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A SEMICONDUCTOR STRATEGY FOR THE UNITED STATES

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EXECUTIVE SUMMARY

Semiconductors are the lifeblood of the digital economy. The semiconductor industry has moved to the foreground of political discourse both in the United States and other countries. The pushes from America's economic rivals and the challenges faced by its own domestic industry, coupled with supply chain shortages, prompted calls for the U.S. government to "do something" to support the industry. The most visible response is the CHIPS Act, which allocates $39 billion in government funding for domestic semiconductor manufacturing facilities and billions more for semiconductor research and development (R&D) and workforce programs.[1]

Many cite America's declining share of semiconductor manufacturing as the justification for such measures, with "unfair" subsidies by other countries as the root cause. Much of the debate has centered on evaluating what other countries are doing and matching their programs.

Of course, benchmarking is not a strategy. Voluntarily exiting global markets is not a strategy. Fixing short-term product shortages (in ways the industry cannot) is not a strategy. In fact, the argument that the industry needs funding to fix shortages is ringing hollow at the time of this writing, as demand for semiconductors for personal computers and smartphones drops.[2] This "downcycle" is not only good for consumers of these products, but it also shifts the policy debate to a more appropriate objective: How does the United States build a sustainable, market-centric semiconductor policy that leverages the strengths of the American financial, industry, and academic environments to collectively accelerate the industry — and not just for a few years, but in the decade to come? How does the United States ensure that global competition in semiconductors does not devolve to "zero-sum" negotiations around shifting manufacturing capacity, but rather that competition brings out the best in America: its ability to harness the world's best scientists and entrepreneurs to solve hard technical issues, build business around those solutions, and scale those solutions to the world?

In short, how does the United States build a government strategy that is open, global, long-term, committed, patient, and successful?

To do so, the policy must recognize that competitive advantages do not come from emulating the approaches of others (for which U.S. capabilities are not a fit) but rather from deepening the existing advantages of the U.S. position. Those U.S. advantages are deep and broad, and not to be underestimated.

I recommend that the government policy not solely focus on increasing America's manufacturing capacity, but rather holistically strengthen the entire semiconductor industry, enabling it to withstand supply shocks, drive technology transitions, and win future industry control points. Fundamental research and the commercialization of R&D breakthroughs are the ingredients for future success and will determine the global semiconductor manufacturing footprint as much as will subsidies.

I recommend using the CHIPS Act funding as equity capital in a government fund that can scale via industry and Wall Street co-investment to more than $300 billion and can reduce industry cost of capital by leveraging the Federal Reserve balance sheet. This fund would be self-replenishing, as it would harness U.S. innovation to fund projects that have market-level rates of return and generate significant returns for the government. These returns would then be reinvested in the next set of challenges the United States faces three, four, five, and 10 years from now.

As opposed to copying policies that place all hope on singular national champions, often saddling them with policy goals that may or may not be achievable, the equity fund would have tiers of financial and industrial partners — enabling funding to be provided to both small and large companies — and would operate at all levels of the value chain and across the ecosystem. I would urge this U.S. government fund not to compete with incentives from other countries, but would instead encourage it to partner with those willing to co-invest transparently in a growing, global, diverse, de-risked, and market-driven semiconductor industry. The resulting robust global supply chain, populated with more clusters and second supply sources across Europe and Asia, would only help the United States.

In concert with creating this fund, the United States could address other barriers to success. The country simply does not have enough engineers to build and ramp the manufacturing facilities in the plan — targeted and accelerated immigration must start now. Constructing and ramping fabrication plants (fabs) in the United States takes up to one year longer than it does in Asia. This self-inflicted slow pace, if not solved, will cost billions in lost opportunities and technology leadership for those companies building in the United States — thus countering any benefit from the billions financed by the government. The fund would have a policy arm that partners with federal and state governments to aggressively simplify permitting requirements and close timing gaps. Too few entrepreneurs, professors and venture capitalists are taking risks on future semiconductor technologies and applications — government funding can be a catalyst to reverse this trend, without giving the fund the mandate to pick winners.

Finally, to effectively execute a long-term, committed, and patient investment program, the United States needs a new hybrid government team that can evaluate, structure, and monitor investments at the intersection of semiconductors and finance. The government needs to rapidly recruit this team from the semiconductor, financial, and policy spheres and insulate the team (via legislative action) from short-term political considerations while maintaining the oversight capability of elected leaders. Empowered as the primary point of contact for the execution of the U.S. semiconductor strategy, this team would ensure speed, consistency, and clarity in its role as the decision-making authority. It would operate through different administrations, through industry cycles, through new generations of technology, and through changes in geopolitical priorities; and in doing so, it could continuously partner with the global industry to achieve a resilient, winning, global, and market-driven U.S. semiconductor industry.

INTRODUCTION AND SUMMARY OF POLICY RECOMMENDATIONS

A semiconductor, a substance that has specific electrical properties, serves as the foundational foundation for computers, servers, mobile phones and all other electronic devices. It is typically a solid chemical element or compound that conducts electricity under certain conditions but not others. A conductor is a substance that can conduct electricity and a diode is a substance that cannot conduct electricity. Semiconductors have properties that sit between the conductor and insulator. A diode, transistor and an integrated circuit (IC) are all made from semiconductors.[3]

The global semiconductor industry is critical to all advanced economies. The American semiconductor industry is also critical to the global leadership and economic well-being of the United States. The industry directly provides nearly 300,000 American jobs and indirectly supports more than 1 million jobs throughout the supply chain and development ecosystem.[4] It represents one of the country's leading export industries, with an annual value of roughly $50 billion. It invests nearly $40 billion annually in R&D. The semiconductor industry also helps solidify U.S. national security, ensconcing U.S. leadership in cybersecurity and defense, as the frontier of semiconductors enables the advancement of national security tools. And by ensuring that the United States can set the pace of global technology innovation, the semiconductor industry confers enormous strategic advantage in foreign and economic policy.[5]

However, as laid out below, there are acute challenges to America's leadership in semiconductors and there are imbalances in the U.S. supply chain that create geopolitical risk. U.S.-headquartered companies represent about 47% of global semiconductor sales, but the United States itself has only 10% of installed manufacturing capacity.

There has been tangible progress over the last few years regarding increasing investment in the U.S. industry. Intel has proposed investing $20 billion in (i.e. a newly developed location) semiconductor plants in Ohio.[6] The Taiwan Semiconductor Manufacturing Company (TSMC), the world's largest semiconductor manufacturer, is building a fabrication plant in Arizona.[7] Two other large manufacturers, Texas Instruments and GlobalFoundries, have announced plans to build new capacity in Texas.[8] But this is only a starting point for a new U.S. government strategy, not the endgame. U.S. government efforts need to accelerate this momentum and make it sustainable — not just in response to the current industry issues but for the decades to come.

THE PROBLEM STATEMENT

In the simplest terms, the U.S. semiconductor industry faces five problems:

- It is simply easier, faster, and cheaper to build scale front-end semiconductor manufacturing in other countries; for more than two decades, global and American companies have shifted more and more of their investment to Asia.
- The upstream (e.g. inputs into the manufacturing process) and downstream (e.g. circuit boards and other systems integrating semiconductors) industries supporting

semiconductor manufacturing are primarily located outside the United States, increasing the net delivered cost and time to market for the US-based end-to-end supply chain versus those in Asia.[9]

- The U.S. venture capital market spends negligible amounts of its capital (<1%) on new companies in the semiconductor industry and has never really been a major contributor to the leading-edge chip development business.[10] Many more semiconductor startups (albeit of widely varying quality) are established in China than in the United States.
- The United States' overwhelming spending advantage in pathfinding R&D across materials and the physical, chemical, and electrical sciences has dwindled. While federal funding of research has "only" dropped from an average of 1% of the gross domestic product (GDP) in the 1990s to about 0.7% in 2020, actual funding for nondefense general science (the category most applicable to semiconductors) rose by only $500 million or 5% over the last 10 years, a time frame when the industry doubled in size and U.S. GDP rose by 50%.[11]
- The U.S. semiconductor workforce, while of very high quality, is aging and is growing at a pace far too slow to ensure U.S. leadership in the future.

Geopolitical rivals have a playbook to build up their nations' semiconductor industries and have been working hard to execute it. Should the United States simply benchmark those efforts and match them, subsidy for subsidy and tax break for tax break? What would that entail? It would likely include establishing a top-down mandate for technology self-reliance, calling on the industry to build the whole supply chain in America, suppressing wages, pressuring global companies to invest in the United States or lose market access, making the government the (de facto) largest shareholder of unprofitable or politically connected semiconductor ventures, forcing government-subsidized companies to do all of their R&D or manufacturing inside the United States, pressuring customers to "buy American," and allowing subsidized firms to maintain negative margins or negative returns on capital through blank check subsidies.

This will not work. In an industry with a complex, integrated, highly efficient global supply chain that simultaneously feeds the American chip industry and buys its products, any proposed requirements for self-reliance and localization will shrink the U.S. share of the industry. In an industry where success requires constant reinvention, speed, and access to the best talent, money alone is insufficient. And in an economy where capital efficiency is the highest objective, money delivered solely as grants and subsidies will never be enough.

In addition, the political will to maintain subsidies across administrations and constantly changing congressional periods is certain to lapse. It always has in the past. That constant uncertainty would itself undermine any positive lasting effects of the subsidies, as companies would continually have to plan for the cessation of government handouts in the sector.

That is why the United States needs a national semiconductor policy that is strategic rather than politically convenient. Strategy is about what you do differently than your competitors; it requires building upon core competencies, not wishing you had other ones. We need a policy roadmap that other countries, both allies and rivals, simply cannot emulate. The semiconductor strategy I propose builds on the strengths of the United States, which include the following:

- A large and sophisticated set of capital providers with expertise across technologies in every stage of development;
- Wall Street's unparalleled financial engineering capabilities to harness capital efficiencies that other countries can only dream about;
- The venture capital industry's distinct ability to turn new technologies into profitable and scalable global business models;
- A body of laws and cases that provide the world's best investor protections and disclosure requirements;

- The greatest pool of experienced and innovative engineers, and a culture that is attractive to top global talent;
- Direct access to the world's largest purchasers of semiconductors and largest end markets for semiconductor-enabled products;
- Access to semiconductor company leadership teams with a best-in-class ability to sell and source globally;
- A deep and accomplished set of world-class research universities with experience in building pathways to commercialize breakthroughs; and
- Most importantly, a trusted relationship with the other countries and regions that also have semiconductor leadership and substantial end market demand.

A strategy that accelerates these strengths and leverages them to shore up weaknesses via market-driven investment — for example, by financing fab automation breakthroughs that reduce labor requirements — has a much greater chance of success. A strategy that delivers more than one-off industry benefits will help engineer a long future of renewed growth, innovation, as well as onshore manufacturing leadership.

BUILDING ON THE CHIPS ACT: A NEW NATIONAL SEMICONDUCTOR POLICY AND FUND FOR THE UNITED STATES

The centerpiece of our proposal allocates a portion of the CHIPS Act semiconductor funding as equity capital in a domestic government fund (hereafter referred to as the U.S. Semiconductor Fund or the Fund).[12] This equity, scaled via large amounts of industry and Wall Street co-investment, would drive $300 billion or more in total industry investment. The investment would become self-replenishing, harness U.S. innovation to develop projects with market-level rates of return, generate significant returns and ancillary tax income for the government, and reinforce the global semiconductor supply chain's need to have a substantial U.S. presence in both engineering and manufacturing. In other words, I envision the manufacturing incentives as well as a portion of the R&D funding in the CHIPS Act as permanent capital to be invested by experienced professionals on the basis of strategic and financial principles, not as a collection of subsidies and grants that companies would bid for via government lobbying. The Fund would pay ever-higher dividends for the nation and the semiconductor industry by growing through low-risk, high-return investments and thus increase impact over time.

Co-investment is the first objective of the Fund. The recently approved $52 billion is not a game changer in an industry that spends nearly $300 billion annually in R&D and Capital Expenditures (TSMC alone has committed to investing more than $100 billion over just the next three years, while Samsung will invest more than $150 billion in leading logic manufacturing capacity over 10 years).[13] Meeting America's goals in even a single part of the supply chain, such as leading-edge logic front-end manufacturing, means adding five or more fabs in the next 10 years — with each fab potentially requiring $20 billion in startup investment and then billions more in upgrades on a continuous basis. This one segment of the value chain alone could require far more than the current proposed funds — and great investment is required in other segments as well. Without balance across the segments, all industry participants will question from day one the sustainability of a U.S.-centric global manufacturing hub. Hence, the scale of any national semiconductor policy needs to match the scale of the industry's investment needs. That effort clearly cannot fall only on the shoulders of government, but it will if there is no integrated solution that attracts third-party capital to amplify the Fund.

