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No Permits, No Fabs

The Importance of Regulatory Reform for Semiconductor Manufacturing

CSET Policy Brief

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Executive Summary

The ongoing global chip shortage, coupled with China's heavy investments in indigenizing semiconductor manufacturing capabilities, has brought attention to the importance of semiconductors to the U.S. economy, the fragility of semiconductor supply chains, and the decline of U.S. chipmaking capacity over the past three decades. In part as a result of this attention, Congress has advanced legislation to appropriate $52 billion in funding for the CHIPS for America Act. Approximately $39 billion will likely go toward incentivizing semiconductor manufacturers to build new chipmaking capacity in the United States.

But more can be done to improve the resiliency of U.S. access to microelectronics beyond manufacturing incentives. This report outlines infrastructure investments and regulatory reforms that could make the United States a more attractive place to build new chipmaking capacity and ensure continued U.S. access to key inputs for semiconductor manufacturing.

Key Findings:

The United States currently builds fewer fabs[*] at a slower rate than the rest of the world. Part of the reason for this is permitting regulations which require long assessment timelines.

Fabs have extensive infrastructure requirements, which interact with federal, state, and local regulations in complex ways. Modern fabs require access to (1) large plots of (2) seismically inactive land with a reliable, affordable, and stable supply of (3) water, (4) electricity, (5) talent, (6) transportation infrastructure, and (7) nearby land for co-locating with suppliers essential for constructing and operating a modern fab.

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[*] Semiconductor factories, known as "fabs," are the physical structures that house the equipment and operations required for semiconductor manufacturing.

The CHIPS Act correctly aims to increase the number of fabs constructed in the United States, but regulatory support and infrastructure investments are needed to ensure that these new fabs are built on time and on budget. The United States government should prioritize regulatory support at the local, state, and federal level to expedite fab construction. In particular, full implementation of several recommendations from the 2017 President's Council of Advisors on Science and Technology related to environmental review and permitting of high technology facility construction are essential.[1] The United States should also make infrastructure investments targeting utilities, transportation, and supply chain networks that will assist semiconductor manufacturers.

Engagement with allies will be essential for increasing resilience in the semiconductor materials, gases, and chemicals supply chain. In the medium to long term, increasing domestic production and/or stockpiling should be considered. Increasing domestic United States production of many raw materials and chemicals is contingent on opening new mining and/or refining operations, which would require extensive permitting. Thus, coordination with allies who already have existing production and refining capacity may be more expeditious than attempting to establish new capacity in the United States. Though many of these materials have a limited shelf life, stockpiling of certain materials, modeled after existing United States government programs like those operated by the Defense Logistics Agency Strategic Materials, may be an option.

The United States should quantify demand for key material inputs, identify potential alternatives, and support their development. Ongoing efforts supported by the Environmental Protection Agency and the semiconductor industry to develop substitutes for environmentally harmful greenhouse gases used in semiconductor manufacturing could serve as a template for further work to identify substitutes for certain materials, chemicals, and gases used in semiconductor manufacturing for which there is no commercially viable domestic supply.

Introduction: Fab Infrastructure Requirements and Federal Permitting

This paper, in concert with forthcoming companion papers on reshoring semiconductor manufacturing, argues that current semiconductor reshoring efforts should prioritize construction of leading-edge fabrication facilities and increase the resilience of the associated supply chain necessary to support these facilities. The U.S. Department of Commerce's 100-day review of the semiconductor supply chain in response to Executive Order 14017 on Securing America's Supply Chains generally aligns with this argument, finding "federal incentives to build or expand semiconductor facilities are necessary to counter the significant subsidies provided by foreign allies and competitors."[2] However, the United States has many regulations in place which may effectively counteract the purpose of CHIPS Act funds, slowing construction of new leading-edge fabrication facilities. In addition, the semiconductor industry must contend with myriad environmental, health, and safety (EHS) regulations that serve important purposes, but will inevitably slow the development of a more resilient semiconductor supply chain in the United States. Finally, the simple reality is that there are very few leading-edge semiconductor manufacturers in the world, and most of them are headquartered outside the United States. In practice, this means that the United States must craft policies that convince specific foreign companies to build outside of their headquarters country, where presumably they face significant political pressure to build domestically and enjoy easier access to policymakers to facilitate build-out in regulatory environments they can navigate adeptly.

Local, state, and federal permitting processes in the United States are beneficial to the general public but present tradeoffs for semiconductor manufacturers. A 2017 report from the White House found that these permitting processes "minimize[d] environmental and community impact, which companies are not always economically incentivized to do. The combination of the current Federal and state permitting and review processes, however, can be slow, unpredictable, and lacking in transparency."[3] The report goes on to note that semiconductor factories are particularly vulnerable to permitting-related delays due to their long construction times, significant geographic footprint, and complex supply chains. In addition, due to the many specialized chemicals and gases used in the semiconductor manufacturing process, unique permits must be acquired, which can further delay, or even halt, operations. Adding to this challenge, the semiconductor industry's transition to a fabless-foundry operating model (in which semiconductor design and semiconductor fabrication are done by separate firms) in the past 20 years largely caught U.S. firms flat-footed. Many leading U.S. companies maintain an Integrated Device Manufacturer (IDM) operating model of doing both design and manufacturing in-house, an increasingly costly proposition, especially given the success of Taiwanese foundries that focus solely on manufacturing. In part as a result of both the U.S. regulatory environment and this ongoing structural shift in the industry, the United States builds fewer fabs at a much slower rate than other countries, and at a greater cost to companies. The United States should recognize the nature and value of indirect EHS regulatory support provided by other countries interested in attracting semiconductor manufacturers, and adopt policies that make it equally attractive to build fabs in the United States.

