5G smartphone. China's long-term policy options include undermining or gaining control over TSMC's business through a variety of means, ranging from competition to outright military conquest of the island of Taiwan. More largely, China's aggression in the region threatens suppliers from nearby countries which produce a large and growing share of the semiconductors, which are used in items ranging from smartphones to automobiles to military vehicles.
- The U.S. must respond by strengthening its enforcement of the 2018 Export Control and Reform Act. U.S. semiconductor equipment makers and electronic design automation tool companies must be prevented from selling to entities with Chinese military ties. Today, that enforcement is too weak, and the list of restricted companies does not capture the breadth of the relevant entities. For example, firms like Applied Materials, KLA, and Lam Research sell to Yangtze Memory Technologies (YMTC) and ChangXin Memory Technologies (CXMT), companies which should be designated as Military End Users, if not Entity List actors, for their ties to the Chinese military.
- Building on its leadership in chip design, the U.S. must implement reforms to support a substantial increase in U.S. chip manufacturing, with a goal of producing 50% of semiconductors in every major category. This will strengthen U.S. national security and diversify supply and resiliency. Moreover, it will create hundreds of thousands of high-paying manufacturing jobs in the U.S.
- U.S. policymakers should focus on greater international coordination on strategic trade control to ensure that semiconductor inputs and equipment are not sold to Chinese military end users or uses. U.S., European, and Japanese suppliers produce 90% of the world's semiconductor manufacturing equipment. The U.S. should provide leadership to these nations and their companies to strengthen trade outside of China and beyond Chinese influence. As a leader and innovator in the semiconductor industry, the U.S. should resume its position as the world's leading manufacturer of semiconductors.

INTRODUCTION

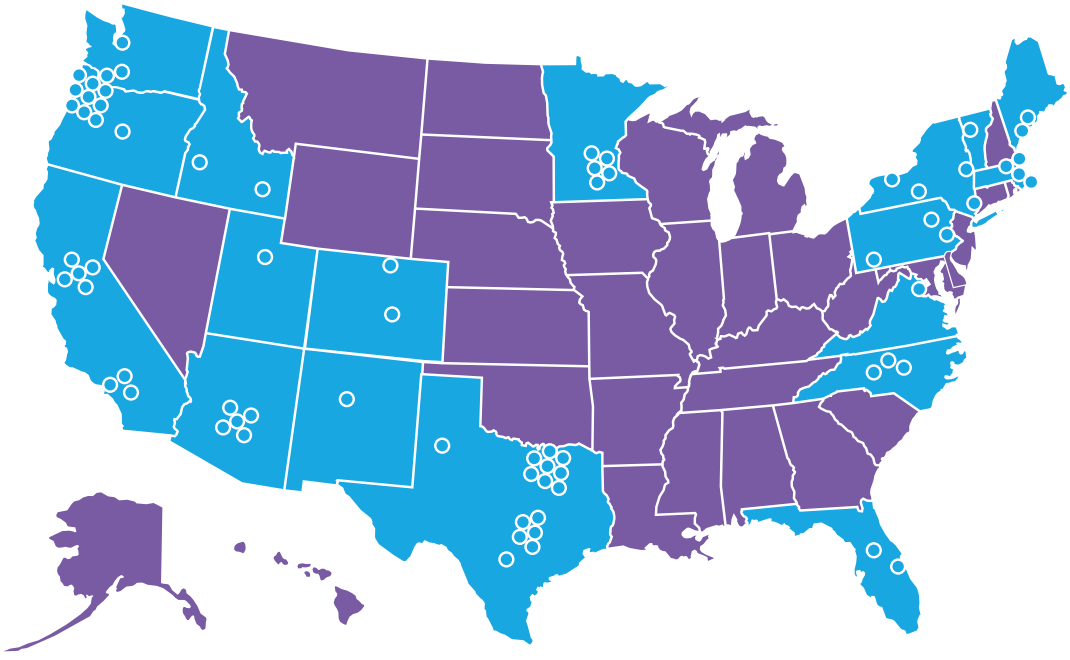
Between 2000 and 2020, the United States shed five million manufacturing jobs.[1] In the computer and electronics sector, the U.S. lost 800,000 jobs, or 42.5% of the total, over that same period. In those same years, with the rise of the Internet, the global semiconductor industry's revenues doubled, from around $200 billion to $400 billion last year. The sale of mobile phones skyrocketed, from 400 million units globally in 2000 to 1.4 billion last year. Over those years, virtually every type of phone used more semiconductors as devices added capabilities like photography, video, 4G network speeds, and now 5G.