Continuity and consistency is the second objective. Semiconductors are the ultimate long game. Few projects pay back in less than five years; the climb to leadership is hard and arduous; and once you reach the summit, you need to invest incredible amounts every year to stay there. In general, it takes more than 10 years to research, design, and launch a new front-end manufacturing process technology.[14]

In another example, it took Qualcomm — the pioneer in code division multiple access (CDMA) and one of the world's top 10 semiconductor companies — 10 years to commercialize its technology after founding.[15] A one-off injection of government capital can spark complementary co-investment in the next few years, but what about the checks that come due in 2025, 2030, and 2035? Under a new administration, a new Congress, and a new set of economic pressures, will there be political appetite for another large appropriations bill? The United States is a country that took nearly two decades to pass a true, higher spend infrastructure bill. A permanent capital fund, designed to be self-sustaining, insulates investment decisions from short-term political winds and shifting national priorities and appropriation environments.

Transparency and an equal playing field is the third objective. An investment fund with clear investment guidelines, decision-making rules, conflict-of-interest guardrails, and standard investor communication procedures would give both industry players and private co-investors greater assurance, thereby reducing their risk calculus and increasing their desire to invest. This means that decisions would need to be well out of the reach of politicians aiming for their states to have an ever-bigger piece of the pie; instead, U.S. capitalism, global semiconductor companies, and leading investors would need to drive the implementation and execution of the Fund. Companies would need to understand that if they put together a proposal that meets Fund guidelines and objectives, it will be accepted — rather than rejected in favor of a proposal by a competitor that hires better lobbyists. At the same time, politicians and voters would need to know how this capital is being put to work, that there is constant oversight of the Fund and governance structures, and that there are clear and regularly published measures on how well the Fund is meeting all the objectives.

The final objective is investment rigor, project due diligence, and execution accountability by enforcing the requirement for market-consistent returns. By bringing in third-party financial investors, the U.S. Semiconductor Fund would benefit from their due diligence and their demands for market-consistent rates of return; this would ensure that the investments are more likely to be successful and self-sustaining. And there is an added side benefit: such an effort would increase the pool of financiers who understand, invest in, and have a passion for semiconductor and related technologies. The leveraging of that knowledge and passion into new core technologies beyond semiconductors could have a multiplier effect.

To fulfill these objectives, a new semiconductor policy (hereafter referred to as the National Semiconductor Policy or the Policy) would need to structure the Fund to draw in and tap the country's top private equity and venture capital firms to de-risk government investment and provide an additional layer of both diligence and governance. To ensure investment into the broadest set of needed opportunities, not just "leading edge fabs," the Fund would have a tiered structure that enables smaller investors to write smaller checks to the small- and medium-sized businesses that support the overall semiconductor supply chain and ecosystem. To efficiently provide seed capital to the widest possible set of "new ideas and new technologies," the Fund would leverage existing tools like the Small Business Administration's Small Business Investment Companies (SBICs) to broaden reach to qualifying researchers and entrepreneurs. To protect government investment, the Fund would have a capital allocation approach that puts government investment "at the top of the capital stack." Finally, to spur nationwide investment into diverse and innovative foundational research, the Fund would invest direct government research funds into a network of labs and universities that can drive fundamental research across all technologies needed to drive future industry transitions, from materials to software.

Money, even if smartly allocated and well spent, is not enough to supercharge the American semiconductor industry. The industry needs to recruit more talent, from top Ph.D.s to tradespeople specializing in fab construction. Targeted interventions in immigration policy are needed to allow skilled manufacturing and R&D personnel who can help to build up these fabs and R&D facilities, and incentives are needed to ensure that many more U.S.-trained graduates with semiconductor-relevant doctorates remain in the United States after their study ends. A coordinated push to streamline the permitting and approval processes for new constructions and expansions across jurisdictions and agencies is also needed; this could cut in half the time from initial inquiry to installed semiconductor tools on the fab floor.

The United States also needs to market this effort via encouraging American talent to study the hard sciences that underpin semiconductor success (such as electrical engineering, mechanical engineering, optical engineering, and materials science). Essentially, the United States needs to create a series of holistic incentives and policies, so that the capital invested in the U.S. Semiconductor Fund goes much further and becomes an intergenerational, transformative industry road map.

The new Policy would also need to reimagine the United States' technology collaboration with its allies. It is economically infeasible and operationally impossible for the United States to build and maintain a top-class, end-to-end domestic supply chain that provides every input for every chip consumed by American businesses and consumers. Even a successful U.S. semiconductor industry will have to rely on a diverse and broad set of imported products and technologies from a wide range of countries. Therefore, diversifying and strengthening the U.S. supply chain can only be achieved when like-minded countries strengthen their own domestic industries, diversify their supply chains internationally, and partner deeply with the American semiconductor ecosystem. To drive such actions by global partners, the Policy's investments and the associated messaging need to center on innovation, new applications and new markets, rather than solely on risk reduction.

The Policy needs to provide equal incentives to, and a level playing field for, American and non-American semiconductor companies; it should invite co-investment and "club deals" with semiconductor funds driven by U.S. global allies. It also should encourage the United States to offer reciprocal market access and customer prioritization, so that both the United States and its allies know neither party will be shortchanged in times of capacity constraints.

The Policy should also espouse the "global use" of technologies created in the United States. As many technology companies learned the hard way over the decades, proprietary technology that cannot be leveraged by global partners will eventually fail or be worked around. The United States cannot afford to make the same mistake, even if in the short term, it makes for a domestic political win.

This last point is controversial. Global collaboration combined with the global free use of technology has helped the American industry reach its current level of success. But such collaboration will be difficult to achieve in the future if companies believe that the intellectual property (IP) created from R&D in the United States will de facto be excluded from global use. Limiting which U.S.-based technologies can be exported or used by companies headquartered in our economic rivals has a negative impact on U.S.-based research investment by both local and global companies. The industries built on leading-edge semiconductors (mobile communications, cloud, autonomous driving, artificial intelligence, the metaverse, and more) are based on robust ecosystems that demonstrate network effects. Each additional participant strengthens the ecosystem for every other participant. The removal of a substantial number of (Chinese or other) participants from the American ecosystem weakens the ecosystem and decreases the ecosystem's attractiveness as an investment destination. As the removal of any participant reduces the ROI of all R&D spending across the entire American ecosystem, export controls need to be used in transparent, judicious ways. It is important to thoughtfully execute a U.S. export control strategy that is balanced with the highest possible return on investment for R&D performed in the United States.

These actions, in sum, will drive the industry and U.S. allies to view efforts related to the U.S. National Semiconductor Policy and the Fund as open, global, long-term, committed, and patient. Not only is this the positioning required for success, it is the positioning that U.S. economic rivals will have difficulty adopting due to the differences in their economic and financial systems.

Finally, along with this new strategy, I propose a new approach to implementation. Without an executable plan, the U.S. Semiconductor Fund and the corresponding investment and policy strategy would undoubtedly fail through either negative returns or a lack of focused coordination. There are many ways this could happen: if responsibility for the National Semiconductor Policy is spread across multiple agencies and teams; if there is no centralized decision-making; if Policy objectives are fuzzy and can be manipulated for political gain; if there is no continuity of investment because the decisionmakers keep changing; if investment decisions are constantly being shifted by short-term legislative horse trading; if investment managers change every time there is a new administration or the control of Congress changes; and if investment decisions are made by teams lacking industry expertise. Even if just one of these instances were to become a reality, it is hard to envision the Fund being successful.

How can the United States ensure that a good strategy is not undone by poor execution? First, I propose that the U.S. government appoint and empower a single organization to be the point of contact for the semiconductor and financial industries; the organization would coordinate and orchestrate semiconductor policy across all the relevant government agencies. Second, I propose that the government model this organization — comprised of financial, industry, and policy experts — on the successful Overseas Private Investment Corporation (OPIC). OPIC leveraged market-based investment programs, permanent investment teams, a transparent set of investment guidelines, and impactful and rigorous government oversight. It persisted through multiple administrations, invested at scale, returned capital to taxpayers, and effectively took on both private sector and public sector roles.

The remainder of this report provides further details on the Policy and the Fund.

SETTING THE BACKGROUND

Building a more robust semiconductor industry via government policy will not be easy.

Spending money alone is not enough to dramatically change the semiconductor industry nor its global manufacturing footprint. China has been funding domestic semiconductor projects at a rate far greater than CHIPS envisions. Yet in the eight years since the launch of China's effort to boost its semiconductor industry (the so-called "Guideline for the Promotion of the Development of the National Integrated Circuit Industry"[16] and the complementary "Big Fund," a vehicle for funneling capital to its domestic chip industry), Chinese policy has not delivered a major shift in semiconductor market share, product leadership, or manufacturing footprint. For every successful government investment, there are far more failures, and the Chinese government has detained or is investigating many of the fund managers and recipients of government investment vehicles.[17] There is little evidence that the policy attracted substantial foreign talent or capital. In the five years prior to the policy launch, four major foreign manufacturers built greenfield fabs in China; since the launch of the policy, only one major global semiconductor company broke ground on a greenfield fab – at technologies three generations behind the leading edge.[18] Despite major investments, the share of chips supplied by China-based fabs to China-based customers increased only slightly between 2011 and 2021: from roughly 13% to around 17%. China-based semiconductor production still represents much less than 5% of the global total.[19]

The challenges to any country's industry are complex and intertwined.

SEMICONDUCTORS: A HIGHLY DIVERSE, MULTI-ECOSYSTEM GLOBAL INDUSTRY

The manufacturing chain for any given semiconductor is extraordinarily complex and relies on up to 300 different inputs, including raw silicon, commodity chemicals, specialty chemicals, and bulk gases. All of these inputs are processed and analyzed by upwards of 50 different types of processing and testing tools (see below for the taxonomy of the industry value chain). Those tools and materials are sourced from around the world and are typically highly engineered. Further, most equipment used in semiconductor manufacturing, such as lithography and metrology machines, rely on complex supply chains that are also highly optimized and incorporate hundreds of different companies that deliver modules, lasers, mechatronics, control chips, optics, power supplies, and more. Finally, economies of scale and learning efficiencies have consolidated the industry, leading to a high concentration of market share being held by one company at each level of the value chain.

The installed base of tools and equipment within a semiconductor factory today represents the cumulation of hundreds of thousands of person-years of R&D development. The manufacturing process that integrates these tools into a single manufacturing chain could represent hundreds of thousands more. Each company contributing to that ecosystem is taking action based on market opportunities, engineering feasibility, and financial returns, not government objectives.[20]

In addition, different segments comprise a different set of companies, capabilities, key success factors, technological hurdles, and capital needs.

INDUSTRY VALUE CHAIN LAYERS

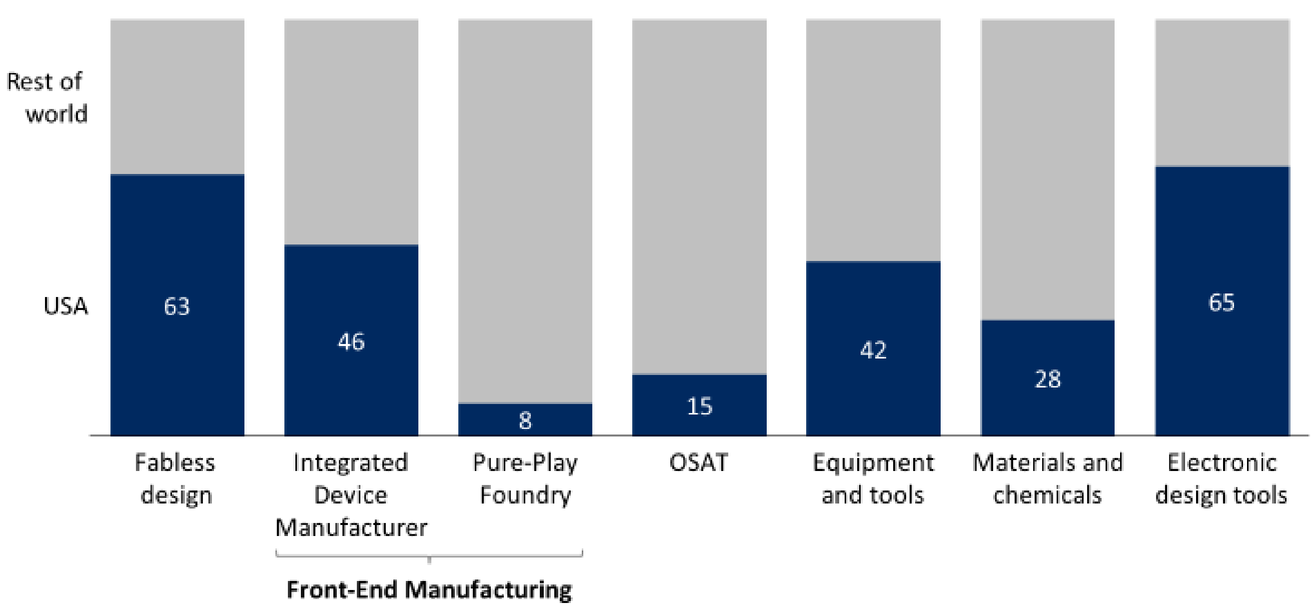
The following is a simplified summary of the semiconductor value chain and its seven key layers:

1. *Manufacturing process technology* — the expertise and IP that enables the manufacturing capacity.
2. *Fabless design* — the design of complete semiconductors, relying on third-party outsourced manufacturers to fabricate them.
3. *Front-end manufacturing* — the large-scale fabrication of wafers.
4. *Outsourced assembly and testing (OSAT)* — the dicing of the manufactured wafers, testing of the chips, and packaging of the chips so that they can be further integrated into an electronic system.
5. *Equipment and tools* — the large machines that process and test the wafers.
6. *Materials and chemicals* — the highly engineered raw materials that make up the physical structure of the final semiconductor and/or are used in the manufacturing process.
7. *Electronic design tools* — the software packages that help companies design chips and prepares the physical layout of transistors such that the front-end manufacturing facilities can physically make the chips.