This paper begins by reviewing fab rates of construction worldwide from 1990 to 2020, finding that the United States builds fabs far more slowly than other competitor countries and regions, notably Taiwan and China. Next, this paper reviews fabs' myriad unique infrastructure requirements. Finally, this paper discusses how these infrastructure requirements must contend with U.S. environmental, health, and safety regulatory permitting processes, potentially slowing the construction timeline for fabs and the associated supply chain necessary to support semiconductor manufacturing.

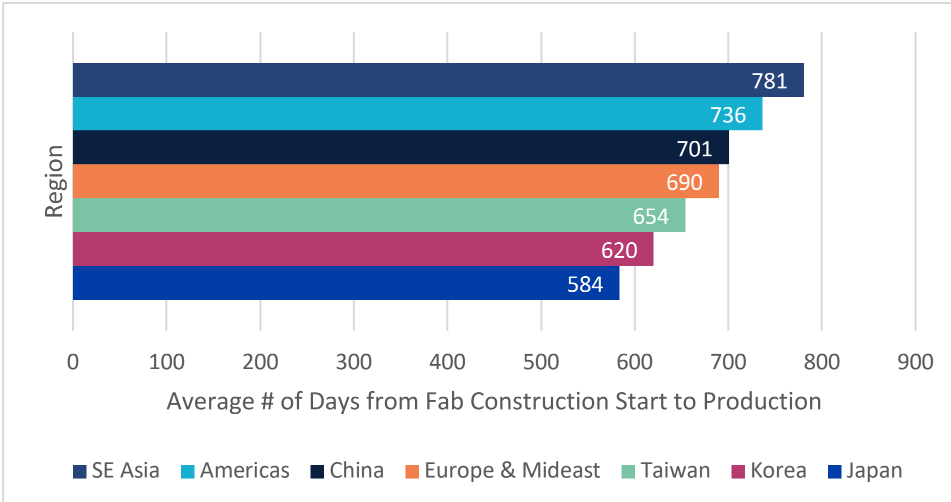
The United States Builds Fewer Fabs More Slowly Than the Rest of the World

It takes a long time (typically two to four years) to build a fab in any country. But analysis in this section shows that fab construction takes much longer in the United States than in the East Asian countries where most chipmaking currently takes place. There are many factors underlying the decline in U.S. chipmaking capacity, but one underappreciated factor may be the longer construction timelines associated with building new ("greenfield") American fabs.

In part because of the unique infrastructure requirements of fabs and the regulatory processes these large construction projects must navigate, construction of semiconductor fabs takes several years. Between 1990 and 2020 there were approximately 635 greenfield semiconductor fabs built around the world. The average time between the construction start date and the beginning date of production was 682 days or roughly 1.86 years. This timeline does not include pre-permitting and pre-construction considerations, indicating that fab construction times exceed two years on average.

There is considerable regional variation in the time it takes to build a new fab. As Figure 1 shows, Japan (584 days) and South Korea (620 days) build fabs significantly faster than the rest of the world on average. The Americas, of which the United States is the primary site of semiconductor fabrication facilities, build fabs at a significantly reduced speed, taking an average of 736 days, or roughly five months longer than Japan. Only construction of fabs in Southeast Asia takes longer than in the Americas. Until the recent slowing of Moore's Law, this industry introduced a new generation of chips every 12 to 18 months, meaning a five month delay in construction could be damaging to a firm's competitiveness. For context, in a period of five months, leading edge foundries like those operated by Samsung and TSMC could produce roughly 500,000 wafers. This trend is particularly troubling as the U.S. industry's position as a leading-edge manufacturer has been ceded to firms in Taiwan and South Korea. Both of these countries maintain the ability to build the world's most advanced fabs at rates that exceed the United States' ability to build trailing-edge fabs.

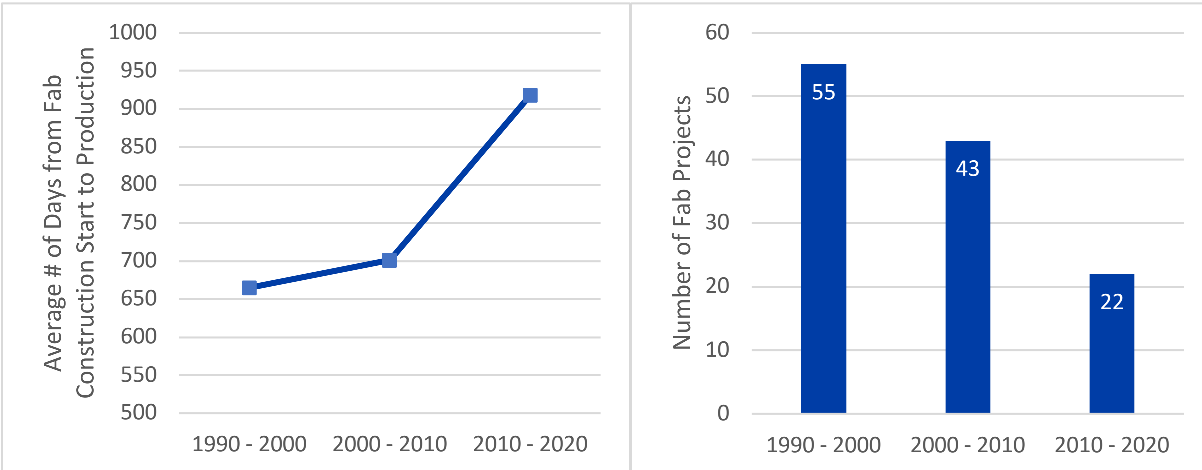
Figure 1. Average Number of Days from Fab Construction Start Date to Production Date, by region 1990-2020



Source: World Fab Forecast. Sample consisted of 635 greenfield fab construction projects with a "construction start" date between 1/1/1990 and a "production date" no later than 12/1/2020. The difference between "construction start" and "production date" was calculated for each fab project and then averaged by region. Figures 2-4 follow this methodology and further break the analysis out by decade.

