CHIPPING AWAY

ASSESSING AND ADDRESSING THE LABOR MARKET GAP FACING THE U.S. SEMICONDUCTOR INDUSTRY

JULY 2023

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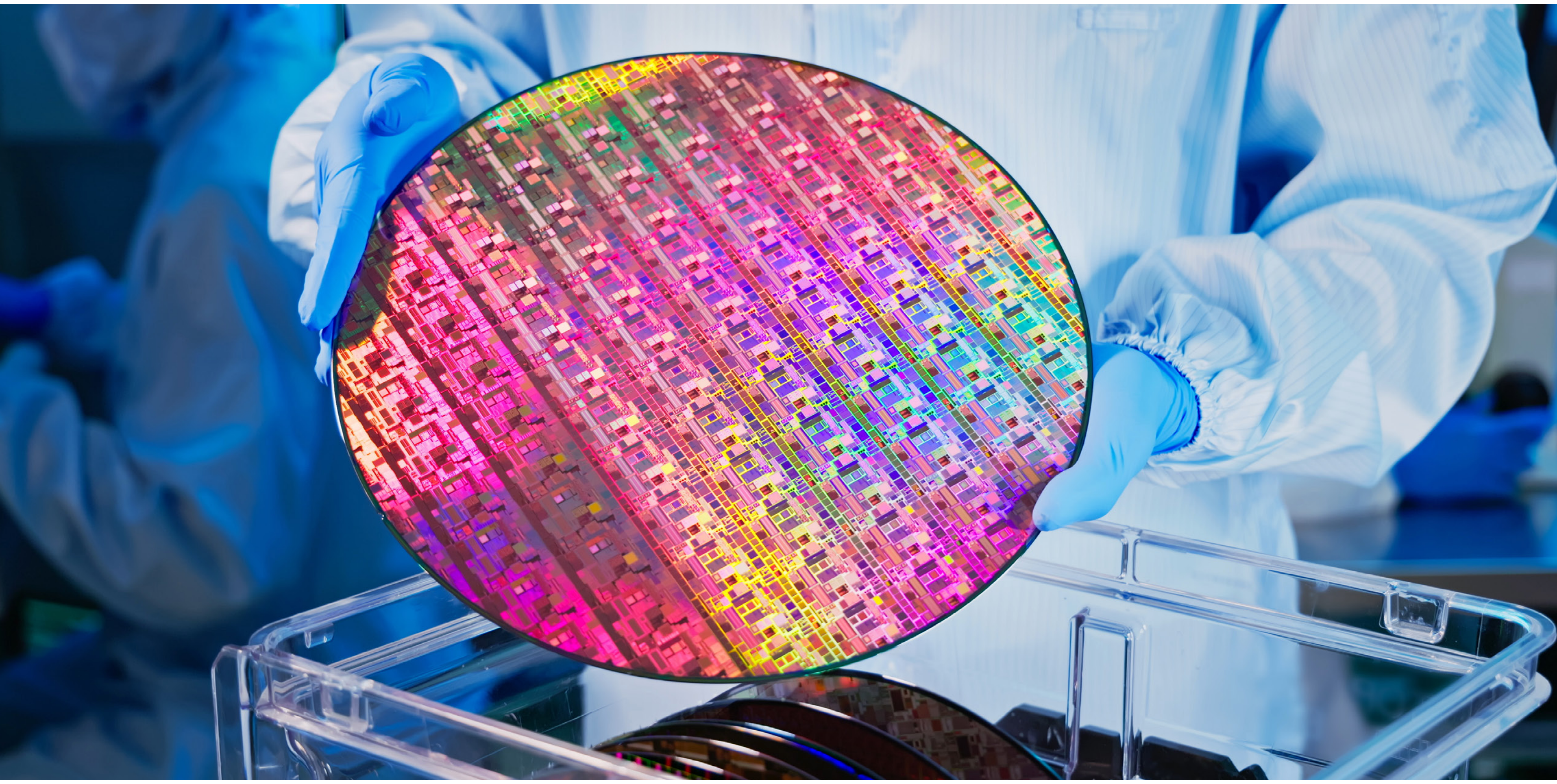
CONTENTS