Even though much of that technology was invented in the United States, America's manufacturing industry did not share in that growth. According to Bureau of Labor Statistics (BLS) data, U.S. semiconductor manufacturing employment fell by 36% between 2000 and 2020, to just 186,000 last year. U.S. policymakers increasingly recognize the true cost of offshoring vital industries as a "hollowing out" of the U.S. manufacturing sector, which now threatens high wage jobs and the security of vital products from foreign production risk.[2]

China entered the World Trade Organization (WTO) in 2001 on the presumption it would uphold basic rules and norms. Experience has shown that China ignores WTO rules. Its industrial growth is driven by massive government subsidization of targeted industries, currency manipulation, and widespread intellectual property theft. It routinely violates the environmental standards and labor protections, which are norms in developed countries. Offshoring manufacturing to China has not only deprived American workers of their rightful share in the growth of the U.S. technology industry, and other industries—it has also unduly strengthened the Chinese military with direct access to production capability and technology.

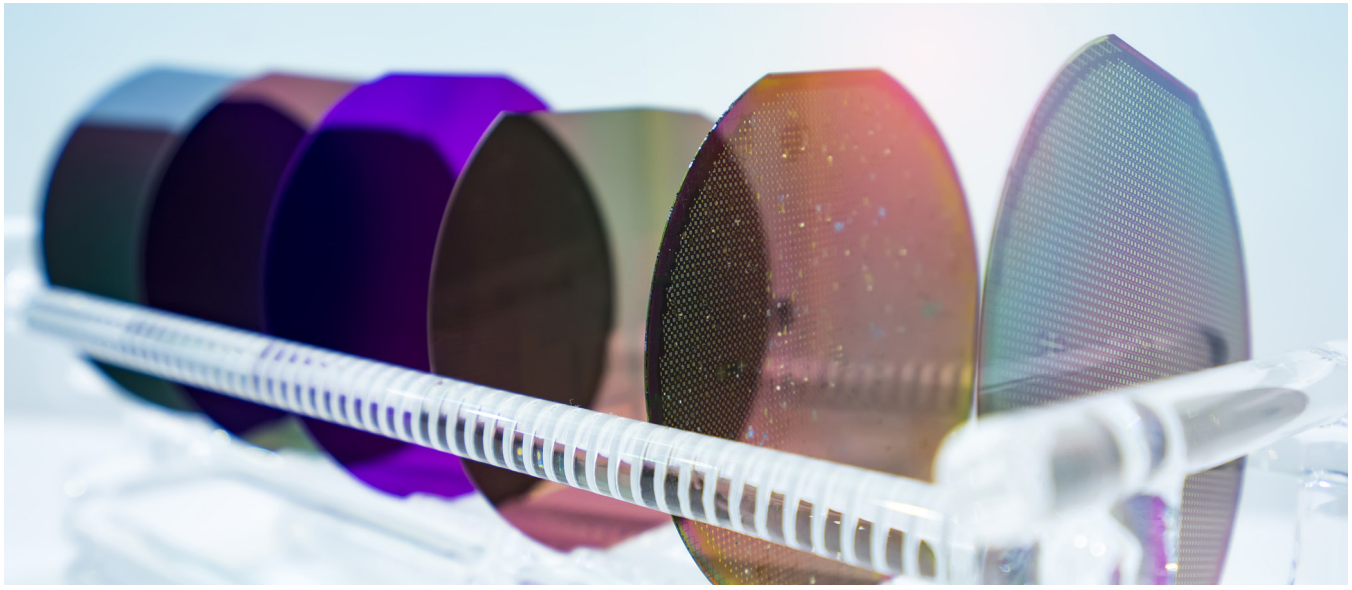
Semiconductors, a field once dominated by the United States, is a prime target in China's current industrial plans. China has already made progress in the semiconductor industry while the U.S. has steadily lost market share in chip manufacturing. The economic and national security implications of the United States' waning grip on the semiconductor industry are immense. Semiconductors power virtually every form of

SEMICONDUCTOR MANUFACTURING ACROSS AMERICA



The U.S. manufactures semiconductors in 18 states, directly employing over 241,000 people and as much as another 1 million workers in jobs supporting this vital industry.