The United States' ability to expeditiously construct fabs has declined at the same time as the total number of fab projects in the United States has declined. Some of this is due to changes in the global semiconductor value chain, which has concentrated resources in Asia as foundries have risen in prominence, and countries like Taiwan, South Korea, and China have established significant market share in the industry from 1990 to 2020. However, during this same 30-year period, the time required to build a new fab in the United States increased 38 percent, rising from an average of 665 days (1.8 years) during the 1990 to 2000 time period to 918 days (2.5 years) during the 2010-2020 time period (Figure 2). At the same time, the total number of new fab projects in the United States was halved, decreasing from 55 greenfield fab projects in the 1990-2000 time period to 22 greenfield fab projects between 2010 and 2020.

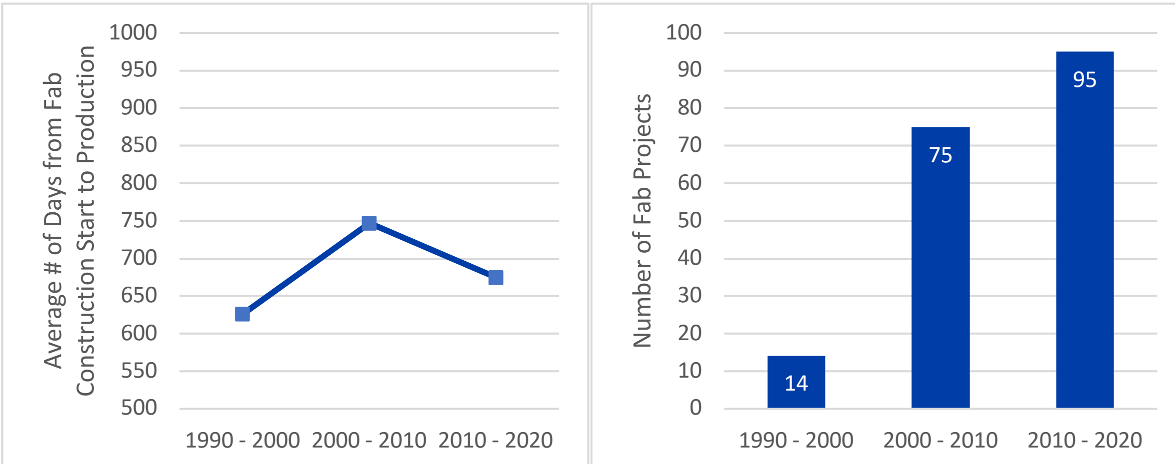
Figure 2. Time Required to Build New Fabs in the United States (L) and Total Number of New Fab Projects (R), 1990 - 2020



Source: World Fab Forecast.

The decline in the total number of new fab projects in the United States, as well as the speed with which those projects are completed, is striking when compared to other countries. In China, for example, the total number of new fab projects has increased from 14 during the 1990-2000 time period to 95 during the 2010-2020 time period (Figure 3). At the same time, China has seen the average number of days from construction start date to production date for these fab projects decrease from a high of 747 days (2 years) during the 2000-2010 time period to 675 days (1.85 years) during the 2010-2020 time period. China is building more fabs and building them faster.

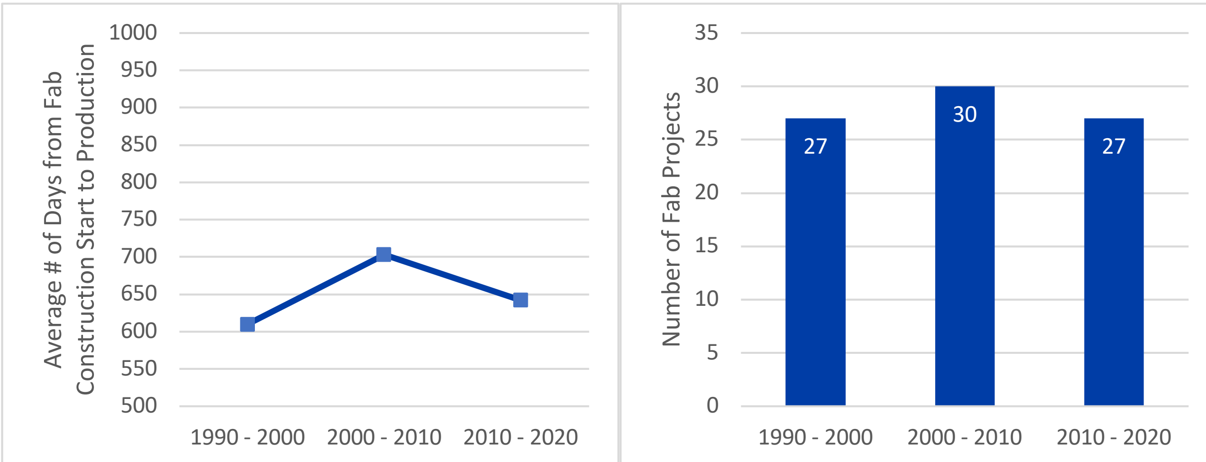
Figure 3. Time Required to Build New Fabs in China (L) and Total Number of New Fab Projects (R), 1990 - 2020



Source: World Fab Forecast.

