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Reshoring Semiconductor Manufacturing

Addressing the Workforce Challenge

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On August 9, 2022, President Biden signed the CHIPS and Science Act, sweeping legislation that seeks to strengthen the U.S. semiconductor supply chain, encourage investments in semiconductor manufacturing facilities in the United States, stimulate semiconductor research and development (R&D), and disincentivize U.S. investments in chip-making plants in China. Among other things, the legislation will provide $52.7 billion in federal outlays over five years for loans, loan guarantees, grants, and other financial support for domestic chip-making investments, as well as a 25 percent tax credit for semiconductor investments in the United States. Bolstered by this unprecedented level of federal support, six major chip makers are investing in new wafer fabrication facilities ("fabs") in the United States: Intel, Samsung, TSMC, GlobalFoundries, Texas Instruments, and Micron Technology.

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FINDING THE CONSTRUCTION WORKERS AND FAB OPERATORS

This is very good news for the U.S. economy from many perspectives. Yet while a number of these projects have already broken ground, they are encountering a significant challenge: a shortage of construction workers needed to build the new facilities and a lack of qualified workers to run them. A prime illustration is in Arizona, where TSMC and Intel are racing to build new fabs while competing for scarce workers in the tightest U.S. labor market in decades.

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Six thousand construction workers are currently engaged in building TSMC's new Arizona fab, but the company, which had planned to begin installing equipment in September 2022, now says the date will be pushed to the first quarter of 2023 because of construction delays. The situation is similar in Ohio, where Intel is building new fabs at two sites near Columbus which will require 7,000 construction workers—a workforce that labor leaders and state officials insist Central Ohio does not have.

The shortage of construction workers is national in scope, driven not only by new chip investments but also by the $1.2 billion 2021 Infrastructure Investment and Jobs Act, and most recently by the $739 billion Inflation Reduction Act, leading to a "demand for a volume of construction workers that, in many markets, simply doesn't exist."

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While the current shortage of construction workers to build new fabs presents a serious immediate challenge to U.S. efforts to reshore semiconductor manufacturing, the problem is overshadowed by the longer-term question of where the workers will be found to staff the new fabs once they are built. Although semiconductor manufacturing is a highly automated process, each fab requires hundreds of skilled workers, in some cases over a thousand. U.S. chipmakers are already grappling with a talent shortage, and according to some estimates, when the new U.S. fabs now being planned come on stream, an additional 70,000 to 90,000 fab workers will be needed. Some suggest that if the United States were to seek to become self-sufficient in chips, the number would rise to around 300,000.

Semiconductor manufacturing requires a diverse array of highly specialized skills. Sayed Alam, the global head of Accenture's semiconductor practice, observed that "you need the PhDs in materials sciences and electrical engineering for some advanced silicon technology work, you need electrical engineers for manufacturing and other things, and then you also need a lot of people who will be working on the software, or as print technicians, factory supervisors, or factory machine operators." At present, in the U.S. semiconductor industry, a "skills gap" exists in virtually every job category. As one chip start-up CEO asserts, "it's not like there's a specific type of person or function missing. It's across the board."

The chip-making skills gap has been long in the making. During the past several decades, much U.S. chip manufacturing moved offshore or was outsourced to foundries in Asia. As a result, the chip-making competencies of the U.S. workforce have eroded. At present, chip manufacturing is a career path that many Americans are not aware of. One Arizona-based human resources director observed in 2022 that "you say 'semiconductor manufacturing' [to potential recruits], people look at you like you have two heads. It's just unfamiliar." And while the United States retains some semiconductor manufacturing—accounting for about 12 percent of the world total—U.S. production is several generations behind the leading edge, which is now held by producers in Taiwan and South Korea. For the most part, the know-how for the most advanced chip-making processes resides outside the United States.

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TALENT SHORTAGE AND COMPETITION: A GLOBAL CONCERN

The talent shortage in semiconductor manufacturing is not merely a U.S. phenomenon—it is global in scope, affecting even the leading-edge producers in Taiwan and South Korea.