In examining the challenges to the U.S. industry, it is helpful to know the rough global market share of U.S.-headquartered companies in each layer of the value chain.

FIGURE 1

U.S. relative market share by value chain layers



Source: McKinsey & Company[21]

Likewise, it is helpful to narrow the focus to high-level industry segments, as the vast number of product types can be confusing. The dozens of semiconductor product categories can be grouped into the following major segments:

- *Leading-edge logic* — high-end central processing units (CPUs) and graphics processing units (GPUs) designed to power the most advanced phones, personal computers, and servers.
- *Lagging-end logic* — lower capability, less expensive processing units designed for applications with lower requirements (consumer electronics, large household machines, automotive sector).
- *Memory* — semiconductors designed to hold data and usually made with the most leading-edge processes.
- *Analog and power* — specialty semiconductors for power management, radio transmission, wireline transmission, and other niche applications.
- *Discrete* — nonintegrated chips, such as resistors, capacitors, and diodes.
- *Optoelectronic* — semiconductors designed to handle both electrical currents and light.
- *Photonic* — components for creating, manipulating, or detecting light, such as laser diodes, light-emitting diodes, and solar and photovoltaic cells.

"BEYOND THE CHIP" ECOSYSTEM: AS IMPORTANT FOR SUCCESS AS THE SEMICONDUCTOR PRODUCT ITSELF

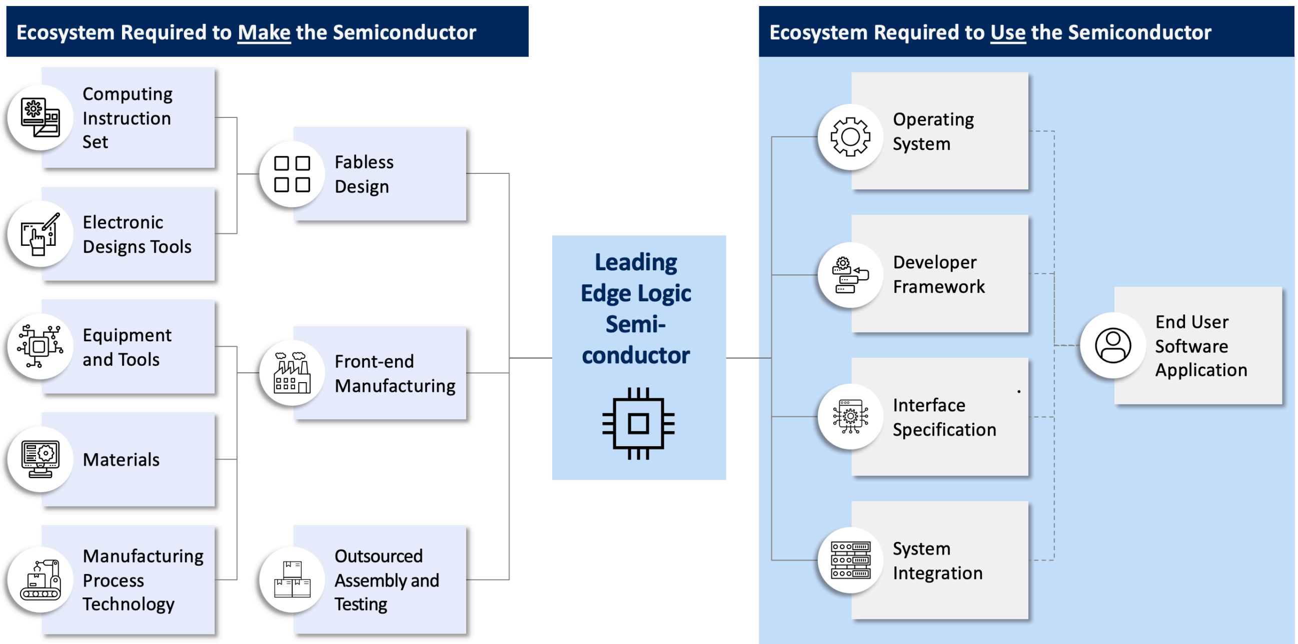
A healthy semiconductor industry requires delivering far more than just physical chips. The larger ecosystem that turns a chip into an end-user application is essential to semiconductor success. System-level technologies such as operating systems, development frameworks, application software, as well as physical and virtual interface standards, define how a chip becomes a usable product in the hands of an end consumer. These system-level technologies create 'control points' whereby companies or consortia can exert influence on the end-to-end supply chain. Semiconductor vendors that individually, or via partners, define control points improve their product competitiveness, increase switching costs for competitors, and enable global scale. Therefore, leading-edge logic semiconductor vendors such as Intel, NVIDIA and Qualcomm increasingly define, deliver and package system-level technologies as part of their semiconductor offerings. They are some of the largest employers of software engineers in the United States and employ more software engineers than they do hardware engineers.[22]

In parallel to this business model expansion by semiconductor vendors, major consumers of semiconductors, such as mobile phone makers, PC vendors, and cloud service companies, have entered or will enter the fabless design segment of the semiconductor industry. These moves are blurring the traditional differences between the "providers" and the "users" of semiconductor technology — there is more and more overlap.

The global technology industry is always in a process of transitioning to new end-to-end capabilities, often on multiple vectors at once (for example, the industry is transitioning currently from 4G to 5G technologies, from on-premise to cloud computing, and from standard to artificial intelligence workloads in high performance computing systems). Each of these transitions require new system-level technologies, creating new control points for semiconductor vendors to win or to lose. Maintaining American leadership across these control points from generation to generation requires the entire ecosystem that defines, develops and scales technology transitions to be as strong as possible. Strengthening the ecosystem requires coordinating fundamental research to define the end-to-end system-level roadmap, accelerating that roadmap into commercial production, and engaging downstream "beyond the chip" industries to use the system-level technologies espoused by the American semiconductor industry; even if major participants in those downstream industries are located within the borders of America's economic rivals.

FIGURE 2

Summary of "beyond the chip" ecosystem required to make leading-edge logic semiconductors successful



ISSUES TO ADDRESS AND PITFALLS TO AVOID IN GOVERNMENT POLICY

Beyond industry complexity, other difficult issues to deal with include the following:

- **There is ample private funding available for many industry endeavors, but it is not necessarily aligned with a national strategy.** The industry in the United States does not, in general, have a funding problem. In fact, U.S. semiconductor companies currently have strong industry fundamentals and high profit margins. U.S.-headquartered semiconductor companies invest heavily already, roughly $40 billion dollars in R&D and $35 billion in Capex per year. In the latest annual reporting period, the ten largest U.S.-headquartered semiconductor companies had over $110 billion in cash and generated over $40 billion in cash.[23] There is also a mature and efficient private equity, growth equity, and venture capital industry that can adequately fund any commercial efforts with market-level returns on investment (ROIs).

  It makes little sense for the government to invest in areas where there is alternative private financing. Yet, while private financing optimizes outcomes for individual companies, it is failing to close industry-level or country-level gaps that an individual company is unwilling to close by itself. For instance, since private capital companies can generally make higher ROIs by scaling U.S.-developed semiconductor innovations in other countries, they have been doing so over the last two decades.

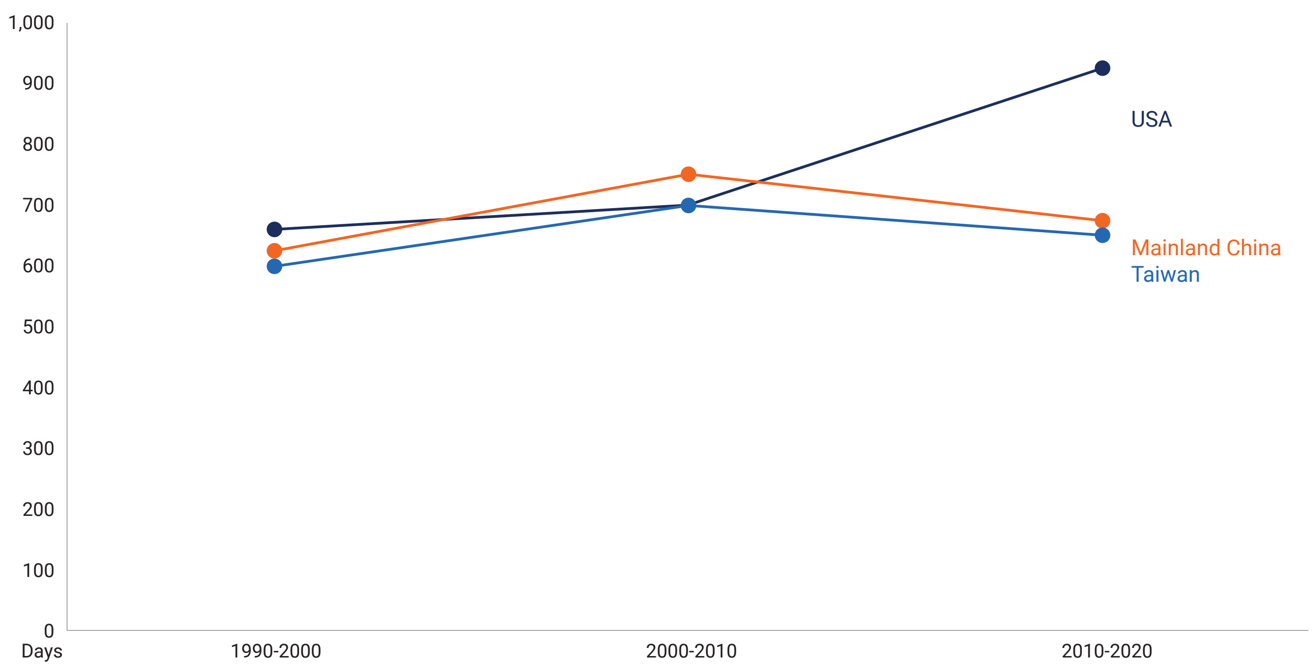
- **Publicly driven research efforts and consortia have less and less impact over time.** Over the lifespan of the industry, governments and government-related industry groups (for example, the Interuniversity Microelectronics Centre, Sematech, and ITRS) have attempted many times to establish common industry road maps. However, these industry groups' efforts have become less relevant to technology advancement than the individual efforts of major manufacturers who coordinate their suppliers and customers according to a privately driven road map.

- **The U.S. industry has big challenges beyond capital.** Even with equivalent input costs, U.S.-based manufacturing will likely end up with higher finished product costs than their Asian competitors. Too often, U.S.-based facilities lag behind Asian-based facilities in speed and efficiency (in launch, in ramp to scale, and in continuing operations) due to more stringent regulatory regimes, Asian governments' long experience in "making manufacturing easier," and the outstanding manufacturing culture demonstrated by Asian competitors.[24] The United States, at both the policy and company levels, needs to accelerate every part of the end-to-end manufacturing approach and pursue innovations (e.g., via automation) to overcome inherent disadvantages to U.S.-based manufacturing. The government can help most readily in areas such as permitting/regulatory approvals and industrial site setup (e.g., clearing land, delivering gas and water lines, and constructing access roads). These efforts can make a real difference in the return on investment to manufacturing investment. Studies show that over the last 20 years, it has taken about 25% longer to build fabs in the United States versus in South Korea or Japan. The United States is doing little, if anything, to increase the speed, while Asian countries are doing everything possible to accelerate it. In fact, the speed has been decreasing in the United States; the average U.S.-based semiconductor facility took 38% longer to construct in the years 2010-2020 versus 1990-2000.[25] For leading-edge semiconductors, a nine-to-12 months head start is of enormous financial and strategic value; a more slowly built U.S. facility is a much less competitive U.S. facility.

  Another problem is that the United States has a very talented but too small, aging workforce. Roughly doubling the U.S. semiconductor manufacturing base and R&D capacity in the next decade would require tens or even hundreds of thousands of highly skilled, highly trained (and highly sought-after globally) engineering talents to join the industry. A foreign company looking at investing in the U.S. semiconductor industry today may doubt that the United States can provide such talent and would scale back their aspirations accordingly.

FIGURE 3

Comparison of the time from construction start to production



Source: World Fab Watch[26]

- **The United States is competing with a rising bar, as other countries execute their own semiconductor strategies.** Other countries also aiming to scale their next-generation semiconductor manufacturing capacity are offering lower wages, few labor protections, less stringent environmental review processes, and looser subsidy rules. Particularly notable, Chinese policies entice both American and third-party country semiconductor suppliers to invest in an emerging Chinese ecosystem. Many U.S., European, South Korean, and Taiwanese companies (and American-trained engineers) will continue to take up China's offers because of financial and market share reasons. U.S. policy may slow but will not stop this trend — companies and engineers will not respond well to messages such as "do not serve the Chinese market" or "turn down a big pay package to work in Shanghai." U.S. policy will need to make investing and working in the United States a more attractive proposition.