Similarly, Taiwan, which accounts for 92 percent of leading edge pure-play foundry semiconductor manufacturing today,[4] also builds fabs quickly. Taiwan built 27 fabs between 1990 and 2000 and again from 2010 to 2020, though from the 2000-2010 period the number increased slightly to 30 (Figure 4). At the same time, the average number of days to fab completion rose from 610 days during the decade following 1990 to 703 days during the decade following 2000, before decreasing to 642 days during the decade following 2010. The decrease in the overall number of greenfield fabs constructed in Taiwan coincides with an increase in overall Taiwanese capital expenditures on semiconductor fabs. This could indicate that Taiwanese firms are building a smaller number of large advanced fabs, that Taiwanese firms are simply expanding on existing fabs rather than building new ones, or some mix of both.[5]

Figure 4. Time Required to Build New Fabs in Taiwan (L) and Total Number of New Fab Projects (R), 1990 – 2020

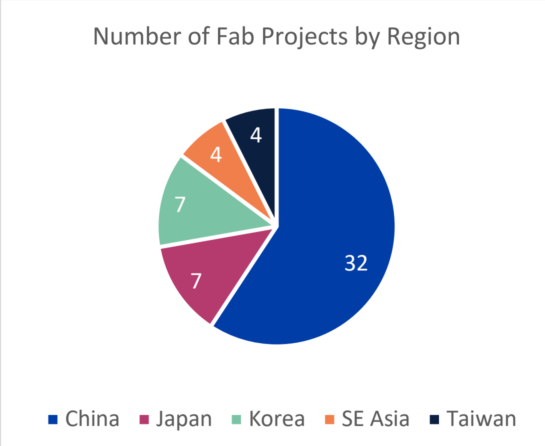


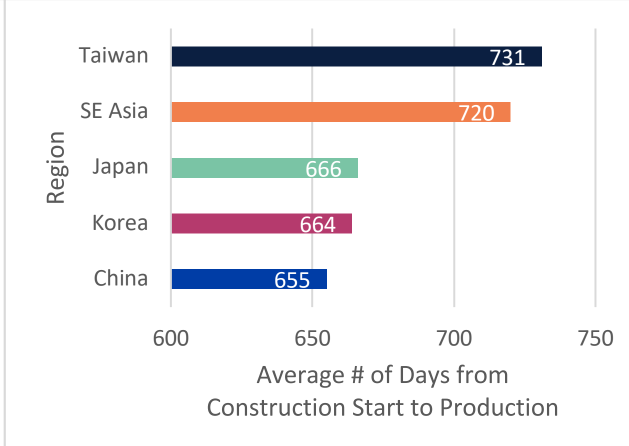
Source: World Fab Forecast.

Comparing average fab construction time across regions while controlling for the size of the fab construction project further illustrates the U.S. deficit in advanced semiconductor manufacturing. As Figure 5 shows, from 1990 to 2020, China built 32 fabs that produce 100,000 or more wafer starts per month (WSpM), while the rest of the world only built 24 during the same time period.* The United States had no greenfield fab projects that involved construction of factories with capacity greater than or equal to 100,000 WSpM during this time period.

* High WSpM correlates strongly with advanced fabrication. The newest and most advanced fabs in the world can have WSpM greater than 200k.

Figure 5. Number of >100k WSpM Greenfield Fab Projects (L) and Average Number of Days from Fab Construction Start Date to Production Date for those Projects (R) by Region, 1990-2020





Source: World Fab Forecast.

There are several important caveats to this data. First, this analysis is limited to greenfield projects and thus does not take into account fab expansion projects frequently undertaken by leading firms like Samsung and TSMC. Second, while China builds large advanced fabs faster than any other region in the world, most of these advanced fabs are owned and operated by non-Chinese headquartered firms. For example, Samsung and SK Hynix (South Korea) and TSMC (Taiwan) operate high volume fabs in China. This is also the case in Southeast Asia, where firms like Micron (USA) have built their most advanced and highest-WSpM fabs. The fact that some U.S.-headquartered firms are choosing to build their most advanced fabs outside the United States speaks to the challenge U.S. policymakers face in crafting subsidies, regulatory support, and an infrastructure environment that is competitive with allied and adversary countries in Asia.

Fab Infrastructure Requirements

This section reviews some of the infrastructure constraints facing chipmakers deciding where to establish greenfield fabs. Modern fabs require access to (1) large plots of (2) seismically inactive land with a reliable, affordable, and stable supply of (3) water, (4) electricity, (5) talent, (6) transportation infrastructure, and (7) nearby land for co-locating with suppliers essential for operating a modern fab.

These infrastructure requirements touch on construction and permitting processes in complex and sometimes costly ways. This section concludes with a discussion of infrastructure investments that other countries with strong semiconductor manufacturing industries have made, which could provide a model for future U.S. infrastructure investments.

(1) Large plots of land. Fabs require large plots of land on which to locate their operations. While the cost of land is not as expensive an input in the semiconductor supply chain as the capital expenditures required to purchase and install semiconductor manufacturing equipment, it can present an obstacle to prospective semiconductor manufacturers. Fab "shells," the physical structures that house semiconductor manufacturing equipment (SME) and all associated materials and supporting operations, can occupy hundreds of acres and account for between 20 and 40 percent of the total capital expenditures associated with a greenfield semiconductor manufacturing facility.[6] For example, Samsung's Austin, TX-based fab occupies 640 acres (1 square mile).[7] Semiconductor manufacturers frequently purchase more land than they initially need in anticipation of future expansion.

(2) Low seismic activity. Fabs and the semiconductor manufacturing equipment inside them are extremely sensitive to ambient vibration, meaning that they must be located in regions that are not seismically active, and on plots of land relatively isolated from highways, airports, and rail links.[8] While there are mitigation options available, and the industry has pioneered novel seismic isolation techniques, these unique requirements further limit the overall geographic supply of ideal building sites.