- Taiwan, which has the most advanced semiconductor manufacturing facilities in the world, reportedly had a shortfall in chip-making workers of over 30,000 in the fourth quarter of 2021, a 77 percent increase from the second quarter of 2020.
- South Korea's semiconductor industry is forecasted to experience a shortfall of at least 30,000 skilled workers in the coming decade, with domestic universities producing less than half the number of graduates needed to address the industry's needs.
- China's drive to become a major competitive force in the global semiconductor industry is being hamstrung by an extreme shortage of skilled semiconductor workers; a recent university study found that the worker shortfall exceeded 300,000 and was getting worse.
- Japan's major semiconductor manufacturers are warning the government that the country's shortage of skilled workers is jeopardizing the current effort to revive the domestic semiconductor industry, citing a need to hire 35,000 additional engineers over the next decade.
- Europe faces similar problems. European semiconductor executive Henryk Schoder observed that "the talent shortage is the biggest challenge to semiconductor industry growth in Europe and globally."

The result of the worker shortage is an intensifying global competition for semiconductor engineers and technicians. Taiwan's TSMC, currently the most advanced chipmaker, is reportedly scouring job markets in the United States, India, Canada, Japan, and Europe to recruit experienced semiconductor workers. At the same time, TSMC is struggling to stave off aggressive recruiting efforts directed at its own workforce by Chinese semiconductor firms, which succeeded in hiring over 100 veteran TSMC engineers and managers in 2019 and 2020.

In Taiwan, the government and more than a dozen major semiconductor companies have pledged to invest $300 million over the next 10 years to create graduate programs for the semiconductor industry. Four top Taiwanese universities have applied to the Ministry of Education to establish new chip schools, with more schools envisioned after these. The schools are expected to raise funds from the private sector, and the government National Development Fund will match the private funds. The first of the new schools, being established under the auspices of the National Yang Ming Chiao Tung University, will be operated independently from the university system in order to attract more top-flight professors and industry executives to serve as faculty. The institution will be run like a successful medical school, integrating research and clinical experience.

Similarly, China, facing a major shortage of workers to support the semiconductor industry, is establishing new microelectronics schools and programs. In 2021, a leading Chinese academic institution, Tsinghua University, established a specialized chip college to train semiconductor engineers. Peking University, a major university in Beijing, also recently opened its first integrated circuits school.

SOURCES OF U.S. STRENGTH

While the chip-making talent shortage is a serious global problem, it is a challenge that the United States is comparatively well positioned to surmount if it can make effective use of its assets and resources.

- Crucially, the United States has by far the best system of research universities in the world, many of which are already offering curricula and engaged in research directly relevant to semiconductor manufacturing.
- The United States has some excellent community colleges offering curricula and training programs designed to give graduates the skills necessary to enter careers in semiconductor manufacturing.
- The CHIPS and Science Act is making available over $13 billion in federal funds for semiconductor research and training, including funding for a National Semiconductor Technology Center and a Department of Defense program to establish a university-based microelectronics commons, both of which have strong education and training dimensions. The act also allocates $200 million to the National Science Foundation for education and training in microelectronics.
- The U.S. semiconductor industry has long demonstrated, notably through the Semiconductor Research Corporation, that it is prepared to make large and continuing investments in the research relevant to future industry needs in partnership with the government in order to ensure a supply of trained engineers to support U.S. competitiveness in chip research and manufacturing.
- Importantly, despite onerous visa restrictions, the United States remains a favored destination for foreign engineers and scientists with chip-making skills.

UNIVERSITY CURRICULA AND INDUSTRY COLLABORATION

U.S. research universities have a long history of developing and offering curricula and research collaborations relevant to the needs of the semiconductor industry. The early successes of the U.S. chip industry were given considerable impetus by the Department of Electrical Engineering at Stanford, which launched courses on the design and manufacturing of integrated circuits soon after the first devices became available in 1961 and added engineers from leading companies to its faculty to ensure the current relevance of its curricula. University-industry research collaborations have been a principal source of talent for the U.S. chip industry down to the present day.