  This means accelerating innovation, making it easier and cheaper to get things built in America, and burnishing the United States' reputation for transparency, IP protection, and rule of law. Aptly playing to America's strengths and creating a favorable and competitive ecosystem at home are going to be far more successful approaches than blunt nationalist or protectionist policies.

- **Previous U.S. industrial policies have repeatedly failed to avoid common pitfalls.**

  The United States needs to avoid common missteps that have plagued industrial policy. These include the following:

  - *"Protect" over "promote" thinking* — protectionist and/or punitive policy stances advanced by well-intentioned U.S. stakeholders without the sufficient involvement of U.S. industry champions and executives.
  - *Half-hearted investments* — limited scale investments in an extremely capital-intensive industry, with a focus on current not future technologies cannot lead to transformation impact.
  - *Blunt subsidies and industry handouts* — subsidy-led policies that lead to import duties on U.S. chip exports, which hurt, rather than help the industry. Subsidy-led policies are not sustainable.
  - *Ineffective bureaucratic team structures and decision-making processes* — those that do not reflect industry expertise and do not move at the pace of the industry.

A TOP 10 OBJECTIVES LIST TO DEFINE SUCCESS

A new U.S. National Semiconductor Policy must have a tangible impact, so I propose these top 10 objectives for the nation's industry push — a "North Star" to drive concrete policies:

1. The global and American semiconductor industries are financially healthy and continue to drive global innovation, with positive annual revenue growth across industry cycles with stable or increasing R&D intensity (R&D spending as a % of sales revenue).

2. The United States maintains or improves its global semiconductor revenue share (47% today) and fabless revenue share (about 60%), while increasing its share of global semiconductor manufacturing from about 10% today to about 15% within 5-10 years, with a goal of reaching about 20% within 10-15 years.

3. The top-five leading-edge semiconductor manufacturers (Intel, Samsung, TSMC, Hynix, and Micron) all have or are planning scale-level, best-in-class fabs in the United States, each with the capability to ramp leading-edge nodes as the alpha or beta ramp site.

4. The supply chain for these U.S.-based manufacturing facilities (including materials, chemicals, and equipment) is resilient, with capacity via domestic suppliers, foreign companies manufacturing in the United States, or U.S. company-owned assets in low-risk foreign locations. In addition, the overall global semiconductor industry has no single point of failure with global leaders (e.g., leading-edge foundry providers) possessing distributed networks to provide backup capacity even during unexpected, disruptive geopolitical or economic events.

5. Each major, non-U.S. player in the global ecosystem (e.g., TSMC, Infineon, ASML, Nikon, Tokyo Electron, Merck, ARM, MediaTek, and Hynix) and their much broader set of ecosystem partners are focusing their road maps on the requirements of the U.S. semiconductor market and prioritizing U.S. customers (i.e., the United States is their "must-win" market).

6. Across emerging semiconductor segments and the fundamental technologies (e.g., new materials, neuromorphic computing) underlying those segments, the United States has a clear leadership position in research, development, and commercialization. This means that American companies, universities, and labs are spending more, developing more breakthroughs, and retaining more of the absolute best talent in all key semiconductor research areas (e.g., the creation of new semiconductor elements, transistor structures, lithography, wide bandgap materials, silicon photonics, and quantum computing).

7. U.S. companies (both in semiconductors and in downstream industries) lead the global industry in delivering the critical system-level technologies that define the control points for technology transitions in semiconductors (e.g. mobile, PC and cloud operating systems; machine learning frameworks; software developer tools, interface standards, communication standards, etc.).

8. U.S. investors double the amount of investment in emerging semiconductor companies (e.g., startups, spinouts, business model expansion from the system or software industries), with efforts spread across all key emerging segments.

9. The U.S. industry doubles the annual number of new Ph.D. hires and increases its U.S. job base by more than 25% while increasing the participation and representation of underrepresented groups in the industry.
10. The U.S. industry establishes at least three new semiconductor research clusters that have the scale and expertise to thrive long term. This can create a network effect that goes well beyond the semiconductor industry, reducing regional economic disparities and developing economic multipliers.

I recognize no set of objectives is perfect; industry experts could debate and refine these objectives ad infinitum, leading eventually to a different list. The key idea is the Policy (1) has defined quantitative objectives to help measure progress, rather than ambiguous objectives such as “supply chain security” that have no concrete meaning; (2) is aggressive, because the United States should be playing to win; and (3) comprises a holistic set of objectives that makes the entire global industry stronger, rather than objectives focusing on a single topic like leading-edge fabs.

A DURABLE APPROACH TO FINANCING THE TOP 10 OBJECTIVES

So, how can the U.S. government achieve the best results? What type of government funding program would avoid waste, loss of capital, and negative geopolitical implications? A good approach would be to think about the ecosystem more broadly, focus resources on the big problems, encourage other "smart capital" to co-invest, be open and global, and operate with transparency.

KEY INVESTMENT CRITERIA FOR ACHIEVING SUCCESS

The United States should develop clear investment criteria that allocate public and private capital dollars to the initiatives that will have the most impact and that can organically compound success in perpetuity. These criteria include the following:

- Advancing America's interest in the semiconductor industry (the top 10 objectives) while returning taxpayer money and making a return on that money;
- Investing in areas that are intriguing to private capital and companies but for which there are limited lead investors;
- Taking a full ecosystem view by building a healthy, durable, and secure supply chain supported by a robust software and system architecture ecosystem;
- Supporting both American companies and foreign companies critical to the U.S. ecosystem in a cohesive manner that promotes the unavoidable global interconnectedness of the industry; and
- Generating co-investment from third-party investors to effectively cap the overall government investment required, de-risk these efforts, and simultaneously harness American capitalistic ingenuity and government dollars to gain the massive scale necessary.

SUPPORTING BOTH AMERICAN AND FOREIGN COMPANIES

As discussed previously, the goal of the proposed funding program is to leverage global industry investment to sustain American competitiveness in the semiconductor industry. In the current fraught geopolitical environment, the external positioning of this effort would be vital. The United States should avoid positioning this promotion effort as a competitive response to, or retaliation for, the industry-building efforts of other countries. The proposed U.S. effort is about building a strong American ecosystem that can provide innovation and growth for the technology industry around the world. If foreign companies meet the United States' investment criteria, allow full due diligence, and operate with the required transparency, they should be allowed to participate no matter where their headquarters are located. American companies would have little basis to complain in taking this level-playing-field approach; since 2000, U.S. companies have located 85% of their greenfield fab construction outside the United States, taking advantage of the incentives and favorable operating environment in those locales.[27]

A BROAD SET OF OPPORTUNITIES ALL REQUIRING INVESTMENT

Logically, with a complex value chain, many types of investment are needed to ensure success. Each type carries a different level of return potential as well as different technical, execution, and other business risks. The Fund should look for the following opportunities:

- *Strategic efficiency and capital stack investments* — Level the playing field for American manufacturers competing with overseas companies through fundamentally lower cost capital and/or labor.
- *Optimization and automation investments* — Invest in the companies and technologies that automate manufacturing and reduce labor intensity and cost disadvantages.
- *Scale-up and commercialization investments* — Accelerate the link between advanced, early-stage research and the companies and investors that could commercialize the resulting breakthroughs.
- *Business expansion or new market entry investments* – Support semiconductor companies to make disciplined and well-managed efforts to enter adjacent semiconductor markets or downstream (e.g. software or system-level technologies) integration; and partner with system companies as they invest to enter the semiconductor design market specific to their product offering (e.g. automobile manufacturers designing autonomous driving logic semiconductors)
- *Innovative foundational research* — Provide funding for truly advanced research efforts that benefit the whole industry, that are beyond the investment time frame of most companies, or that one single individual company would not have an incentive to invest in, as well as for long-shot but strategically critical projects to remove industry single point of failures.
- *Government procurement accelerator programs* — Build concrete links (e.g., seed capital programs) between U.S.-government-driven infrastructure (e.g., the space program) and emerging U.S. semiconductor innovations and companies.
- *Future industry workforce foundations* — Strengthen the semiconductor-focused technical workforce (e.g., physics Ph.D.'s) by investing in research programs at U.S. universities, providing incentives for U.S. and foreign-born talent to attend these programs, and encouraging the graduates to remain in the United States and remain in the semiconductors field after graduation.

THE INVESTMENT OPPORTUNITIES AND CORRESPONDING PROGRAMS

I summarize here the various proposed investment programs reviewed in this section.

Generating co-investment from partners: Turning $52 billion into $200-250 billion-plus

America absolutely needs more than $52 billion to meet the proposed top 10 objectives.[28] The Policy leaders need to figure out how to use third-party capital to sustainably grow the funding to $200-250 billion-plus, the amount necessary to make a truly significant and durable impact.

The approach to partnering with third-party investors must be flexible, depending on the type of investment to be made, the time frame, and the underlying business being financed. The approach needs to meet the return and risk requirements of sophisticated investors or the government fund will bear all the risk. Over the past decade, the U.S. government has successfully implemented and executed several financial structures that can be utilized to achieve this goal.

Co-investment by private investors and semiconductor companies will help stretch the $52 billion (provided by American taxpayers) to

FIGURE 4

Summary of proposed investment programs and capital allocation targets

	Government Provided Capital	Capital Allocation		Partners	Government Fund Component
		Government	Private Sector		
Foundational Research	Subsidies and Grants	~$9B	$10-20B	Enterprises Universities National Labs Venture Capital	***National Semiconductor Technology Center***
"Scale Up" and Commercialization	Venture Capital Funding	~$2B			***National Semiconductor Venture Capital Pool***
Strategic Efficiency, Capital Stack, Optimization and Efficiency	Subsidies, Preferred Equity and Debt via STARP and TALF	$39B	~$200-250B	Enterprises Private Equity Debt Lenders	***Partnership for Revitalizing American Semiconductor Manufacturing***

approximately $200-250 billion, enabling the U.S. semiconductor industry to gain enough capital, at the right cost, to drive change. Third-party capital will also provide a second layer of governance and human resources to ensure that these investments are a success. Likewise, over time, as government incentives help bring top-tier investment firms into the semiconductor sector, the firms' increased knowledge and sophistication around such a complex industry and set of technologies should lead to a more robust set of third-party capital providers for decades to come. Again, extending the investment multiplier well beyond the envisioned taxpayer capital makes this a self-sustaining, capitalistic solution that will build a more robust and thriving industry.

Attracting different types of investors to maximize capital

The U.S. financial system and the associated asset management industry are nearly as complex as the U.S. semiconductor industry. The key to raising the maximum amount of capital from third parties, at the right cost of capital, is to understand the different types of capital providers and their different return requirements and risk tolerances. The three main groups I propose focusing on are private equity, debt lenders, and venture capital. (Of course, the Fund can also work 1:1 with operating companies as co-investors, as there is no mandate that an investment must have a third-party source of capital.)

Private equity — $70 billion of additional capital

Private equity investors are logical partners for manufacturing capacity investment. These firms generally search for investment returns in the high teens, but with government support and the asset-heavy nature of the business, a sufficient number of firms might be willing to accept 14-16% gross returns to invest alongside industry. While this is below the targeted gross returns for many private equity funds, the lower risk profile and predictable returns could justify the lower returns, especially as private equity firms can partner with industry-leading companies.

The typical return on equity for a big semiconductor fabrication plant, a different financial metric, is in the high single digits. To close the gap, the government fund could invest in debt and/or preferred equity that is more senior in the capital structure; this would solve two big problems for private equity investors and the government: taxpayer risk and the cost of capital. First, U.S. taxpayers will far less likely to lose money by making third-party capital subordinate to taxpayers, as is the case with investments by the U.S. Development Finance Corporation (DFC). Second, investing in debt and/or preferred equity is lower risk and can involve a fair but lower cost of capital, enabling common equity invested by private equity funds and semiconductor companies to generate the higher returns demanded by their investors, who are mostly U.S. pensions, endowments, and high net worth individuals.

This similar structure was used during the financial crisis to recapitalize banks through the Troubled Asset Relief Program (TARP). Not only was TARP successful in recapitalizing some of the most challenged parts of the U.S. banking system and in flowing credit back into the economy, but taxpayers also made money. If the United States could combine the best of what worked with TARP and the DFC, it could create an entity with a track record of success modeled on public-private collaboration. To this end, I propose a new Semiconductor Technology Asset Revival Program (STARP), which when blended into the capital stack of a particular investment, would enable $70 billion of private equity capital to be economic and invested alongside STARP, but critically, on a subordinated basis to U.S. taxpayers.

Debt lenders — $120 billion of additional capital

A significant driver of ROIs is the considerable time it takes to construct a fab and the necessary capacity in the ecosystem to feed it. In addition, cost is a factor; the equipment for a fab plant is extremely expensive, especially leading-edge semiconductor equipment. The Fund could reduce the total capital cost of asset-heavy investments by leveraging a lending program like the Federal Reserve's Term Asset-Backed Securities Loan Facility (TALF), which was used in the administrations of both Barack Obama and Donald Trump to great success (TALF and TALF 2.0, respectively).[29] In this case, instead of the Federal Reserve lending money to purchasers of certain asset-backed securities, it would lend money to any qualified fund that made loans or leases to companies building new semiconductor plants in the United States. This new TALF-like facility, or a Term Asset Lending Facility (TALF 3.0), borrowers of TALF 3.0 provide low-cost loans for property and equipment investments. This program could attract massive amounts of low-cost capital, leveling the playing field for new fab construction in the United States with highly subsidized fab construction overseas. This effort would require the Fund to provide $5 billion in capital to the U.S. Treasury.