(3) Stable supply of water. Some estimates indicate a modern fab consumes around five million gallons of water per day.[9] This reliance on a consistent supply of water was recently highlighted in Taiwan, when a record drought forced the government to institute measures to ensure the country's semiconductor manufacturers had access to adequate supplies of water to continue operations.[10]

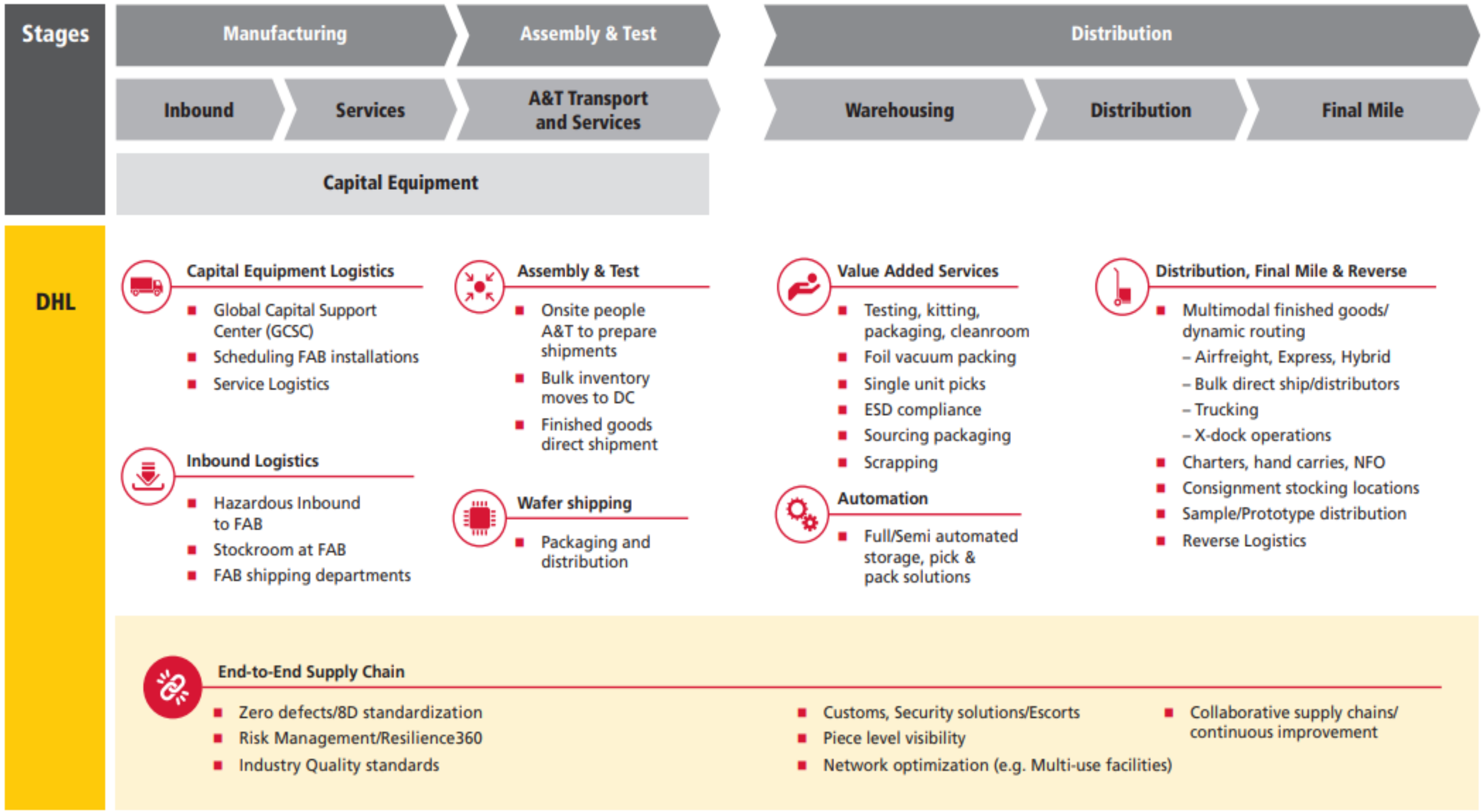
This intensive water consumption frequently necessitates that individual companies take action. For example, TSMC recently announced plans to establish on-site water storage and treatment facilities to prevent potential disruptions stemming from droughts and impurities.[11]

(4) Stable supply of electricity. Fabs rely on a stable electrical grid to sustain their 24/7/365 operations. As wafer processing has increased in complexity and automation, energy consumption has gone up proportionally. Leading edge fabs can now consume as much electricity in one year as 50,000 homes.[12] Once a fab has reached volume production, energy costs can account for up to 30 percent of the fab's operating costs.[13] For smaller countries that are home to significant fab operations like Singapore, Taiwan, and South Korea, these factory operations consume a notable percentage of overall electricity in the country. The OECD estimates that TSMC alone accounted for 7.7 percent of total industrial electricity consumption in Taiwan in 2017.[14] The cost of an electrical grid failure that disrupts fab operations is substantial. A February 2021 power grid failure in Texas shut down Samsung, NXP, and Infineon chip factories for several weeks, costing Samsung alone over $270 million.[15]

(5) Talent. Fab sites need to be strategically located in an area nearby a skilled workforce. This has resulted in fab clusters in close proximity to university systems with a consistent talent pool and in relative proximity to metropolitan areas. In the United States, these clusters include California's Silicon Valley, New York's Tech Valley, and Oregon's Silicon Forest, all of which draw technical talent from nearby cities, universities, and firms.[16]

(6) Transportation infrastructure. Transportation infrastructure also drives the cost of fab construction around the world. The vast majority of semiconductor-affiliated commerce occurs by air freight, necessitating that fabs be close to an international airport. However, there are some chemicals and materials used in the semiconductor production process which, due to their hazardous nature, low value, or extreme weight, ship via ocean freight. In addition, fabs need adequate last-mile road infrastructure to take delivery of particularly large pieces of semiconductor manufacturing equipment and associated material handling devices. For example, ASML indicates one of its Extreme Ultraviolet Lithography systems "ships in 40 freight containers, spread over 20 trucks and three cargo planes."[17] This combination of air, ocean, and land transportation logistics presents myriad supply chain and regulatory bottlenecks. Specialty logistics services have been developed to facilitate semiconductor transportation. One supplier of transportation logistics services targeting the semiconductor industry advertises that they handle everything from SME and hazardous chemical delivery to air freight distribution of finished products (Figure 6).[18]

Figure 6. Transportation Infrastructure Requirements for Semiconductor Production



Source: "DHL Semiconductor Logistics" (DHL, 2017), https://www.dhl.com/content/dam/dhl/global/core/documents/pdf/DHL_Semiconductor_Logistics_2017.pdf.