Source: "2020 State of the U.S. Semiconductor Industry," SIA, June 2020. https://www.semiconductors.org/wp-content/uploads/2020/06/2020-SIA-State-of-the-Industry-Report.pdf



modern technology, from everyday devices to defense systems. China has already succeeded in capturing and dominating many strategic technology industries like telecom equipment, solar panels, and LED displays, and traditional industries like steel and aluminum. In each case, it uses predatory pricing and other anticompetitive practices to drive non-Chinese competitors out of business.

If China succeeds in dominating this industry, the economic, political, and military consequences for the rest of the world will be deep and severe.

Semiconductors are among the most complex products manufactured today, with over 1 billion transistors on a one-square-inch piece of silicon. If China succeeds in dominating this industry, the economic, political, and military consequences for the rest of the world will be deep and severe. Beijing's determination, and its ability to put huge resources behind its efforts, should not be underestimated.

American companies are playing into Beijing's hands by selling semiconductor manufacturing equipment (SME), the hardware tools used to design and manufacture semiconductors, and electronic design automation (EDA) software tools to Chinese companies. Under normal circumstances such sales would be welcome, but in China's case, it is difficult to distinguish between its civilian and military sectors. In fact, China purposely combines the domains in a strategy called "Civil Military Fusion" to advance their global supremacy goals.[3] This means that U.S. companies selling to China may unwittingly be strengthening its military.

This paper explores these challenges and the necessary policies at home and abroad to strengthen America's semiconductor industry and protect Americans' security. This includes policy incentives to create domestic, state-of-the art chip manufacturing facilities owned and operated by U.S. companies. This is critical for Americans' national security and prosperity. Per national and international law, we must take firm action to deprive Chinese military actors of access to the hardware and software tools needed to design and manufacture advanced semiconductors. We must also strengthen coordination with like-minded nations in the practice of strategic trade control so semiconductor exports go to their intended users and uses. These relationships should also be leveraged to expand semiconductor trade outside China and beyond its influence.

PART I: MAINTAINING U.S. LEADERSHIP IN SEMICONDUCTORS

Chip Design and Manufacturing

Semiconductors are a critical technology for our economy and our national security. The United States leads the world today in the semiconductor industry. Six of the top ten chipmakers in the world are American. However, this general statement hides an important divergence within the industry. The U.S. is the undisputed leader when it comes to designing chips, with about 56,000 Americans employed in the field, most of them in Silicon Valley, Boston, San Diego, and Austin. In every cutting-edge application for *designing* chips, including 5G wireless, chips for internet communications, high-speed graphics, automotive semiconductors, or artificial intelligence, U.S. companies are at the forefront and pushing the boundaries forward.

But when it comes to *manufacturing* chips, the U.S. is lagging, and losing ground by the day. The ability to manufacture cutting-edge chips is a critical issue for the U.S., with China's determination to become a world leader in this industry. The chip shortage that stemmed from a surge in demand for electronics during the pandemic is now very clearly impacting the auto industry – it has led to plant closures and layoffs – and only reinforces the importance of manufacturing crucial components of the modern economy within the U.S. and maintaining a robust supply chain.

According to a well-researched Boston Consulting Group (BCG) study, the U.S. has 12% of global semiconductor manufacturing capacity, and that is projected by BCG to fall to 10% by 2030.[4] By comparison, China's share is now at 15% and is projected to rise to 24% by 2030. At that point, China's will become the largest chip-manufacturing region, exceeding Taiwan, Korea, and Japan as well as the U.S. Even though 18 U.S. states have semiconductor fabs, many of these are old, and the owners have not necessarily invested to keep them at the cutting edge or to increase their volume to meet demand. With skyrocketing demand for semiconductors, the U.S. continues to lose global market share in the manufacture of semiconductors.

Geopolitical considerations make the problem worse. Taiwan has 22% of global chip manufacturing capacity; South Korea, 21%.[5] The island of Taiwan, only 110 miles from China, is claimed by the increasingly aggressive Chinese government and is subject to its increasing military presence. After China's apparently successful takeover of Hong Kong, in violation of its 1997 treaty with the United Kingdom, there is no guarantee that China won't try something similar with Taiwan. Our dependence on Taiwan and other Asian semiconductor centers (South Korea, Singapore, Japan) is endangered by Chinese expansionism, unreliable cargo ship availability, and even the current Taiwanese water shortage, which is hampering production by Taiwanese industry.