The Treasury would use this capital to "equitize" the Federal Reserve's TALF 3.0 13.3 Facility. With first lost capital from the Treasury and significant private equity capital in the form of subordinated, first loss common equity, TALF 3.0 could provide borrowers in the program 12.5-to-1 leverage, as was done for the many of the asset-backed security types in TALF 2.0 (some asset-back securities categories were leveraged even higher than this). With 12.5x leverage, and a guarantee from Treasury, the Federal Reserve could lend short- to medium-term capital at a 1.5% interest rate to qualified TALF 3.0 borrowers to create a compelling opportunity to invest in these borrowers' asset management products. The borrowers would raise additional capital, representing approximately one-twelfth of the total loans and leases made. Investors of the TALF 3.0 borrowers would, after accounting for asset management fees, likely receive returns in the low teens, with the semiconductor companies receiving medium-term financing at just 2.50%. As the fabs enter the construction phase, the TALF 3.0 equipment loans could be rolled into new, senior-term debt loans at the senior most part of the capital stack, matching the semiconductor companies and private equity's common equity investments into these massive projects.

The initial cash flow, after accounting for TALF 3.0 debt service and STARP returns, would go to pay back STARP. Depending on how high the returns of the new fab were, this payback could be achieved in seven to nine years. However, it is likely that the capital structure could be refinanced and STARP could be paid back from this refinancing much sooner than this time frame. Altogether, the Fund's $5 billion to Treasury could attract more than $10 billion in first lost investor debt capital that the Federal Reserve provides $110 billion of loans against through TALF 3.0 — thereby amounting to an additional $120 billion at the top of the capital structure. Obviously, more capital could be attracted if Treasury and the Federal Reserve were to deem a higher level of leverage appropriate, which they have in the past for mortgage-backed securities, for instance.

The Fund, STARP, and TALF — enabling a partnership for revitalizing American semiconductor manufacturing

The Fund, STARP, and TALF programs would be synergistic and thus need a common governance umbrella to ensure the best fit for investment opportunities. With increased government and third-party support, the United States would need a structure that validates investors and enterprises but, at the same time, allows the market to set valuation, structuring terms, and perform investment due diligence. To do so, the government would set the terms for receiving co-investment, based on a sliding scale of government support in relation to private sector support and on the amount of third-party private equity capital provided as a percentage of the total common equity pool for a project. The sliding scale would enable more government funding and greater leverage of TALF 3.0, as third-party capital increased.

This package would be collectively known as the Partnership for Revitalizing American Semiconductor Manufacturing (hereafter referred to as the Partnership). This Partnership would be the fundamental mechanism for managing the Fund's private equity and manufacturing capacity investments. Semiconductor companies and third-party investors would be welcome to bring any investment proposal to the Partnership. The proposal would be approved if it supports the semiconductor strategy goals, meets the governance terms, and has committed investor capital. Whenever a semiconductor company and private equity investor start to draw on the approved, initial government capital (i.e., invested in the project or joint venture), they would be legally bound to invest their proposed amount of capital, according to the Partnership.

Through the Partnership and the Fund, the U.S. government would become a minority equity investor at either the project or corporate level. After making the investment, the government's sole role would be to protect it — as is the role of any investor in any venture — by ensuring that the project meets the investment commitments made during the proposal negotiations. This financially driven governance role is preferable to a more nebulous and idiosyncratic governance role the U.S. government would have to play as a provider of "strings attached" grants or subsidies.

Research grants and venture capital — $10-20 billion of additional capital

Major industry players make limited investments in advanced research because the payoff time frame is so far in the future. Venture capitalists (VCs) have shifted their investments to asset-light/digital business models that can scale up and provide much higher returns much faster. In addition, with the cost to design just one semiconductor on a leading-edge process semiconductor exceeding $100 million, the cost of entry for new design companies is simply too high and uncertain for most VCs. As a result, semiconductors today account for less than 5% of U.S. investment in venture capital (as opposed to more than 20% of Chinese investment in venture capital in 2021).[30]

This is a problem. Startup companies provide benefits that established giants cannot: dynamism, technology experimentation, and a pathway for new talent into the industry.

The United States needs two separate approaches for stimulating venture capital. The first would be very early-stage investments and the second would be later-stage commercialization investments.

- *Very early-stage/"lab to world" tech transfer* — In this area, the government would want a broad set of investors looking at thousands or tens of thousands of ideas. But the government would not be able to micromanage individual research investments; it would need to create a matching grant program that engages a wide-ranging set of organizations, such as SBICs, to administer a simple grant application in return for a fee. Applicants would need to work for an accredited U.S. higher education institution, as is often the case with National Institutes of Health grants. As the potential for loss is higher, this would be a relatively small pool of investment.

- *Later-stage scale-up or commercialization investments* — I propose a government-led National Semiconductor Venture Capital Pool in which the Fund and private venture firms would be limited partner investors. Government-matching funds would have preference in the capital structure over third-party capital investors. In return, third-party investors would receive nearly all the upside (above and beyond a preferred return of about 5% to the Fund), as opposed to the standard venture capital 80/20 split. This setup would induce VCs to deploy much larger portions of their third-party capital funds in the semiconductor industry, as the VCs would gain additional upside potential from the government-invested dollars, thereby lowering the cost of capital in these riskier projects. The government investment team would have a simple veto right up front — before a VC spends significant time, money, and effort — but only to make sure that the potential investment meets the broad strategic parameters of the National Semiconductor Policy. VCs would then use their standard investment toolkit and governance approach to build winning companies and take them public, without government interference. This approach enhances the scale and scope of VC funding flowing into the industry and does not place the Fund in the role of picking winners.

- *Government Procurement Accelerator Programs (GPAP)* — The U.S. federal and state governments purchase billions of dollars of semiconductors (directly or indirectly) annually. While many programs are in place to promote the purchase of U.S.-sourced technologies, the complexity and fragmentation of these programs makes it difficult for all but the largest companies to identify and pursue opportunities. The United States needs to simplify the interface and process to expand the links between industry and government. All companies and programs supported by the Fund should be eligible for inclusion across all government procurement efforts related to semiconductors. The United States could also design a "matchmaking" mechanism that communicates all procurement opportunities to registered participants. Similar to the philosophy of the rest of the program, this matchmaking support would open to U.S.-headquartered companies *and* global companies that are making qualifying investments in the United States.

In addition to increasing the financing available for R&D activities, the United States should use tax credits to encourage more R&D investment. These credits should be extended on an even playing field to both U.S. and global companies investing in the United States.

Funding pure foundational research

The last investment focus of the Fund would be foundational research. In many ways, this is more important than the manufacturing investments. A semiconductor fab is the physical instantiation of R&D investments that were initiated up to a decade earlier. The United States cannot lead in manufacturing if it does not lead in early-stage research. The semiconductor industry (and all the industries that depend on semiconductor innovation) cannot grow if it cannot continuously identify, improve and industrialize new materials, new transistor architectures and manufacturing techniques that increase the performance and lower the cost of computing. As current materials and manufacturing techniques are hitting physical limits, we cannot assume that the industry will simply "figure it out". There is an immense amount of basic research that must be completed – much of which is not underway in the United States today.

In prioritizing pure research topics, the focus should be on end-to-end ecosystem leadership across technology transitions. In other words, the research themes should comprehend both "winning in transitions" and building technology leadership across system-level technologies: investing in the full spectrum of standards, system architecture, processor architecture, operating system and applications that enable future technologies to be launched. For example, the future move to quantum computing will require fundamental breakthroughs across transistor architecture, materials, design, manufacturing, supply chain; as well as entirely new approaches to software and system design. The research agenda needs to comprehend all of these components. It will be the holistic strength of the U.S. end-to-end ecosystem that ensures America's future leadership in semiconductors, not just the strength of the U.S. manufacturing base. Therefore, focusing research investment on an R&D pilot line for leading-edge semiconductor manufacturing is useful, but too narrow to be the sole focus of the research effort.

The government team, in conjunction with the Industry Advisory Council created by the CHIPS Act, needs to develop a comprehensive R&D approach, one that allocates funding at scale across a series of R&D themes required to meet the top 10 objectives, and generates co-investment from both private and public sectors sources of research capability.

A National Semiconductor Research Center would be the centerpiece of this advanced research effort. The research center would operate as (1) a steering committee to drive nationwide research programs; (2) a connector across government, research, and industry; (3) a designer of programs to encourage talented students to pursue advanced degrees in the disciplines critical for semiconductors; (4) an evaluator of America's competitiveness across different technology areas, and (5) the direct driver of research execution efforts on "moonshot" technology breakthroughs or government priority projects that would be untenable for private industry to finance. The Fraunhofer-Gesellschaft research organization in Germany is a compelling example to explore and potentially emulate as a model. This group comprises 76 affiliated institutes across Germany, employs nearly 30,000 researchers and is the biggest applied research organization in Europe.[31] The Institute's ability to self-finance 70% of its expenditures via contract work, royalties and other means demonstrates that government funding can be multiplied (in this case by 2.5x) through an effective industry engagement model.

In addition, the United States could accelerate the connection between the government and emerging technology providers via the GPAP program. This would allow the U.S. government to become a far more common alpha customer of new technologies, thereby de-risking the efforts of third-party investors. By sharing startup risk, the United States can vastly accelerate the flow of capital and innovation in this critical research area of the industry.

ACCELERATING DEPLOYMENT AND ACCUMULATING TALENT

FUTURE INDUSTRY WORKFORCE FOUNDATIONS: RECRUITING, TRAINING, AND TARGETED IMMIGRATION

The U.S. semiconductor workforce is strong and world-class; but as one would expect, it is concentrated in the areas where the United States has greater share, such as fabless design. However, for the country to achieve the proposed top 10 objectives over the next decade, it would need to launch 10 or more manufacturing facilities (in the leading-edge, lagging-edge, analog and power, memory segment, and front-end and assembly/testing areas). With a simplistic assumption that each facility would require 5,000 highly skilled employees, such an expansion in facilities would require 50,000 new workers.[32] And this is just workers for fabs to be built — the industry needs new researchers, architects, designers, validation, verification, and software engineers. The demand for new personnel could reach more than 100,000 highly trained employees in the next five years — a growth of 40%.[33] The need for new talent is increased by an aging workforce. Roughly 60% of semiconductor engineers in the United States are over 40 years old, representing a much higher proportion than in the software industry.[34]

With every major country in the world now aiming to build up its semiconductor industry, the United States is in a talent war. U.S. companies are, of course, working hard to recruit and train talent. However, their efforts are not enough. While hiring for commercial activities is best performed by labs, universities, and companies, the government should do more to increase the size of the pool and remove roadblocks to accessing it.

Forty percent of the semiconductor workforce in the United States is foreign-born; the country is great at attracting foreign talent.[35] But with the war for global talent accelerating, with everyone chasing the same limited supply, the U.S. needs to up its game. America needs to incentivize large-scale immigration of the top South Korean, Taiwanese, and Japanese semiconductor workers (and, of course, talent from other leading semiconductor countries). These workers are best positioned to accelerate and de-risk the investment of South Korean, Taiwanese, and Japanese companies in the United States. Second, these workers run the best fabs and OSAT facilities in the world; the experience and tacit knowledge they could bring to new U.S. efforts (and could impart to U.S. workers) would be invaluable.

Another type of talent will be urgently needed as multiple new fabs are built in the United States: specialized construction workers with specific talents required for high-end manufacturing facilities. Typically, up to 6,000 total workers are required for each greenfield fab construction.[36] The “cleanroom” in a fab is the most advanced building in the world and therefore requires specialized and experienced construction capabilities, including translating 3D models to physical spaces, making the world’s tightest welds, designing lethal gas protection systems, and inspecting airflow to sub-parts-per-million accuracy (and hundreds more). These skill sets are in short supply in the United States and will be in increasing demand. The gaps offer opportunities to generate high-quality blue-collar jobs that can later become advanced construction jobs (e.g., to design and build facilities for lithium batteries and hydrogen capture systems).

While the industry itself is making efforts to close these gaps, the National Semiconductor Policy can and should partner with the industry to accelerate the efforts. The United States needs to adopt a holistic set of bold initiatives to attract and grow more talent. These could include the following:

- *Employee training and development funds as side-by-side Fund investments* — The United States could ensure that each Fund investment includes a small amount of money, matched by financial and corporate investors, for training and recruitment efforts.
- *University research hiring programs* — The United States could ensure that university grant programs funded by the proposed National Semiconductor Research Center have explicit targets and money for bringing Ph.D. and postdoctoral talent into the program.
- *Targeted immigration relief programs* — The United States could remove the hard caps on H1-B visas for workers seeking to join semiconductor manufacturing and research programs. In particular, to attract talent from leading semiconductor manufacturing countries in Asia, the U.S. government could set up country-specific programs, leveraging the template set by the 10 existing country-specific programs setup for other purposes.[37]
- *Targeted attraction of global semiconductor talent* — The U.S. government, in collaboration with research universities and top companies, could identify the top several hundred to a thousand research personnel globally; co-develop incentive programs; and provide an expedited, low bureaucracy path for these personnel to take on academic or corporate research roles in the United States.