(7) Nearby land for co-location with key suppliers. Semiconductor fabrication facilities rely on a vast supply chain. Intel, for example, reports that it has identified over 16,000 suppliers.[19] However there are some suppliers whose products or services are so essential to the operations of modern fabs that they must co-locate production and warehousing facilities with the fabs they are supplying. Suppliers of rare gases and specialty chemicals used intensively in fabs need proximate land to establish production and warehousing facilities. Following the announcement that TSMC will be constructing a new fab in Arizona, several Taiwanese suppliers of specialty chemicals and gases to TSMC indicated they will be establishing operations nearby the new facility in addition to their current locations near TSMC's fabs in Taiwan.[20] In this instance, having additional land nearby prospective greenfield semiconductor fabrication sites is another important consideration.

Government Policies to Reduce Infrastructure Costs and Accelerate Fab Construction

Recognizing the costs that these infrastructure requirements impose on semiconductor manufacturers, many countries offer incentives to offset some of the price of constructing new factories. A joint report from the Semiconductor Industry Association and the Boston Consulting Group found that some countries provide both direct support to individual semiconductor companies and also incentives that are designed to facilitate the creation of a semiconductor ecosystem in close proximity to fabs.[21] The Japanese government has offered tax breaks, subsidies, and investments to attract semiconductor companies to establish joint ventures with Japanese firms, mirroring the sorts of incentives proposed by South Korea.[22] Similarly, the Taiwanese government's Ministry of Economic Affairs offers tax and tariff incentives as well as research and development (R&D) subsidies to attract semiconductor companies. Specifically, Taiwan maintains a business tax rate of 17 percent, allows semiconductor firms to credit up to 15 percent of their research & development expenses against their income tax bill annually, and permits firms to import semiconductor manufacturing equipment tariff-free.[23] Subsidies are also available for up to 50 percent of total spending by semiconductor firms who establish an R&D center in Taiwan. International semiconductor firms are clearly responsive to these incentives. The Taiwanese government notes these incentives have successfully attracted Micron, the U.S. memory chip company, to build a fab in Taiwan, while equipment suppliers like ASML from the Netherlands, as well as Applied Materials and Lam Research from the United States, have all set up R&D centers or training headquarters in Taiwan.[24]

In addition, some countries focus on minimizing pre- and post-fabrication operating costs for semiconductor manufacturers. A recent OECD report found that some governments support semiconductor manufacturers through the provision of water and electricity at below-market rates via state utilities.[25] Furthermore, the provision of land at below-market prices to semiconductor manufacturers was observed by the OECD to be a form of investment incentive. The OECD highlighted the case of Tsinghua Unigroup, a Chinese semiconductor firm which "purchased land for its foundry in Chengdu for CNY 240 per m^2, while the official average price for industrial land in second-tier cities was CNY 724 per m^2."[26] The Government of Israel also made use of similar land-specific incentives which were used by Intel to expand its operations in the country.[27]

Finally, many countries in Asia also provide infrastructure support in the form of utilities and logistics investments, as well as providing for expedited procedural consideration and eased regulations associated with semiconductor factory construction.[28] When Micron first considered establishing a fab in Taiwan, the country's investment authority "assisted Micron in terms of land acquisition…accelerated the administrative process…eliminated investment barriers (such as coordinating underground pipelines and sidewalk construction) [and] organized job fairs to help the company recruit talent."[29] Taiwan has also established a series of free trade zones designed to facilitate efficient trading, warehousing, transport, and customs clearance processes that are critical to international semiconductor manufacturers.[30]

The government of Singapore has provided myriad infrastructure investments designed to attract semiconductor manufacturers.

Through government agencies like the Economic Development Board and JTC Corporation, Singapore has established four industrial estates that provide shovel-ready plots of land for semiconductor manufacturers and their suppliers that come pre-equipped with basic infrastructure like power, electricity and roads.[31] These estates also include ready-built facilities that feature chilled water, bulk industrial gas supply, high ceilings to accommodate SME, and incorporate vibration-control construction techniques.[32] The results of the Singaporean government's efforts are clear, having successfully attracted 14 global semiconductor firms employing 18,600 workers in the industry across these estates.[33]

The value of this infrastructure support is not easily quantified but lowers the cost of doing business for semiconductor manufacturers and decreases construction timelines. And the success of this regulatory facilitation and infrastructure investment is clear: GlobalFoundries, one of the leading foundries in the United States, recently chose to substantially expand its semiconductor manufacturing facility in Singapore rather than doing so at its factory in New York.[34]

Semiconductor Fabrication Regulatory Permitting Considerations

Fabs' many infrastructure requirements touch on local, state, and federal EHS regulations. These regulations implicate agencies at each level of government, sometimes with overlapping jurisdictions. As a result, construction must carefully navigate arcane regulatory processes to develop greenfield semiconductor fabs. Recognizing the time delays that these regulations and permitting processes place on semiconductor manufacturers, other countries provide incentives and indirect subsidies to expedite fab construction timelines.

To date, the United States government has not provided sufficient local, state, and federal regulatory support to match the efforts offered by peer semiconductor-producing countries. Regulatory support steps could include fully implementing 2017 recommendations from the President's Council of Advisors for