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U.S. Over-Reliance on TSMC Is a Risk

It is hard to overstate the dependence of the U.S. semiconductor industry on Taiwanese manufacturing, and specifically the 11 fabs (as chipmaking facilities are known) of the Taiwan Semiconductor Manufacturing Corporation (TSMC). TSMC stands alone as the world leader in the fabrication of leading-edge chips using 5-nanometer (nm) transistors. The latest Apple smartphones are completely dependent on TSMC's 5nm chips. The fastest graphics chips, designed by Nvidia in Silicon Valley, are also manufactured by TSMC. The fastest-growing business making processor units for internet data centers, designed by AMD in Silicon Valley, are produced at TSMC. Some of the key chips in 5G telecom infrastructure, again designed in Silicon Valley or Massachusetts, are manufactured at TSMC.

TSMC is the third largest chipmaker in the world, with revenue last year of $48 billion. That's more than the gross domestic product of 122 nations in the World Bank database. Its success is due to its engineering excellence, highlighted by the fact that its technology is one generation ahead of its closest competitor, Samsung, and two generations ahead of Intel, the largest chipmaker in the U.S. and the world, but which has fallen badly behind in recent years.

TSMC's success is due to a major shift in the industry, the divorce between chip design and chip manufacturing. U.S. chipmakers jumped on this trend to get out of the manufacturing business. Most U.S. chipmakers have no manufacturing capability today. Instead, they design chips with a team of engineers and get those chips "fabbed" overseas, typically by either TSMC or Samsung.

The U.S. has only one "foundry," as fabs that only manufacture chips are called. That is GlobalFoundries (GF). Several years ago, GF announced it would withdraw from the costly competition to stay at the leading edge in terms of tiny transistor sizes. GlobalFoundries today concentrates on chips based on transistors in the 22nm to 90nm range.

GlobalFoundries' chips are perfectly adequate to control the brakes in your car, your television remote control, and many of the devices in a military vehicle. But for more demanding tasks, like the LANTIRN system on the F-16 fighter jet[6], which enables a single-seat pilot to fly low at night and place bombs with precision accuracy, cutting edge chips are needed. An influential report published earlier this year by the National Security Commission on Artificial Intelligence (NSCAI) summed up the problem this way:

> *"If current trends continue, the United States will soon be unable to catch up in fabrication and could eventually also be outpaced in microelectronics design. If a potential adversary bests the United States in semiconductors over the long term or suddenly cuts off U.S. access to cutting-edge chips entirely, it could gain the upper hand in every domain of warfare."*[7]

To maintain global leadership in semiconductors, the U.S. needs to invest in U.S. companies to bolster chip manufacture capabilities and strengthen chip design.

Policy Solutions for Chip Design and Chip Manufacturing

THE U.S. SHOULD AIM FOR 50% MARKET SHARE OF CHIP MANUFACTURING

The U.S. must address its weakness in semiconductor manufacturing. The NSCAI report recommends that the U.S. must aim to stay two generations ahead of China in chip technology. This is achievable. To do so, we need to alter the financial landscape to make it profitable to build and operate several leading-edge fabs in this country. We should set a target of a 50% market share in every major category of semiconductors. It is good that both TSMC and Samsung are considering building new fabs in the U.S., but it is unlikely these will be at the cutting edge. Those companies build their most advanced fabs at home. So, too, should the United States. We need cutting-edge fabs here, to preserve U.S. leadership in the industry, to create a partner that can work closely with our defense and security establishment, and to increase the level of competition in an oligopolistic industry.

> The ability to manufacture cutting-edge chips is a critical issue for the U.S., with China's determination to become a world leader in this industry.

Numerous members of Congress have spoken in favor of this approach. A bill, the Creating Helpful Incentives to Produce Semiconductors for America Act[8] (CHIPS Act) was introduced and passed last year, although the funding has not yet been appropriated. The original CHIPS Act included a 40% refundable investment tax credit for any U.S.-based company purchasing semiconductor manufacturing equipment. Updated language offered $15 billion to fund a grant program overseen by the U.S. Department of Commerce to companies seeking to build fabs in the U.S., and it includes numerous programs to support research and development.

U.S.-BASED FABS MUST BE ABLE TO DELIVER CONTINUOUS IMPROVEMENT AND RELIABILITY TO POWER AMERICA'S LEADING ELECTRONICS COMPANIES

Building a leading-edge greenfield fab is expensive, more than $20 billion. The ten-year cost (initial investment plus annual operating costs) is about 30% higher in the United States than Taiwan, South Korea, or Singapore and up to 50% higher than in China. Between 40% and 70% of the cost differential is attributable to government incentives.[9] The U.S. government must use federal and state money to create a level playing field. Labor costs are not a critical factor in billion-dollar chip fabs. The costs are mostly in land, electric power, taxes, and other fixed costs.