ACCELERATING THE INDUSTRY: STREAMLINING PERMITTING AND REGULATORY PROCESSES

As mentioned, the United States is one of the most expensive and slowest countries in which to build manufacturing facilities — issues that constrain investment in both leading-edge semiconductor fabrication facilities and the many smaller facilities that make the tools, gases, chemicals, and construction materials needed for giant cleanrooms. There are numerous underlying causes of these issues, and many of them bring great benefits (such as citizens' demand for clean air and water and the respect for private property rights) or are products of the United States' federalist system. It is too far a stretch to propose refashioning the national regulatory system in the pursuit of greater success for the semiconductor industry. It is unlikely the U.S. system could ever match the decision-making efficiency of a monolithic city-state or a single-party political system. However, the United States should not accept the status quo; the Policy team must direct a set of partners to reduce the time-to-market gap from 40%-plus to less than 20%. I propose a set of common-sense, feasible steps to accelerate the process:

- **Create a central mechanism to coordinate and streamline regulatory engagement by semiconductor companies.** Staff an empowered organization to be the single window through which semiconductor company investors can understand, review, discuss, and monitor permitting and regulatory processes. Similar, successful setups can be found in other countries and regions.[38]
- **Delete duplicative reviews and procedures.** Create a mechanism to review federal permitting procedures for technology manufacturing facilities, with two purposes in mind: removing those procedures that are outdated or no longer needed and removing those are duplicative of state requirements.
- **Build best practices and a problem-solving culture.** Staff a national expert team to develop a sustainable process to share best practices with industry players and state and local officials and to collaborate together to remove bottlenecks that slow down launches.
- **Prioritize speed in the investment process.** Incorporate into team training, investment evaluation, and decision-making the understanding that speed is a core competitive

factor and that locations and companies that do not have best-in-class speed are less attractive investing targets.

- **Benchmark the best.** Evaluate the “speedy semiconductor starts” of global leading countries such as Japan and Singapore, identify their best practices, and bring those practices back to the United States. One reason to create a stand-alone team for the Fund is so that the Fund can replicate global best practices in a way that established government agencies cannot.

WIN-WINS FOR THE UNITED STATES AND ITS GLOBAL PARTNERS

Governments around the world understand that the semiconductor industry is the underpinning platform for innovation-led economies. These governments are rolling out policies either to promote investment in semiconductors, to protect their industry from overseas competitors, or to stop their national champions from investing outside their home market. For instance, in December 2020, 19 European Union member states signed the European Initiative on Processors and Semiconductor Technologies in a bid to reestablish the EU as a global powerhouse in the semiconductor industry.[39] The joint declaration aims to enhance cooperation and increase investment in equipment and materials, design, and advanced manufacturing and packaging and includes a total pledge of 145 billion euro in support (of which little is new funding and therefore readily available for European companies). In February 2022, the European Commission announced the European Chips Act, which includes a target to more than double Europe's share of global manufacturing output to 20%.[40] In May 2021, South Korea announced a 50% reduction in tax rates for semiconductor companies and that, together, South Korean companies and the government will invest more than $400 billion in the industry over the next 10 years.[41] In December 2021, India announced a new policy to build up the semiconductor industry in the country, with a goal becoming a global hub for lagging-edge manufacturing facilities.[42]

U.S. policy will need to be successful within this context. But success does not depend on these other country efforts failing. In fact, the growth and success of semiconductor industries in similarly aligned countries could be a great boon to the U.S. industry; diversified geographic footprints increase supply chain resilience, provide market opportunities for U.S. firms, and supply more "smart brains" to solve the hardest industry-related problems.

The endgame needs to be a stronger and more resilient order in the global semiconductor ecosystem.

First, success means that the globally leading semiconductor companies, such as those headquartered in Taiwan, South Korea, and Japan, are manufacturing at scale in the United States, are performing R&D in the United States, and consider the United States a second home. Non-American partners are essential to achieving the top 10 objectives, as many are important suppliers, customers, or intellectual property owners. These non-American companies will need tacit or explicit approval from their home governments to invest in the United States. Therefore, a common understanding and agreement with governments in key semiconductor countries will be required.

Second, success means engagement with Europe on technology has been renewed, whereby the American and European industries — especially in the areas of automotive, industrial, medical, and telecommunications semiconductors — consider themselves part of the same ecosystem that leverages common technologies, manufacturing capacity, and business rules. Renewing this engagement is of particular importance to the European technology industry, and specifically Germany. As noted later in this paper, semiconductors are the foundation of Germany's most important industries, and that foundation has been progressively weakening. Partnering to turn that around offers the United States a rare opening to renew the critical US-German relationship.

Third, success means careful diplomacy with Asian nations to define the "win-wins" and global industry rules with the Asian nations that lead in many semiconductor segments and now represent more than 70% of global installed manufacturing capacity.[43] The United States needs to identify ways in which Asian countries, companies, and capital benefit from, rather than bear costs from, U.S. policy. There is only one path to accomplish this win-win scenario: expanding the pie by creating new technologies, markets and customers, so that all countries can increase employment and deploy more capital. Innovation through R&D is a far more compelling centerpiece of America's foreign policy regarding semiconductors than supply chain realignment. The former creates opportunities for everyone to grow and benefit, while the latter drives countries to defend their turf and see the policies of the United States as a threat.

ENGAGING FOREIGN COMPANIES TO INVEST IN THE UNITED STATES

For the United States to achieve the top 10 objectives, non-American leading companies need to invest in U.S.-based manufacturing capacity and U.S.-based advanced R&D activities. In fact, the objectives cannot be achieved without the substantial contribution of many of the most important non-American semiconductor companies.

In the long term, the United States needs to have a simple but aggressive goal: for leading foreign companies to consider the United States a second home, a base from which they can serve U.S. customers and scale their business globally.

Leading companies are constantly making investment decisions to boost production and enhance their capabilities and innovation leadership. In all cases, investment and research decisions made years ago are still being implemented today. The challenge for the United States will be to convince global leaders to invest outside their home market, which is usually where they acquire the technical talent, engineering talent, suppliers, and services needed to build their business. Fitting into the ongoing long-term capital expenditure programs of these global leaders will be no easy feat, even for companies willing to work closely with the United States. Key plan imperatives include the following:

- Encouraging and incentivizing global leaders in leading-edge logic, advanced packaging, memory, and other industry segments to build and invest in the United States and to bring along their partners. Besides offering financial incentives (e.g., low-cost capital and tax incentives), the United States must unequivocally demonstrate a long-term commitment, provide access to other suppliers and their IP, and espouse certainty to ensure a proper return for the leaders' time, money, and effort. The effort will involve complex and difficult decisions by all parties.
- Compelling global companies to build R&D centers in the United States, or to add staff to their existing centers. Again, the resulting IP and know-how must be allowed to cross borders freely, or they will not invest.

Global leaders will decide on manufacturing and R&D locations from a business standpoint; first and foremost, investing in America must make business sense.

For manufacturing, they will need inducements similar to those required by U.S. companies: adequate returns on capital invested, the meeting of customer needs, and the avoidance of stranded capital. They will want to be part of a flourishing industry cluster that can both reduce risk and attract talent for their operations. Therefore, they will follow the lead of big players in their industry segment. This is why it is so important for the United States to first gain the commitment of a few strategic partners, in each corresponding segment, to invest in capacity in America.

R&D investment: A more challenging task

The strategy must incentivize global R&D investment into the United States with as much vigor as it does factory investment. Without a constant stream of new process technologies based on continuous R&D breakthroughs, a leading edge fab will soon fall behind and become economically unviable.

Promoting a global shift in R&D will be more difficult (or at least less straightforward) than in manufacturing. Foreign companies will find it hard to separate out R&D functions and place them in different locations; they tend to cluster their core R&D functions at headquarters and around the "alpha fab" where new process technologies are rolled out.

Companies make R&D decisions based on these factors:

- Strategic considerations;
- Proximity to the market and customers;
- Talent, at both the senior and junior levels;
- Associated costs and overall financial returns; and
- Political, regulatory, and operational risks.

In general, U.S.-based R&D will score well on strategic considerations and market proximity. However, global companies will have substantial concerns about access to talent, the level of returns, and the comparatively higher regulatory and political risks. Some major concerns and issues to be addressed include the following:

- *Organizational costs* — While the United States has clear leadership and significant senior research talent, it, unlike other countries, has a smaller and more expensive pool of junior engineers. For instance, China is graduating more than 10 times the number of bachelors-level electrical engineers than the United States. In addition, the average engineering salary in the city of Hsinchu, Taiwan — site of the world's largest semiconductor cluster — is only about $30,000, versus an average of roughly $75,000 in Hillsboro, Oregon, a large U.S.-based manufacturing cluster. Add in insurance, other benefits, and taxes and the U.S. labor costs are roughly four times higher.[44]
- *Other financial return drivers* — Beyond labor costs, there are many other issues that affect an R&D center's financial returns. These include the center's ability to receive U.S. government grants to help support direct R&D expenses, its access to equivalent R&D tax credits as U.S.-headquartered companies, and the existence of a large enough U.S.-based ecosystem to warrant a separate well-funded R&D operation.
- *Open access to major U.S. customers* — The government should not push U.S.-headquartered companies or government agencies to "buy American," as this will minimize a major reason to invest in the United States — proximity to the world's largest customer base.
- *Free global use* — Non-U.S. companies will be concerned that if they develop IP in the United States, they might not be allowed to export it to their overseas affiliates or will be subject to export controls. The United States needs to establish substantial coordination between the National Semiconductor Policy team and a separate, independent government team that sets related export control policies.
- *Open access for home-country capital providers* — Global leading semiconductor companies have home-based capital providers that will want to access investment in new U.S.-based facilities; non-U.S. investors need comparable access to the U.S. Fund program.

ENGAGING FOREIGN GOVERNMENTS: TAILORED APPROACHES TO HOME MARKET ISSUES

The home countries of leading semiconductor companies face broader issues, including a more complicated calculus beyond near-term financial returns (e.g., national security, foreign policy, domestic politics, and industrial relations). Their semiconductor strategy is one piece of a much larger plan to support multistakeholder national interests. A U.S. policy approach must take into account these specific hot button issues, which will vary in each country.

As part of this broader engagement, the United States must make building in the country an easy decision. The following considerations are important:

- *Foreign government buy-in* — Winning foreign government buy-in will require highlighting the economic rationale for the companies to produce in the United States, as well as demonstrating how U.S. semiconductor policy is not meant to choke off local production and negatively impact that country's industry employment. Just like the United States does, foreign countries benefit when their companies enter new markets and have diverse global supply chain footprints.

- *Local regulatory changes* — In certain cases, it will make sense to request foreign governments to change laws to enable local companies to invest in the United States (e.g., export controls or technology transfer restrictions).

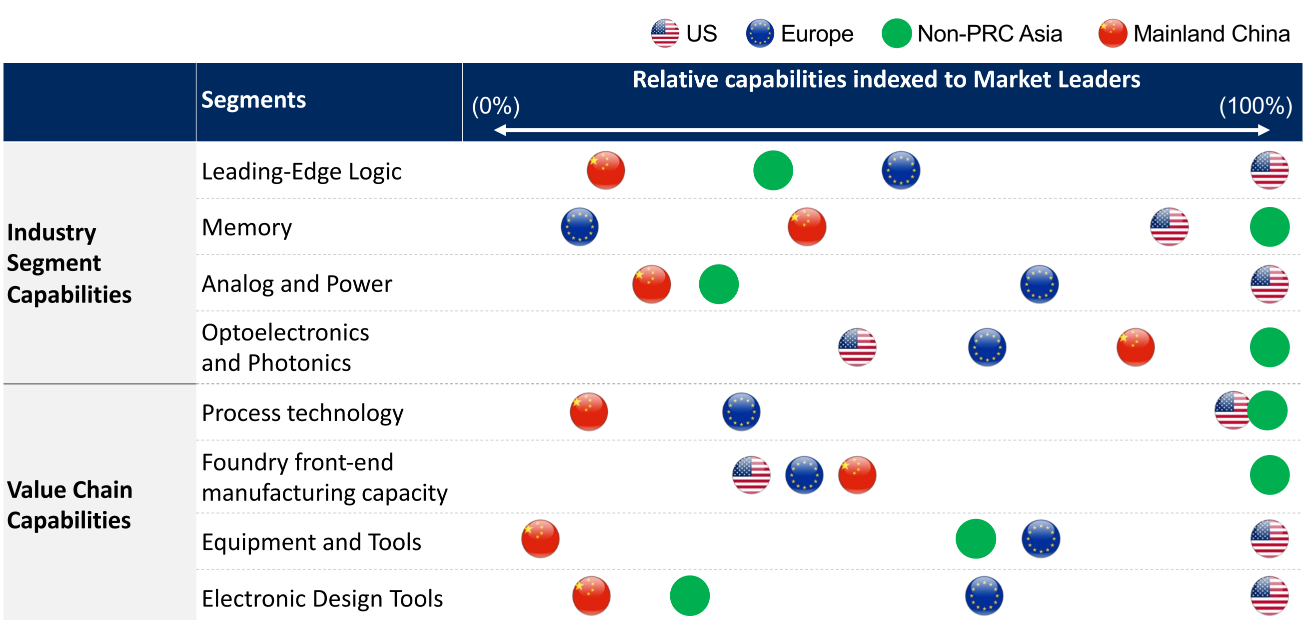
- *Appropriate countermeasure deterrents* — The United States must avoid bidding wars (e.g., country X promises its home players "we will match or beat U.S. economics" for semiconductor investments) not only by building friendly, collaborative relationships with semiconductor authorities in other countries, but also by emphasizing that transparency in government support is essential and that the United States will use proper channels, such as the World Trade Organization, to stop or fully offset new subsidies created in a race to the bottom. While there are no tools that can fully stop "secret" or excessive subsidies, global cooperation can deter the worst excesses.