Science and Technology, such as identifying where federal permitting regulations for high-technology facilities are redundant with state rules and might therefore be modified or removed.[35] The U.S. Environmental Protection Agency (EPA) could also consider creating a "fast track" process for preconstruction and operating permits related to the Clean Air Act (CAA). State and local environmental agencies perform a first review of these permit applications, but the EPA retains the right to review any draft permit and provide comments to state or local authorities. The EPA has experimented with the use of flexible air permits in the past and should create a program specifically tailored to the needs of U.S. semiconductor firms that would accelerate construction of new fabs and re-tooling of existing fabs. For example, following receipt of a flexible air permit, Intel Corporation used this permits' advance approval to make 150-200 equipment changes and process modifications to its Aloha, Oregon fab that would have otherwise required EPA New Source Review permits and resulted in concurrent permits from the Oregon Department of Environmental Quality.[36] This flexible permit allowed Intel to make changes to its fab without notifying environmental regulators, so long as the changes did not result in the fab's emissions exceeding previously agreed-upon levels. This saved the company "hundreds of business days associated with making operational and process changes to ramp up production."[37] Representatives from Intel stated that, had they not received the flexible air permit, continued permitting-related delays would likely have pushed Intel to redirect its production investment and operating facilities to locations where changes could be made within existing environmental regulations (e.g. other U.S. states or the company's fabs in Ireland or Israel).[38]

United States Federal EHS Regulatory Processes

Federal EHS laws and regulations govern both the construction and operation of fabs. These laws and regulations are generally overseen by the EPA, the U.S. Army Corps of Engineers, and the U.S. Department of the Interior. These agencies are tasked with auditing proposed construction projects for compliance with relevant federal regulations that touch on fab utility, transportation, and supply chain infrastructure requirements. For example, a regional economic development association in the state of Washington that sought to increase fab construction in the Pacific Northwest observed that “among local and federal agencies, the Bonneville Power Administration (BPA), the United States Army Corps of Engineers (USACE), and the Environmental Protection Agency (EPA), would be key players in coordinating site reviews with parallel agencies in Washington State.”[39] Table 1 describes federal environmental requirements for construction in greater detail.

Table 1. Federal Environmental Requirements for Construction

Regulation	Relevant Law	Agency Jurisdiction	Associated Requirements
Air Quality	Clean Air Act (CAA)	Environmental Protection Agency	Permit for construction-related pollutant emissions
Asbestos	Clean Air Act (CAA)	Environmental Protection Agency	Report of asbestos releases above a threshold
Dredged and Fill Material/Waters	Section 404 of the CWA	Army Corp of Engineers or state regulator	Permit for discharge of dredged material
Environmental Impact	National Environmental Policy Act	Environmental Protection Agency	Submit Environmental Assessment
			Submit Environmental Impact Assessment
Hazardous Substances	Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)	Environmental Protection Agency	Permit to excavate contaminated soil
Historic Properties	National Historic Preservation Act	United States Department of the Interior	Pre-construction consultation for historic property considerations
Polychorinated biphenol (PCB) Wastes	Toxics Substances Control Act (TSCA)	Environmental Protection Agency	Storage and disposal requirements
Solid and Hazardous Wastes	Resource Conservation and Recovery Act (RCRA)	Environmental Protection Agency	Transporters of hazardous waste must register with EPA
Spill Reporting			Maintain a material safety data sheet (MSDS)

	Emergency Planning and Community Right-to-Know Act (EPCRA)	Environmental Protection Agency	Report any spills of a "reportable quantity" of hazardous chemicals
Storm Water Runoff	Clean Water Act (CWA)	Environmental Protection Agency	Submit a Notice of Intent
			Submit a Storm Water Pollution Prevention Plan (SWPPP)
			Submit a Notice of Termination upon completion
Threatened or Endangered Species	Endangered Species Act	United States Department of the Interior	Pre-construction consultation for potential harm to threatened or endangered species

Source: U.S. Environmental Protection Agency, “Federal Environmental Requirements for Construction,” https://www.cem.va.gov/pdf/fedreqs.pdf; “Chapter 17 – Environmental Requirements for Construction Projects” in *Ames Environmental Procedural Requirements* (Mountain View, CA: NASA Ames Research Center), https://procure.arc.nasa.gov/assets/docs/APR8800.3-R/8800_3_C17.pdf.

At the federal level, there are many laws designed to maintain environmental quality that are also known to often significantly delay major construction projects. Notably, the National Environmental Policy Act (NEPA) review process governs construction projects deemed to be a “major federal action.”[40] If the provision of CHIPS Act incentives are determined to be a “major federal action”[41] then the construction of new semiconductor fabs could be significantly delayed.[42] In 2020 the White House Council on Environmental Quality compiled data on timelines for 1,276 Environmental Impact Statements (EIS) filed between 2010 and 2018 and found that NEPA reviews averaged 4.5 years.[43] This permitting process does not include the average of 1.86 years it takes to physically construct a semiconductor fab. This number also does not reflect other federal environmental reviews, some of which may happen concurrent with the NEPA process or entirely separately. A 2017 report from the White House also identified preconstruction permits and operating permits required under the Clean Air Act as “the primary barrier to responsible and timely facility permitting” finding that “for some large projects, [this] permitting process can take 12–18 months.”[44] More recently, the EPA has announced a goal to make permitting decisions within six months of receipt. But as discussed earlier, given the tight timelines on which this industry operates, any delay can be costly to a firm's competitiveness.[45]

U.S. State and Local EHS Regulatory Processes

State and local EHS regulations and agencies also have a bearing on semiconductor manufacturers. In some cases, the EPA delegates authority to implement regulatory programs to states and other agencies. For example, the U.S. Army Corps of Engineers (USACE) administers Section 404 of the Clean Water Act, which regulates the discharge of dredged and fill material into all waters of the United States. The USACE's Fort Worth, TX District reviewed an application of Samsung Austin Semiconductor LLC in 2014 to expand their fabrication facility in compliance with Section 404 of the CWA. However, this application also invoked reviews being conducted concurrently by the Texas Commission on Environmental Quality and a City of Austin Development Permit.[46] Even after federal and state-level concerns are addressed, semiconductor building sites may run into local regulatory barriers. When GlobalFoundries was considering building a new fab in Malta, NY there were lingering zoning changes at the local level that needed to be made by the Town Boards of Malta and Stillwater, NY which delayed the site's initial development.[47]