But money is only part of the recipe for success. Technological innovation must be combined with reliability. In other words, new U.S.-based fabs must manufacture chips with continuous improvement and provide high-quality products on time to customers all the time.

To maintain global leadership in semiconductors, the U.S. needs to invest in U.S. companies to bolster chip manufacture capabilities and strengthen chip design.

In this market, price is actually secondary. TSMC has succeeded because it unlocked that puzzle. For a new U.S. fab to succeed, it needs to find that formula and deliver for the customers. The U.S. Department of Defense is an important potential customer, perhaps the most important, but its volumes are small and it cannot make a huge fab profitable on its own. This is yet another case of military industrial synergy. Apple and Nvidia are critical corporations that can make new U.S. fabs successful and profitable. In designing an incentive program for new U.S. fabs, the U.S. government must include incentives that attract U.S. chip designers to give business to the new fabs.

TAX DEDUCTIONS TO INCENTIVIZE U.S. COMPANIES TO PURCHASE U.S.-MADE CHIPS

Bill Barrett, Vice President of Tax at GlobalFoundries, has proposed just such a plan. Under Barrett's plan[10], fabless chip companies would get a 30% tax deduction for the semiconductors they purchase from a U.S.-based fab. This would give U.S. chip design companies the incentive to work closely with new cutting-edge fabs and help them become world-class.

Where would these new fabs come from? GlobalFoundries is the obvious first choice. It is the only foundry business in the U.S., and, in response to skyrocketing demand in 2020, it is planning this year to invest $1.4 billion in a new fab at its Malta, New York location.[11] GlobalFoundries is also rumored to be considering a stock market listing this year or next. Ironically, as a result of retreating from the cutting edge, GlobalFoundries is achieving profitability and able to consider a public listing. It is in the national interest that GlobalFoundries get its cutting-edge back, including the 5nm logic chips as well as 3nm.

INVESTING IN SUPPLY CHAIN DIVERSIFICATION

A U.S. semiconductor leadership strategy is necessary to de-leverage and diversify the semiconductor supply chain, which is over-exposed to China. It should also take into account the different categories of semiconductors and build up U.S. leadership so we are strong across the board. While the U.S. has a strong presence in the design and sales of logic, analog, and memory chips, it is steadily losing share in the manufacture of each of these sectors. And of course, China's rise threatens U.S. (and all non-Chinese) manufacturing in these sectors. These sectors are vital and have parts to play to ensure U.S. leadership with next-generation technologies for artificial intelligence, autonomous vehicles, and 5G as well as defense systems. As such, we need to target a 50% U.S. market share in all these sectors.

POLICY FOCUS ON LONG-TERM LEADERSHIP, NOT NEXT YEAR'S PROFITABILITY

A stock market listing for GlobalFoundries will likely hold the company back from the level of capital spending needed to get back into cutting-edge logic chips. As an illustration, TSMC is eight times the size of GlobalFoundries, but its capital budget for 2021, at $25 billion to $28 billion, is *twenty times* that of GF. TSMC is able to do this because its Taiwanese government backers take a long-term view. They focus not on next year's profits but on maintaining Taiwanese leadership in this industry for the next 50 years or more.

The U.S. government should learn from this model. We need U.S.-majority owned fabs in this country, and we need to be at the cutting edge in manufacturing, just as we are in chip design. This is not only good for national security, it is also good for the economy. According to BLS data, the U.S. semiconductor and related components manufacturing industry pays an average annual wage of $74,820 to its 362,000 workers, 40% higher than the average annual wage for all U.S. employees.[12]

Criticisms of greater government involvement in the semiconductor industry, such as a recent *Wall Street Journal* editorial, contend the U.S. should stick to its alleged comparative advantage in chip design.[13] But it is nonsense to think of industry segments without taking into account the full supply chain that makes every modern industry possible. Chip design is meaningless without a manufacturing capability, and that capability is under threat from the relentless rival, China. As author John Mathews wrote in 1997, Taiwan in the 1980s "set out to create a comparative advantage where none had existed."[14]

If Taiwan succeeded in creating an industry out of whole cloth, there is no reason why the U.S. cannot rebuild its semiconductor manufacturing industry here, where the semiconductor was invented and where we still lead the world in semiconductor design. In Part II, we explain what the U.S. must do to maintain our lead over China and prevent Beijing from overtaking the U.S., a grave danger not only at home but also to our allies in Taiwan and elsewhere. Moreover, we must tighten export controls, which too often let strategic and sensitive technologies fall into the hands of Chinese military users and uses, endangering America's security and prosperity.