DIFFERENT COUNTRIES NEED DIFFERENT ENGAGEMENT STRATEGIES

While the United States has enough internally generated demand to provide a baseline scale for nearly any investment in semiconductors, other leading countries generally do not. Therefore, these countries specialize in one or more industry segments or layers of the value chain. The table below, which by necessity is simplified and high level, lays out the comparative capabilities of major regions.

FIGURE 5

High-level comparison of capabilities by region[45]



There are several simple takeaways from this chart: (1) Asian countries and regions grade tops in numerous categories; (2) no country has the ability to be self-sufficient, as they all rely on a global value chain; (3) different countries have different problems to solve and therefore will have different engagement models vis-à-vis the United States; and (4) other countries will be more concerned with protecting their own vulnerabilities than with supporting the United States' domestic efforts.

Engaging an important partner: A deeper dive into the German situation

The automotive and industrial automation industries are Germany's economic mainstays.[46] In total, advanced manufacturing drives more than 25% of German GDP and more than 75% of its exports. Leading-edge semiconductors, new materials, and software are critical inputs into these German industries. To protect its world-leading position, the German automotive industry needs access to new technology innovation, stability in supplies, and ecosystem support to put together the full solution for leading electric vehicles (e.g., batteries, battery management systems, sensor systems, power electronics, CPUs for automotive control and autonomous driving, and underlying software stacks).

Roughly 75% of the EU's semiconductor firms are headquartered in Germany.[47] The country's companies have strengths in certain analog, power, and sensing technologies and select equipment markets, but Germany on the whole lacks the semiconductor manufacturing capacity (e.g., in leading-edge logic processing, software capability, and materials) to be a leader in the future automotive and "industrial internet" industries. As a result, German automotive and industrial automation industries rely on foreign suppliers and do not control their own future. In addition, Germany's current semiconductor strengths are being eroded by technology transitions. For instance, the country's traditional, silicon-based, power inverter semiconductors for automotive applications are now less relevant than emerging materials for future electric vehicle powertrains, such as silicon carbide and gallium nitride. This is a significant and growing issue for German car companies and the government.

American companies have strong market share, IP position, and manufacturing know-how in many of the key technology areas where Germany has gaps. They see opportunities in the German and European markets. This is why Intel and GlobalFoundries, major U.S. semiconductor companies, have already announced plans to invest in Germany.[48]

The respective national funds of both countries could jointly facilitate the build-out of the supply chain in both the United States and Germany to leverage economies of scale and foster a more resilient global supply chain. The United States could extend the frontiers of a National Semiconductor Research Center umbrella to include Germany so that the country's research teams can join either broad or individual, specific U.S. efforts. The framework could encourage U.S. and German companies to work together on key semiconductor solutions for the electric vehicle, autonomous driving, and industrial Internet of Things markets. U.S. semiconductor companies would get new customers, new insights into customer needs, and more access to German technology, while German companies (or German subsidiaries of U.S. companies) would gain experience in designing and building out advanced semiconductor manufacturing and more access to better technologies and U.S. markets and customers.

Of course, Germany would need to step up its efforts for this collaboration to work. They would need to commit real capital, invest in partnerships with the Fund, remove roadblocks to allow German companies to invest in the United States, establish common rules on global access to critical semiconductor technologies and supplies, and give U.S. semiconductor companies open access to the German customer base.

A BIGGER OPPORTUNITY: SEMICONDUCTORS AS A FOUNDATION FOR A TECH PARTNERSHIP WITH EUROPE

The engagement with Germany could be both an example of and the foundation for a renewed technology partnership with Europe. A win-win partnership would help align the European technology and business communities closer with the corresponding American communities.

The United States could provide more market access, proximity to customers and capital, and joint investment in future technology breakthroughs. Europe holds less than 10% of global installed semiconductor capacity, less than 4% of annual capital expenditures, and less than 5% of global annual venture capital investment into semiconductors. And its major industries (e.g., auto, industrial, telecoms, and medical devices) are highly dependent on the innovations that semiconductors bring. In return for U.S. support, Europe could provide joint funding and help define a competitive, global, transparent and robust semiconductor ecosystem.

A more robust European semiconductor manufacturing cluster would not only benefit the U.S. semiconductor industry, but also boost the business case for Asian companies to build their capacity to serve the European market — which will be necessary to meet the top 10 objectives for global supply chain resiliency.

This type of global partnership does entail tradeoffs; American companies supported by the Fund would build some of their global manufacturing capacity in Europe rather than solely in the United States. However, these tradeoffs are inevitable if the United States wants global support for its own manufacturing revitalization efforts. In fact, the United States should see the investment by other countries as a way to achieve the Policy's top 10 objectives, because only the United States has the ability and foundational elements to lift all boats in the global semiconductor industry, if policy is coordinated and messaged correctly.

Formalizing the global approach: Launching a global semiconductor partnership framework

To win the hearts and open the wallets of the global semiconductor community, the U.S. National Semiconductor Policy needs to be open, global, long-term, committed, and patient. Just like leading U.S. companies, top foreign companies invest many years, across many cycles, to develop true breakthroughs. The Dutch company ASML spent 17 years developing its extreme ultraviolet technology, while the UK company ARM spent more than six years building its first 64-bit microprocessor.[49] To fully convince the executives of global semiconductor companies and to allay nationalist countries, a branding approach that champions innovation, openness, globalism, fairness, and IP protection will be critical. To ensure that the United States will not revert to protectionist policies at the first sign of supply chain shortages, the Policy needs to buttress reciprocal market access commitments with mediation processes. Global partners need to see continued, long-term, unflinching American resolve to take the lead on future advancements in semiconductors, while enabling like-minded countries to fully participate in a fair, market-driven, technologically robust, integrated and growing global supply chain. This demonstrated resolve will be very important to Asian countries currently in the lead in semiconductor manufacturing; they must have open access to U.S. markets and customers for business viability, as well as access to U.S. technology to run their factories. Therefore, the United States will need to build a partnership with Asian nations, one focused on creating opportunities for all rather than the transfer of Asian manufacturing capabilities to North America.

From a branding perspective, it will not help if the U.S. National Semiconductor Policy is seen (by the Chinese or America's allies) as anti-China. The Chinese technology and semiconductor ecosystem will be important, both as a supplier and market, for the global semiconductor industry for decades to come. The CHIPS Act prohibits recipients from investing in certain types of semiconductor manufacturing facilities in China. However compelling the political motivations for those restrictions may be, forcing companies to choose between the United States and China as a day-to-day input to investment decisions is a poor approach in general. Not only would it make transactions far more complicated, but it would also encourage global partners to think twice before investing in the United States. As every company and venture that is worthy of investment will want to sell us much as they can to Chinese customers, the United States cannot expect anti-China measures to drive exits from the China market. Such measures are more likely to encourage industry players to build exotic and complex structures to continue operating in China.

Therefore, national security, export control, and economic security policies and actions regarding China should be handled via mechanisms and teams that are completely independent from the Policy and its team. In addition, Fund investment considerations should not be influenced by U.S.-China national security concerns. In fact, there is a bona fide argument that the United States would benefit from inviting Chinese companies to partake in the Fund's investment programs so that they are subject to the Fund's oversight, transparency, and market rate-of-return policies. But I will not elaborate here on the relevant arguments; after the Fund's formation, its leadership team should develop the China investment policy based on the two countries' semiconductor ecosystems.

A COMMON INVESTMENT APPROACH THAT INCORPORATES SPECIFIC SEGMENT STRATEGIES

The United States cannot adopt a general-purpose strategy for the semiconductor industry; rather, it will need a separate strategy (and thus separate, corresponding investment programs) for each industry segment. Within each segment, it will need to identify specific R&D needs and specific requirements for capital investment, while prioritizing actions based on the relative importance of the segment to both the top 10 objectives and the current risk of inaction to America's competitiveness. There will, of course, be common themes across segments; for example, all segments can benefit from the dramatically reduced cost of capital to purchase manufacturing tools and equipment via the Partnership for Revitalizing American Semiconductor Manufacturing.

Based on an initial evaluation, the first horizon investment needs to focus on the leading-edge logic, lagging-edge logic, and memory segments (specifically dynamic random-access memory, for which there is no U.S.-based leading-edge manufacturing). Within those segments, the essential areas of R&D investment should be manufacturing process technology (including process scaling); tools and equipment; materials (including gallium nitride, silicon-on-insulator, and other new materials); and assembly and testing (specifically advanced packaging capabilities that enable heterogenous integration for advanced performance).

The latter area is of particular importance. The heterogeneous integration of different semiconductors (basically the combining of many different types of chips together via direct connections) will be a new control point of systems architecture — and be as important as the fundamental chips themselves. With most packaging capacity currently located in Asia, the United States needs a strategy to bring highly automated, low-cost advanced packaging back home; packaging must be co-located with front-end wafer fabrication, or the industry leadership benefits that such fabrication brings could be lost or minimized.

This prioritization should not preclude the Fund from making investments in other segments, such as analog or power. If these investments match the Fund's investment criteria and pass the due diligence process, they should have the Fund's support.

Below, I provide an assessment of the investment priorities and capital requirements for each segment, along with key indicators (regarding U.S. competitiveness) that justify my prioritization. Crucial tasks in the Fund's first six months would include refining the targets to be more concrete and engaging specific partner companies and co-investors on transaction opportunities for each segment. Of course, the urgency and investment horizons for segments will differ, as well as their R&D priorities and capital investment requirements.

FIGURE 6

U.S. investment horizons by segment

✔✔✔High ✔Low

Investment Horizon	Segment	Importance: National Security	Importance: Tech Industry Leadership	US Current Position: "Beyond the Chip" Ecosystem	US Current Position: Design	US Current Position: Manufacturing Footprint	US Current Position: Tools and Materials
1	Leading-edge logic	✔✔✔	✔✔✔	#1	#1	#2-3	#1
1	Lagging-edge logic	✔	✔	Top 2	#1	Below top 3	Below top 3
1	Memory	✔✔✔	✔✔✔	#1	#2-3	#3	#2
2	Analog and power	✔	✔✔✔	#1	#1	#1	#1
2	Radio frequency	✔	✔✔✔	#1	#1	#1	#1
3	Discrete	✔	✔	Top 3	Below top 3	Below top 3	Below top 3
3	Optoelectronics and photonics	✔✔✔	✔	Top 3	#1	Below top 3	Below top 3

FIGURE 7

R&D priorities and capital investment requirements by segment

Investment Horizon	Segment	R&D	Capital Requirements over 10 Years
1	Leading-edge logic	Process scaling, lithography, next-generation materials, advanced packaging (2.5/3D)	$100B+
1	Lagging-edge logic	Limited to process variant refinement	$20B+
1	Memory	Process scaling, lithography, next-generation materials, advanced packaging (2.5/3D)	$100B+
2	Analog and power	Next-generation materials, advanced packaging technologies	$108+
2	Radio frequency	Next-generation materials, advanced packaging technologies	$108+
3	Discrete	New materials, process automation	$5B
3	Optoelectronics and photonics	New materials, process automation	$5B

MAKING THE STRATEGY REAL: A DEEP DIVE INTO THE LEADING-EDGE LOGIC MANUFACTURING SEGMENTS

Here, I discuss investment in U.S.-based leading-edge capacity (a first horizon priority) to illustrate a potential investing approach. I specifically focus on leading-edge logic chips (CPUs for personal computers, phones, and data centers), because they act as the "brains" of the entire technology ecosystem. U.S.-based systems and internet companies are the largest consumers of these chips, and nearly all of the chips are designed in America. But the related front-end fabrication, packaging, assembly, and testing tasks are nearly all performed outside the United States.

Segment dynamics

In the two markets primarily using leading-edge technology, logic, and memory, the playing field has dwindled to three logic competitors (Intel, Samsung, and TSMC,) and three memory competitors (Hynix, Micron, and Samsung). Several factors have caused this consolidation:[50]

- The R&D cost to deliver leading-edge process technology has increased rapidly, roughly twice as fast as industry sales.
- The required capacity and cost of a minimum efficient scale factory has continued to rise. Today's leading-edge semiconductor factories require about 50,000 wafer starts per month to be cost-effective, driving capital investment of $15-20 billion, or about 15 to 20 times more than an "efficiently sized" fab 20 years ago.
- The semiconductor foundry business model, where a company will manufacture products for many other companies and thereby gain economy of scale for both production and R&D, has also continued to rise.