Currently, in response to the talent shortage and the funding incentives in the CHIPS and Science Act, a number of new university-based initiatives are under way:

- In 2022, Purdue University launched its Semiconductor Degrees Program, which will offer undergraduate degrees and masters and postgrad certificates in all of the semiconductor industry's key process steps—chemicals and materials, tools, design, manufacturing, packaging, and supply chain management. This is the first program of its kind in the nation.
- In 2021, the State University of New York (SUNY), which is already one of the world's leading centers of applied chip-making research and education, announced a comprehensive series of initiatives to support U.S.-based semiconductor manufacturing. SUNY is planning a dramatic expansion of education and training programs in the recognition that "the training of many more educated students will be needed, particularly in New York State, for the growing semiconductor industry, and the strategy centers on providing more New Yorkers, as early as possible, with access and education in microelectronics and semiconductor manufacturing."
- The University of Texas at Austin is proposing to lead the Texas Institute for Electronics (TIE), a public-private partnership engaging semiconductor and defense electronics companies, national labs, and 13 academic institutions across the state "to restore leading-edge semiconductor manufacturing back to American soil." The initiative would establish research fabs at the academic sites, including a secure

fab to address defense electronics makers' needs and an innovation fab to support the needs of the commercial chip industry.

- Following Intel's announcement of plans to build two major semiconductor manufacturing plants in Ohio, 11 research institutions in Ohio, Indiana, and Michigan joined to form the Midwest Regional Network to Address National Needs in Semiconductors and Microelectronics, which will collaborate on industry-relevant research and "talent development to meet the workforce needs of Intel and other semiconductor companies." One of these institutions, Wright State University, is launching an Intel Initiative to "align academic programs across the university to help provide a skilled workforce for the company, including Intel internships and co-ops."

As promising as these university initiatives are, they are unlikely to generate the needed numbers of trained scientists and engineers in the short term. There is especially a need for targeted immigration to help the United States acquire highly educated researchers and engineers from other countries. As researchers Will Hunt and Remco Zwetsloot point out, "to give onshoring the best chance of success, the United States must also onshore the STEM talent it needs to compete."

KEY OBSTACLES FOR UNIVERSITIES

Despite the priceless national resource and strategic asset that U.S. research universities represent, these institutions confront a number of obstacles in producing a workforce with the necessary numbers and skill sets to enable the Unites States to regain world leadership in semiconductor manufacturing:

- **Outdated Programs.** The U.S. academic curricula needed to train students for careers in advanced semiconductor manufacturing are comprised of a mix of relevant and obsolete coursework and should be overhauled to be adequately aligned with industry needs.

- **Too Few Students**. Not enough students are entering academic fields relevant to semiconductor manufacturing.

- **Aging Faculty and Equipment**. As stated in a report by the American Semiconductor Academy initiative and the SEMI Foundation, "training programs are faced with an aging population of faculty and instructors and high cost of infrastructure (facilities and equipment, consumables, lab operation/ maintenance, simulation and design software)."

- **Few Training Facilities.** Only a small number of U.S. universities have on-site wafer fabrication facilities sufficiently sophisticated enough to enable students to gain hands-on chip-making experience in a factory environment. Furthermore, these departments are unevenly distributed around the country, limiting the ability of many university programs to offer such practical learning experience. There is only one university site in the United States where the most advanced 300 mm manufacturing facilities are available: the State University of New York's Albany Nanotech Complex, home of SUNY's College of Nanoscale Science and Engineering. Upgrading a university fab even to 200 mm wafer size—a generation behind 300 mm—would cost $80 million initially and $80 million a year afterward, investments on a scale impossible for many academic institutions.

- **Competition for Workforce**. Large U.S. tech firms like Google and Amazon are competing for engineering graduates to write software, reducing the number that enter the semiconductor field.

- **Limited Access.** A number of U.S. populations are historically underrepresented in U.S. university science and engineering programs, including educational pathways relevant to semiconductor manufacturing.

THE CRITICAL ROLE OF COMMUNITY COLLEGES

A recent study of GlobalFoundries' fab in Malta, New York, found that nearly two-thirds of the workforce was comprised of technicians and operators who work in the clean rooms and run the facilities, as well as technicians who operate the fab's utilities—water, HVAC, heating, power, cooling, and other aspects of the infrastructure. These jobs do not necessarily require individuals with four-year college degrees, but they do demand personal qualities such as physical stamina, the ability to function on a team, attention to detail, motivation, math and computer proficiency, and a gamut of specialized skills. The region's community colleges have taken up this challenge, offering a growing range of two-year degree coursework and training programs designed to qualify workers for careers in semiconductor manufacturing.

Hudson Valley Community College (HVCC) in Troy, New York, has been offering a two-year semiconductor degree program since 2005, and in 2010 opened TEC-SMART, an extension center that trains students in semiconductor manufacturing and supporting mechanical systems using miniature versions of manufacturing equipment simulating the operation of a 300 mm wafer fab. HVCC recently launched a $12.5 million expansion of the TEC-SMART site.