PART II: COMBATTING CHINA

Selling Out America's Strategic Semiconductor Advantage to China

The United States has long sold semiconductors and semiconductor manufacturing equipment (SME) to China, which has stirred debate about the impact on U.S. national security. Last year, China imported about $350 billion of semiconductors, which represents a more than 14% increase over the previous year.[15] About half of those chips are expected to be incorporated into products that the country will export.[16]

China is clear about its intentions to expand its control of the semiconductor market. The "Made in China 2025" plan seeks to produce 70% of the country's domestic semiconductors and achieve parity with leading edge design capabilities within the next five years[17] with $120 billion specifically for its chip-making industry.[18] [19] Last year, the country purchased nearly $32 billion of SME, a 20% year-over-year increase, making China the largest market for semiconductor equipment.[20] China has no interest to "share" the market with other competitors. It wants to be self-sufficient and produce all the chips for itself and the rest of the world.

U.S. Companies Are Enabling China's Progress in Chips

U.S. SME producers Lam Research, KLA, and Applied Materials have enjoyed record revenue and profits driven by growing sales to China, which accounts for more of their shipments than any other country. According to Applied Materials' recent earnings report, 32% of the company's sales went to China in 2020, up from 29% in 2019.[21] Applied Materials' sales into the U.S. market were only 10% of its total, behind China, Taiwan, Korea, and Japan. In China, virtually every purchaser of semiconductor equipment is associated with the Chinese government.

It is the same for the software design tools, known as EDA software, that are also vital for designing complex semiconductors. This field is also dominated by American companies, and those companies are also increasing sales into China. For example, Cadence Design recently reported that in 2020, sales to China rose by five percentage points to 15% of its total revenue.[22] Sales into the U.S. market fell by two percentage points to 42%. China is already the leading purchaser of hardware to make chips. If nothing changes, it will become the largest manufacturer of chips, and inevitably chip design will follow in its wake.

Semiconductor equipment companies, along with the semiconductor companies themselves, have actively found ways around the export controls. KLA and Applied Materials both recently said export controls would not diminish their revenue.[23] Doug Bettinger, chief financial officer of SME maker LAM Research, confirmed the industry's focus on increasing sales to China when he said China's demand "has to be satisfied by somebody."[24] In other words, if the United States does not supply China, another country will.

However, this is not an excuse not to respect international agreements and laws. Every year 42 nations recommit to uphold the Wassenaar Arrangement on Export Controls for Conventional Arms and Dual-Use Goods and Technologies, which govern sensitive semiconductor trade, in addition to the national laws which promulgate this regime. When it comes to advanced SME, the relevant group which needs to coordinate is small and defined. The U.S. firms, Dutch ASML, and Japan's Nikon control about 90% of world's advanced SME.[25] The U.S. has worked with Netherlands, Japan, and other countries to stop sales to Chinese military actors. The cost of this coordination is minor compared to the benefits of security.

In this pursuit of short-term sales and profit, the aforementioned American SME makers are naïve. For example, two decades ago Massachusetts-based American Superconductor (AMSC) was the world leader in software for wind turbines. It forged a close collaboration with a Chinese partner and enjoyed skyrocketing sales for a short time. Then in 2011, it discovered its software was being stolen by the Chinese partner. It complained publicly. Its Chinese contracts were abruptly cancelled, and the Chinese company refused to honor its debts to AMSC. AMSC laid off 600 people and was forced to pivot into different businesses. AMSC CEO Dan McGahn explained the Chinese partner's actions to CNN: "Their strategy was to kill us."[26]

Export Controls, When Implemented, Keep Sensitive Technology Out of Enemy Hands

SME makers' soaring sales and profits underscore that export controls are not working effectively and, like the fox guarding the hen house, that those companies do not care where they sell as long as they are making a profit. "As long as the ducks are quacking, [semiconductor and SME makers] are generally not concerned where the end market resides," explained one financial analyst last year.[27]