The leading-edge logic industry has evolved to a position where the core area of expertise, process R&D, resides primarily in three locations: Seoul; Hsinchu, Taiwan; and Portland, Oregon. Due to the incredible technical depth required and the limited number of technical people who fully grasp the complexity of generation-to-generation technology change, it is very unlikely that any other global location can join this list. These factors also make the R&D teams in these countries conservative, secretive, and unwilling to take unnecessary risks.

The location of R&D impacts the location of manufacturing, as the handover of technology from the development stage to the manufacturing stage is complex, iterative, and almost as difficult as making the technology itself. Manufacturing facilities for leading-edge semiconductors therefore benefit from being co-located with research centers. A few locations in the world have been able to ramp manufacturing separate from these R&D centers (e.g., Austin, Texas and Phoenix, Arizona), but fabs located there tend to ramp slightly behind the first manufacturing facility and have taken many years to get the R&D-to-manufacturing handover correct. These locations have also required companies supporting parts of the value chain (e.g., tools, materials, and services) to build local, co-located support (e.g., final assembly, installation, and repair) at scale. The complexity of achieving this co-location cannot be overstated; each manufacturing leader likely has 75 to 100 direct suppliers that would need to follow the leader and invest in any new location.[51] Thus, even if the U.S. government were to be successful in encouraging TSMC and Samsung to build capacity in the United States, these companies would transfer mature technologies to avoid the risk of poor technology transfer.

Increasing capacity at the leading edge is not simply about building fabs, but also about activating the upstream value chain that must deliver the tools, chemicals, and raw materials to these fabs and accelerating the time frame from capital expenditure to mass production. In the current supply chain environment, all the global fabs are demanding new equipment and all the equipment vendors are pushing their sub-suppliers to deliver components. The proposed U.S. Semiconductor Fund would need to identify areas where targeted investment can increase supply and tilt that supply toward U.S. fab efforts. Beyond strengthening the upstream value chain, the United States would also need to drive knowledge transfer, especially around process technology transfers and fab operations, from South Korea and Taiwan to the United States. Today, Asian fab operations are processing wafers faster and more efficiently than U.S.-based fabs are, due to both best-in-class processes and a culture of operational excellence. To compete, U.S.-based fabs will need to both learn and adopt these best practices.[52]

Four gaps to close in leading edge: Capital cost, operational labor cost, speed, and taxes

To motivate profit-seeking companies that have their choice of manufacturing locations, the Fund would need to structure its approach to close four gaps in the American value proposition:

- *Capital costs* — Cleanroom construction and semiconductor equipment, the basic building blocks of fabrication facilities, are essentially the same price anywhere in the world. However, not surprisingly, non-U.S.-based fab facilities have benefited from higher subsidies to pay for these building blocks. While there are no concrete numbers, it is estimated the fabs built in China, South Korea, Singapore, and Taiwan have between 15 and 50% of their capital costs covered by subsidies and incentives (in China, there are examples of nearly 100% subsidy of Capex). Since depreciation can represent about half the cost of a leading-edge semiconductor product, a U.S.-based fab operating today cannot build cost-competitive products.

- *Labor costs* — The primary cost differentials between factories operated in the United States and those operated in places like China, South Korea, and Taiwan are labor and benefits. Analysts estimate that running a fab in Taiwan is 30 to 40% cheaper than running the same type of fab in the United States.[53] This cost is for both direct and indirect labor. While semiconductor factories are highly automated, there is still a substantial amount of labor need for other tasks such as construction, maintenance, spare parts, and waste removal. These costs need to be compensated for with either automation or productivity. There is substantial engineering overhead in a mega factory (potentially 1,500 engineers and another 500-plus administrators). Higher labor costs and associated taxes (e.g., payroll and state and federal taxes) in the United States make the playing field unlevel, giving the advantage to foreign manufacturers. Labor regulations and taxes are not bad per se; they simply need to be comprehended in the overall investment approach.

- *Speed and operational efficiency* — As mentioned before, faster speed is a critical advantage for Asian countries throughout the lifespan of their manufacturing facilities. This is the case whether the facility is in the pre-production phase (for regulatory approval, site planning, site setup, construction, and tool hookup) or in the production phase (for pilot-line ramp, mass manufacturing ramp, and cycle time). At the leading edge, "speed kills": being first to market increases margins, returns on investment, and long-term competitiveness. While certain barriers to accelerating speed are operations-based, many are related to permitting and are often found at the state or local level. A joint effort by the federal, state, and local governments will be needed to identify bottlenecks and fix them.

- *Taxes* – Due to more favorable tax policies and tax incentives for capital investment, non-U.S. manufacturing facilities tend to have lower tax burdens — another factor that makes non-U.S. manufacturing investments more attractive than U.S.-based alternatives. For instance, TSMC's effective tax rate of around 10% is less than the Taiwan statutory tax rate of 20% due to a five-year tax exemption.[54]

The scale of investments required to support the fab efforts of all three global leading-edge logic manufacturers will be greater, by an order of magnitude, than any previous effort the U.S. government has made in the high technology industry. Building just one greenfield scale leading-edge fab would require roughly $20 billion of initial capital and then 20 to 40% of this amount every two to three years for new process technologies and upgrades. And the strategy objectives require building out between three and five advanced leading-edge fabs in the United States. If the proposed Fund were to subsidize around 40% of the capital costs needed for all these efforts, it would quickly spend all $39 billion in CHIPS funding specific to semiconductor manufacturing — even before any effort to support other industry segments, other components of the value chain, or operating costs. Co-investment, delivered via the proposed Partnership for Revitalizing American Semiconductor Manufacturing, will be essential.

Investment in facilities without investment in manufacturing innovation will leave a manufacturing base that needs subsidies in perpetuity to survive. Higher operating costs are not sustainable over the long run. Industry, supported by the Fund, would need to step up with automation, yield improvement, and other innovation investments that provide sustainable buffers against lower input costs in Asia. The Fund would need to work with investees to identify and fund the innovations that can help close the gaps; and it would also need to invest in the startups and established companies that can work with the major manufacturers to fund these improvements.

Along with the above manufacturing inducements, the United States needs to leverage other policy tools to bring the associated ecosystem partners, home-country employees, and R&D capabilities to the U.S.-based manufacturing facilities. The United States must launch country-specific fast-track immigration procedures to allow Taiwanese and South Korean expatriate workers to come end masse to the United States. The country must benchmark best-in-class global efforts to welcome expatriate workers, including by partnering with states and localities to deliver the goods to these expatriates (Mandarin-language international schools are one obvious requirement). In addition, the U.S. government should fully understand the specific support leading global players need to transfer R&D to the United States and then leverage its full portfolio of tools, from R&D tax credits to intellectual property transfer procedures to guarantees of full global use. As mentioned before, making America the second home of these global leaders requires far more than building a plant. Whether building, ramping, or sustaining an R&D and manufacturing base, the Fund and its co-investor partners would need to offer a competitive "package" that creates more value than what a leader's home country is offering. In addition, U.S. diplomats would need to engage the home-country governments to demonstrate the win-win nature of such arrangements, to assuage home-country concerns, and to fend off counterproposals. This whole-of-government effort illustrates the need for a single company & investor contact window to build, align, and promote this package to the world's best companies, so that they choose to invest in the United States.

BUILDING THE GOVERNMENT TEAM TO DELIVER THE MANDATE

More important, and more difficult, than laying out a U.S. semiconductor strategy is building a team and structure that can effectively execute the strategy. Doing so will require new thinking and a break with past practices.

Semiconductors represent, quite simply, the heights of human scientific and engineering achievement. The government team that partners with this industry cannot succeed if it is staffed with part-timers, amateurs, or short-term appointees that operate in siloed, fragmented groups and that are placed into structures that cannot operate at the pace of, and with the trust of, the semiconductor industry. A cohesive, empowered, expert team — whose foremost priority is to deliver the mission — will be necessary. And this team will need to be the single point of contact for semiconductor companies and financiers to engage with the government. Finally, the team must have the express mandate to coordinate semiconductor policies across all government agencies.

THE NEED TO BRING IN DEEP SEMICONDUCTOR AND FINANCIAL TALENT

The National Semiconductor Policy I propose should be implemented by a team of semiconductor industry experts, financial experts, and policy experts. Each group of experts is essential and needs to work together as a cohesive, integrated team. Each team member should have the stature and capability to act as peers to their Silicon Valley, Wall Street, and Washington counterparts.

Due to the complexity of both the semiconductor and financial industries and the need for the Policy to reflect that complexity, some team members should not be current members of the government, but instead be high-capability, early career professionals who can multitask, update their expertise quickly, produce timely quality output, and pull the "so whats" from financial statements and industry reports. This group is likely to include those with political experience, but also likely early career analysts or associates from investment banks and consulting firms.

The primary fitness test for new joiners would be their commitment to the mission — passion for solving problems, doing the right thing, supporting their nation, and pursuing whatever it takes to effectively carry out the Policy. Senior external hires would need to be empowered to stand up the Policy and Fund and have the right level of authority to succeed.

Therefore, the assembled team would need to act quickly to build momentum and show early success to the industry, third-party investors, and the tax-paying public. The urgency of the task and the short window of opportunity require expedited hiring processes. Of course, more senior financial and private equity experts are in high demand and will thus have high expectations for their authority, title, and compensation. But expedited processes will not allow for fully defined roles, at least early on. Therefore, these experts will likely want to reduce risk and just take sabbaticals or leaves of absences from their current positions; and if so, they will probably return to their previous roles after the initial Fund structure and frameworks are set up. This means that, inevitably, their ties to the semiconductor and financial industries will continue after their government service ends.

EMULATING THE OPIC/DFC MODEL

The Fund and associated policy work should operate under a hybrid model, pursuing industrial policy goals while ensuring that projects are commercially viable and pay off for co-investors. The Fund structure should likewise adopt private industry best practices while operating under the guidance of government oversight. The Fund would need to do the following:

- Be a single point of contact for the industry to engage with the government on semiconductor policy;
- Attract top investing and industry talent with appealing, market-level compensation;
- Have a global reach and mandate, with the ability to invest in non-U.S. companies if such investments support the global ecosystem;
- Develop proprietary and top-of-class insights into the industry by hiring semiconductor experts and building a world-class advisory board;
- Deliver to triple the bottom line, as every deal needs to make money, make the industry stronger, and drive job creation;
- Be able to move quickly, as a one-month delay in delivering a new technology or ramping a fab can miss a market window and cost billions;
- Organize and engage a community of co-investors that can provide risk-reducing capital and validate the investment case, thereby stretching federal funds;
- Demonstrate transparency and governance best practices during investment selection, negotiation, and management processes;
- Ensure structural independence to separate investment decisions from short-term political, noneconomic, or nonaligned decisions; and
- Designate a strong oversight board with appropriate government representation.

Few existing governmental organizations provide the structure to deliver the above objectives. Lessons learned from OPIC and its successor, the DFC, can be instructive in understanding the foundational structure and decision-making apparatus needed for the Fund. Created by Congress in 1969, OPIC offered both debt security and equity financing, had a hybrid leadership team of political appointees and long-term expert investors, and had triple bottom-line goals to produce economic growth, drive innovation in financial structures and business models, and deliver benefits to marginalized populations.[55]

By most accounts, OPIC was an economic policy, foreign policy, and bipartisan political success. OPIC allocated more than $177 billion in investment in its first 35 years alone, returning $5.9 billion in investment gains to taxpayers. The bipartisan government agency was able to harness the best of American companies and create a self-sustaining, synergistic public-private partnership.[56]

OPIC provided businesses with the tools to manage the risks associated with foreign direct investment, to foster economic development in emerging market countries, and to advance U.S. foreign policy and national security priorities. OPIC's capital helped magnify its private sector partners' economic reach and activity.

The Fund I propose could adopt a similar structure, modified to align with the capability requirements and investment approach outlined in the Policy. Thinking beyond today's headlines and looking at industrial policy more broadly, the Fund structure could be replicated in other vital American industries important to both the economy and national security (or more simply, the Fund mandate could be expanded to include more industries and technologies).

CONCLUSION: SEMICONDUCTORS AS THE FOUNDATION FOR A NEW U.S.-STYLE INDUSTRIAL POLICY

Working together, the U.S. government, the semiconductor industry, the U.S. subsidiaries of global semiconductor companies, and other stakeholders can grow the global semiconductor industry and re-affirms America's global leadership across the supply chain for future generations. Success in this effort could also make the semiconductor industry a model for public-private partnerships in many other industries. This is a once-in-a-generation opportunity to tap into the strengths of American workers, educational institutions, and government bodies to propel the U.S. economy to a brighter and more secure future. Seizing the opportunity will require enormous efforts to hire and empower a leadership team, create the legal framework for a new type of domestic government financing entity, overcome bureaucratic inertia, and balance a large set of corporate, financial and government partners.

It's time to get to work.

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