- HVCC also provides the non-degree Required Technical Instruction courses to support an innovative Registered Apprenticeship Program for technicians at GlobalFoundries offered by the National Institute for Innovation and Technology under an exclusive U.S. Department of Labor Office of Apprenticeship (USDOL-OA) contract to establish and expand Registered Apprenticeships throughout the semiconductor sector and nanotech-related industries.
- Nearby Schenectady Community College (SCC) introduced an associate's degree program in nanoscale materials technology in 2006, which trains students in high-tech manufacturing.
- Other community colleges in the region have introduced curricula and training programs relevant to careers in chip manufacture.
- With the new wave of chip investments in the United States, the community colleges will have a critical role in addressing the skills gap with respect to workers that comprise the majority of a chip fab's workforce.

KEY HURDLES FACING COMMUNITY COLLEGES

Like universities, community colleges face a number of hurdles in confronting this challenge:

- **Missing Talent Pipeline.** In general, an efficient talent pipeline does not exist to connect community colleges with the various technician and operator positions that comprise the bulk of the semiconductor manufacturing workforce. Despite job fairs, interviews, job-matching sites, and other traditional mechanisms, there is currently no efficient way to match the specific needs of chip makers with job seekers with the requisite skill sets. New approaches are needed and fortunately are now underway—see below—but the challenges are many.
- **Inadequate STEM Preparation.** Despite the strong probability of well-compensated employment after graduation, HVCC, which offers one of the most successful community college semiconductor education programs, has experienced chronic difficulty in filling its semiconductor manufacturing classes, and a significant number of students have dropped out prior to completing coursework. Some observers attribute this phenomenon to weaknesses in STEM education that make it difficult for students to satisfy the demanding requirements of such programs.

- **Inadequate Scale.** Community college semiconductor programs are too small relative to the workforce needs of manufacturers. As an example, in the decade after it started operations in 2011, GlobalFoundries needed to recruit around 300 workers a year just to keep pace with turnover. At that time, the HVCC semiconductor manufacturing program—the most significant community college chip-making program in the state of New York—was graduating roughly 12 students a year, not all of whom pursued careers at GlobalFoundries. The scaling-up need at the community college level is now even more acute given the large-scale new investments in the United States envisioned by chip makers. In Ohio, where Intel's new fabs will reportedly require 3,000 workers, Lorain County Community College offers associate's and bachelor's degrees in a highly regarded program in micro-electronics mechanical systems (MEMS), which features, among other things, three classroom clean rooms supporting manufacturing simulations. However, in 2022, the graduating MEMS bachelor's degree class consisted of only four students—and Lorain offers the only MEMS program in the state of Ohio.

- **Need for Flexibility to Update Courses.** The rapid pace of technological advance in semiconductor manufacturing requires community colleges to frequently update their curricula to remain relevant to specific industry requirements for technicians and operators. While one problem lies in the challenge in engaging industry to ensure that course curriculum reflects job requirements in a fast-changing sector, in some states (e.g., New York) the creation of new courses can require multiple approvals at the state level and can become mired in bureaucratic oversight. New programs are slow to be approved, and colleges cannot enroll students in non-approved programs. Keeping training in step with evolving industry needs may require modifications in university governance, or more probably the creation of parallel institutions focused on the unique needs of semiconductor manufacturing. In New York, the creation of foundations operating with greater independence under the auspices of the university proved highly effective. If used well, the CHIPS and Science Act funding can serve as a powerful lever to encourage institutional innovation among universities and community colleges alike.

NATIONWIDE COLLABORATIONS

The challenges noted above that face the U.S. education and training infrastructure supporting chip-making are now being addressed at the national level through a number of industry-government-academia collaborations. The CHIPS and Science Act is adding impetus to these initiatives; one MIT professor of engineering commented that "no sane university with a strong interest in microelectronics is sitting this out."