Unlike semiconductor firms in democratic nations which must uphold WTO rules, norms of market competition, and financial disclosures, China's strategy to seize control of the global semiconductor industry relies on illegal support from the government, a flaunting of WTO rules, and abuse, if not avoidance, of transparency. In "Moore's Law Under Attack: The Impact of China's Policies on Global Semiconductor Innovation," Stephen Ezell observes:

> *"The Chinese government has become a minority or majority shareholder in most medium- and large-sized semiconductor enterprises in China... Each sale reduces the pace of global semiconductor innovation by taking market share and revenue away from more-innovative non-Chinese firms."*[28]

Ezell estimates that in the absence of "Chinese innovation mercantilist policies" there would be more than 5,000 additional U.S. patents in the semiconductor industry annually than there are now.[29]

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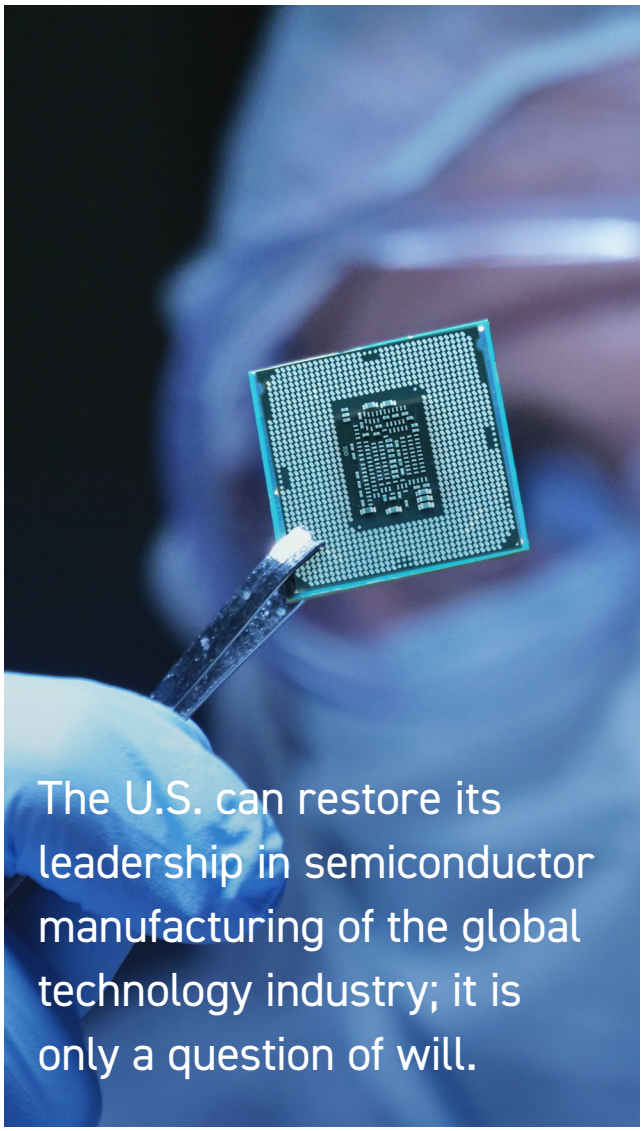
The collusion between China's state-sponsored companies and its military compelled the U.S. Department of Commerce to add more than 300 Chinese companies to the U.S. Entity List, the federal export blacklist. About one-third of these designations are Huawei and its family of companies. Semiconductor Manufacturing International (SMIC), China's largest semiconductor maker was designated as a Military End User in December over "evidence of activities between SMIC and entities of concern in the Chinese military industrial complex."[30] Among the more than 100 Chinese fabs, reports indicate that ChanXin Memory Technologies (CXMT) and Yangtze Memory Technologies Co. (YMTC), among others, also have ties to China's military, but these fabs have yet to be restricted. This reflects a reluctance to implement export controls on certain entities because they are perceived as important to U.S. firms, despite the threat they pose to Americans' security and the fact that trade with them violates U.S. and international law.[31]

CONCLUSION

This report briefly outlined critical issues in U.S. semiconductor leadership at home and abroad. While the U.S. is preeminent in chip design, this advantage is being whittled away by the decline of advanced manufacturing, a vital component of the semiconductor industry. U.S. policy, however well-intentioned, is falling short of what is required to stand up an American-owned, advanced chip manufacturing capability in the U.S. While financial incentives are important, they are not sufficient to strengthen U.S. leadership in chip manufacturing. China will always be able to outspend the U.S., and it is unlikely to change its anticompetitive practices. The U.S. needs durable semiconductor policy to harness the resources of the U.S. government, consumers, defense community, and the U.S. research establishment to create an economic environment that favors American companies to invest in U.S.-based manufacturing over the long-term, 20 years or more.