United States Regulatory Processes Affecting Semiconductor Suppliers

In addition to constructing fabs, a process which takes a minimum of two years, the process of establishing a more resilient semiconductor supply chain in the United States necessitates increased domestic production of critical minerals, materials, chemicals, and gases, all of which require lengthy permitting processes. As a result, ongoing collaboration with international allies may be a more expeditious means of increasing semiconductor supply chain resiliency than attempting to increase domestic production in the short term. Some of the semiconductor supply chain, such as providers of specialty chemicals, would need to construct production facilities that would implicate many of the same regulatory considerations identified in Table 1. Other parts of the supply chain, such as suppliers of raw minerals, would encounter entirely new regulatory considerations such as mining permits that may slow the ability to ramp up domestic production. The June 2021 White House supply chain report found "establishing strategic and critical material production is an extremely lengthy process. Independent of permitting activities, a reasonable industry benchmark for the development of a mineral-based strategic and critical materials project is not less than ten years."[48]

United States-based production of materials, chemicals and gases used in semiconductor manufacturing is, with few exceptions, limited. The United States Geological Survey's 2020 Mineral Commodities survey indicates materials like Arsenic, Beryllium, Bismuth, Boron, Cadmium, Helium, Indium, Rhenium, and Silicon are all used in the semiconductor manufacturing process.[49] The National Institute of Standards and Technology also maintains an index of 49 semiconductor process gases used in semiconductor production.[50] Except for a few materials like Helium and Silicon, U.S. firms do not produce or refine these materials in the United States. For example, Intel reports that it relies on smelters and refiners in China, Japan, Germany, Russia, Vietnam, the Philippines, Austria, and the United States for its supply of Tungsten, a key metal that is used to produce tungsten hexafluoride and tungsten sputter targets, both of which are used in the majority of semiconductor devices.[51]

One reason that United States firms are not major suppliers of semiconductor materials is the increased cost of doing business in the United States. A Taiwanese supplier of specialty gases estimates that it costs five to six times more for them to build a factory in the United States than in Taiwan.[52] This price disparity is driven by several factors. In addition to contending with some of the construction permitting described above in Table 1 and higher labor market rates,[53] Taiwanese suppliers of semiconductor materials identified "the role of transportation systems" and a need for "seamless dual supply of electricity and natural gas at a favorable rate for the operation of purification and solvent recovery plants" as important factors, and requested federal and state government help to improve transportation system connectivity and utility provider reliability.[54] Both of these companies are single source suppliers of chemicals for TSMC in Taiwan and expressed interest in supplying TSMC's United States facility, but observe a clear increase in the cost of doing business in the United States.

United States-based production of materials, chemicals and gases used in semiconductor manufacturing is also limited because many of these goods are derived from, or contribute to, environmentally harmful practices. For example, the semiconductor industry intensively consumes hydrofluorocarbons in the manufacturing process, a type of gas that is recognized by the EPA as a high global warming potential (GWP) greenhouse gas (GHG).[55] HFCs for semiconductor use are generally not produced in the United States. Recently, The Biden Administration's support for the Kigali Amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer committed the United States to cap, and ultimately reduce, the semiconductor industry's use of HFCs.[56] However, until the semiconductor industry can innovate a substitute for the use of HFCs and qualify suppliers, there is no short-term alternative except to continue importing HFCs. Increasing the domestic resilience of this part of the supply chain in the medium to long term requires finding an international supplier willing to navigate the regulatory bureaucracy to establish new operations in the United States.

Several companies and industry associations have highlighted how United States government regulatory decisions may increase the costs of doing business in the United States for semiconductor manufacturers and their suppliers. For example, the EPA has undertaken risk evaluations of several chemicals under the Toxic Substances Control Act that are used in the semiconductor manufacturing process.[57] Depending on the findings of these risk assessments, new regulations may restrict the production and supply of these chemicals in the United States[58] In addition, Executive Order 140083 (January 27, 2021) and the subsequent implementation of a temporary ban on new oil and gas leases under Department of Interior Order No. 3395 may reduce future opportunities for domestic helium development. Helium is recovered from natural gas deposits but exists in economic quantities in only a few places within the United States, mainly on federal lands, and is intensively used in semiconductor manufacturing.[59]

Conclusion

This report demonstrates that the United States is building fewer fabs at a slower rate than the rest of the world. CHIPS Act manufacturing incentives correctly aim to increase the number of fabs constructed in the United States, but more policy work is needed to ensure these new fabs are built on time and on budget.

Prioritize regulatory support at the local, state, and federal level to expedite fab construction. The United States should make infrastructure investments targeting utilities, transportation, and supply chain networks that will assist semiconductor manufacturers. These policies would make the United States competitive with the “foreign allies and competitors” identified in the June 2021 White House supply chain report, and would align United States incentives to match those already offered abroad.

Fully implement several of the recommendations from the 2017 PCAST report:[60]

1. The Federal government should review permitting for technology facilities to identify areas where regulations are redundant with state rules and might therefore be modified or removed.

2. The EPA should create additional “fast track” permitting options that allow fabs to make some operational changes without filing environmental permit applications, potentially modeled after the State of Oregon’s Plant Site Emissions Limit (PSEL) program.[61]

Engage with allies and partners to increase semiconductor supply chain resiliency in materials, gases, and chemicals. Because increasing domestic United States production of many raw materials and chemicals would be contingent on lengthy development of mining and/or refining capacity, coordination with allies who already have existing production and refining capacity is essential.

Quantify current and forecasted demand for materials, gases, and chemicals used in United States semiconductor manufacturing.

Stockpiling of certain materials, modeled after existing United States government programs like those operated by The Defense Logistics Agency Strategic Materials branch,[62] may be an option.

Identify substitutes for environmentally harmful or strategically concentrated resources. The EPA is currently supporting semiconductor industry efforts to develop substitutes for environmentally harmful greenhouse gases used in semiconductor manufacturing. These efforts could serve as a template for further work to identify substitutes for certain materials, chemicals, and gases used in semiconductor manufacturing for which there is no commercially viable domestic supply.[63]

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