ROLE OF THE SEMICONDUCTOR RESEARCH CORPORATION

While it is too early to say whether these new initiatives will succeed, it is worth noting that—as far as semiconductors are concerned—industry, academia, and government share a long tradition of successful collaboration at the national level with respect to workforce development. As noted, a major example was the decision in 1982 by the Semiconductor Industry Association (SIA) to spearhead the formation of the Semiconductor Research Corporation (SRC), a consortium that directed industry funds for long-term university research relevant to the industry's needs. The federal government subsequently contributed matching funding. Since its inception, SRC sponsored over 16,000 undergraduate and graduate research scholars, substantially strengthening the nation's workforce in this key industry.

THE AMERICAN SEMICONDUCTOR ACADEMY INITIATIVE

In a major step forward, in February 2022 the American Semiconductor Academy (ASA) initiative was launched, in conjunction with the Semiconductor Equipment and Materials Institute (SEMI), creating a collaborative national education network of faculty at over 200 U.S. universities and community colleges engaged in semiconductor education and research. The ASA seeks to build a workforce education and training network to close the microelectronics talent gap. Key aspects of this effort include the following:

- **Improved Curriculum**. The creation of an up-to-date and comprehensive curriculum—in partnership with the semiconductor industry—in integrated circuits and systems, semiconductor materials and devices, and microfabrication, which will be shared across the entire ASA network, will help ensure that students receive the education they will need for careers in the semiconductor industry.
- **Apprenticeships**. Offering hands-on training in semiconductors, integrated circuits, microfabrication, and wafer processing tools at designated university hubs in each of the ASA's three national regions will further workforce education. Each hub will be equipped and staffed to support this training, which will be available to students that have completed the ASA's required coursework.
- **Prototyping**. Prototyping services at the university hubs will be essential for innovative materials, processes, and devices to demonstrate their merits and suitability for high volume manufacturing, thereby enabling an acceleration of the movement "from lab to fab."

NATIONAL TALENT PIPELINE DEVELOPMENT INITIATIVE

The Department of Labor took early action on the talent challenge and has helped launch a successful program that has the advantage of being electronically based. This program, known as the National Institute for Innovation and Technology (**NIIT**), provides comprehensive national strategy and infrastructure to develop the skilled workforce needed by the semiconductor industry.

In view of scaling up the required infrastructure and relevant education and training programs to a national level, NIIT has worked with state and local stakeholders to leverage existing programs, resources, and infrastructure. By focusing on what already exists, this initiative is helping free up resources to allow for a more rapid deployment of a proven approach.

With funding support from the National Science Foundation Advanced Technological Education (NSF-ATE) program, NIIT has built the National Talent Hub, a portal to attract, build, and connect the talent pipeline for strategic tech-based industries. Key features of this innovative approach include the following:

- **The Nation's First Semiconductor Competency Standard (SCS)**. Developed with comprehensive industry engagement, SCS provides dynamic, real-time signaling from employers to ensure alignment between course curricula and job requirements.
- **Curriculum Alignment Process (CAP)**. This process aligns training and education course content with up-to-date industry requirements.
- **Skills Assessments and Opportunity Mapping**. This allows individuals to assess their skills in order to determine in detail their alignment with jobs, as well as to identify courses that can fill their skill gaps.
- **Job-Relevant Training**. This feature reaches underrepresented populations and encourages them to build industry-required competencies throughout the education continuum—starting from K-12 through community colleges, universities, and adult and veterans training programs.

- **The Expansion of Registered Apprenticeship Programs**. Designed for the semiconductor and nanotech industries, this program makes "learn and earn" opportunities available to a much broader segment of the population. It includes pre-apprenticeship programs to create a career pathway for younger adults.

A distinctive feature of this program is that it is already in operation and continues to build on active partnerships with the semiconductor industry.

BUILDING A GLOBALLY COMPETITIVE WORKFORCE

The United States faces a significant challenge over the near term in building a globally competitive workforce, even as new investments are being made. Institutions, especially large university systems, can be slow to change. Still, the good news is that over the longer term the education and training required to meet chip makers' needs can directly address some of the adverse socioeconomic effects that have resulted from decades of offshoring of U.S. manufacturing and the accompanying loss of well-paid jobs.

Jobs in the chip industry pay well, including the technician and operator positions that account for most chip-making employment; in fact, the positive downstream effects of fab payrolls can revitalize an entire region. The CHIPS and Science Act provides a unique opportunity to attract and train a more diverse and inclusive generational cohort of engineers and technicians. The new programs and initiatives described here offer a promising path forward, but success will require leadership and persistence to effect the necessary changes. ■

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