The U.S. must also curtail the activities that contribute to the growth of China's techno-nationalistic semiconductor industry, notably by enforcing existing rules that restrict the sales of semiconductor inputs to military end users and uses. Moreover, the U.S. should demonstrate leadership by coordinating more closely with like-minded nations on strategic trade control, not just to strengthen security, but to strengthen legitimate trade outside China and beyond its influence. The U.S. can restore its leadership in semiconductor manufacturing; it is only a question of will.



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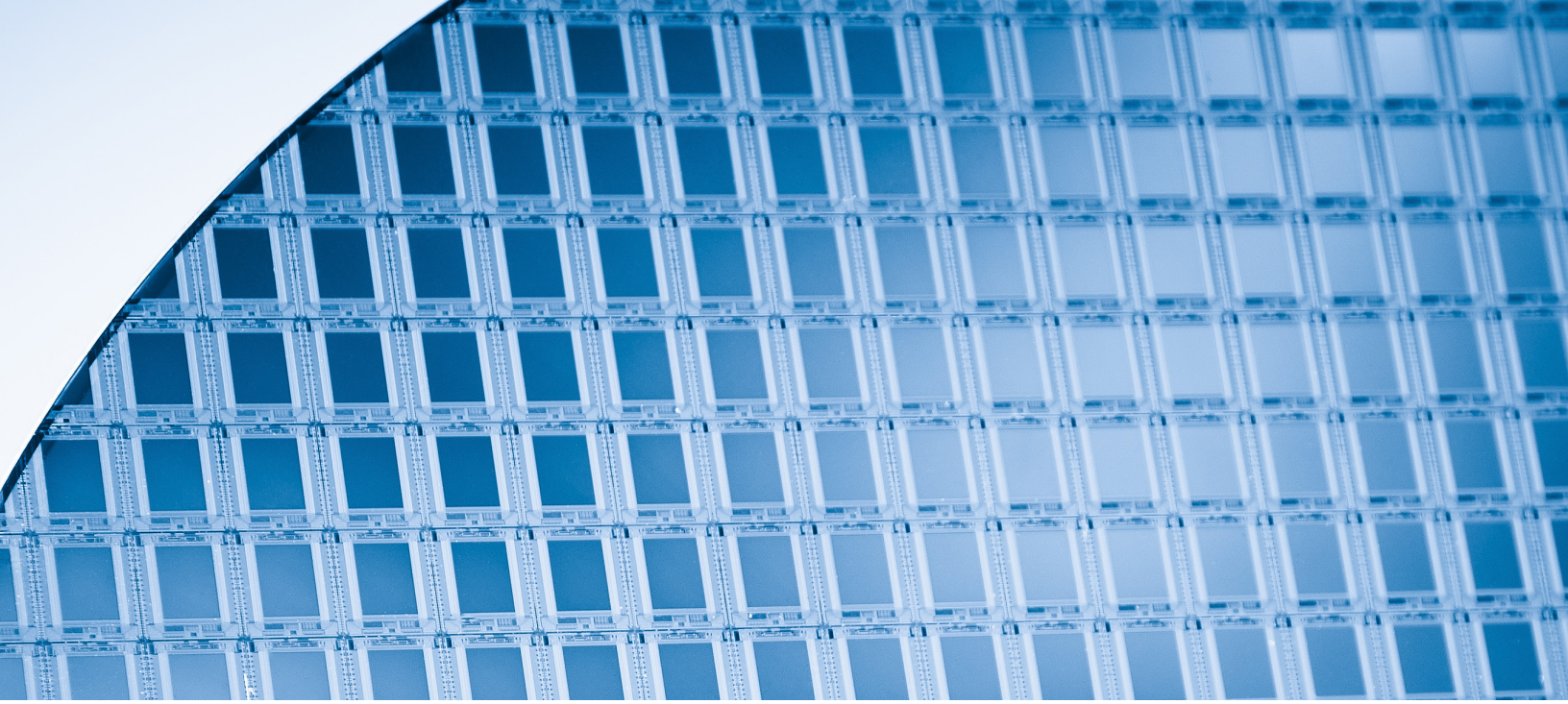

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