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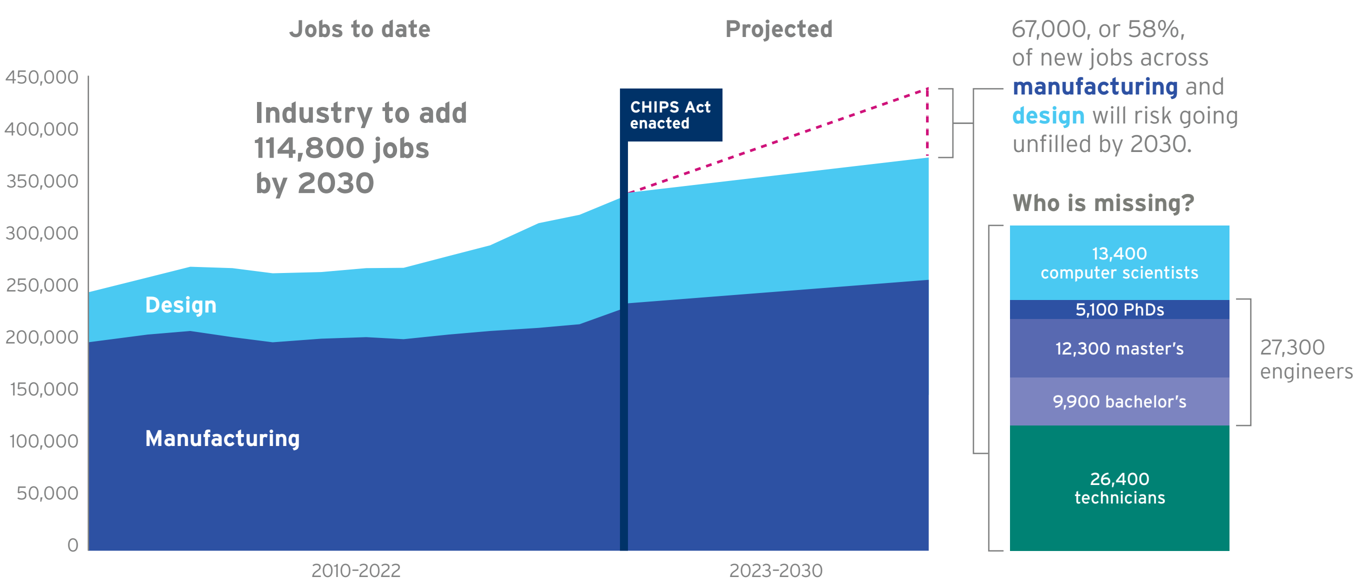
EXECUTIVE SUMMARY

Semiconductors are at the heart of America's strength, enabling the essential technologies that drive economic growth and national security. With demand for semiconductors projected to increase significantly by 2030 and beyond, semiconductor companies are ramping up production and innovation to keep pace.

Fortunately, thanks in large part to enactment of the landmark CHIPS and Science Act of 2022, a significant share of new chip manufacturing capacity and R&D is expected to be located in the U.S. But as America's semiconductor ecosystem expands in the years ahead, so too will its demand for semiconductor workers with the skills, training, and education needed in the highly innovative semiconductor industry.

We project the semiconductor industry's workforce will grow by nearly 115,000 jobs by 2030, from approximately 345,000 jobs today to approximately 460,000 jobs by the end of the decade, representing 33% growth. Of these new jobs, we estimate roughly 67,000—or 58% of projected new jobs (and 80% of projected new technical jobs)—risk going unfilled at current degree completion rates. Of the unfilled jobs, 39% will be technicians, most of whom will have certificates or two-year degrees; 35% will be engineers with four-year degrees or computer scientists; and 26% will be engineers at the master's or PhD level.

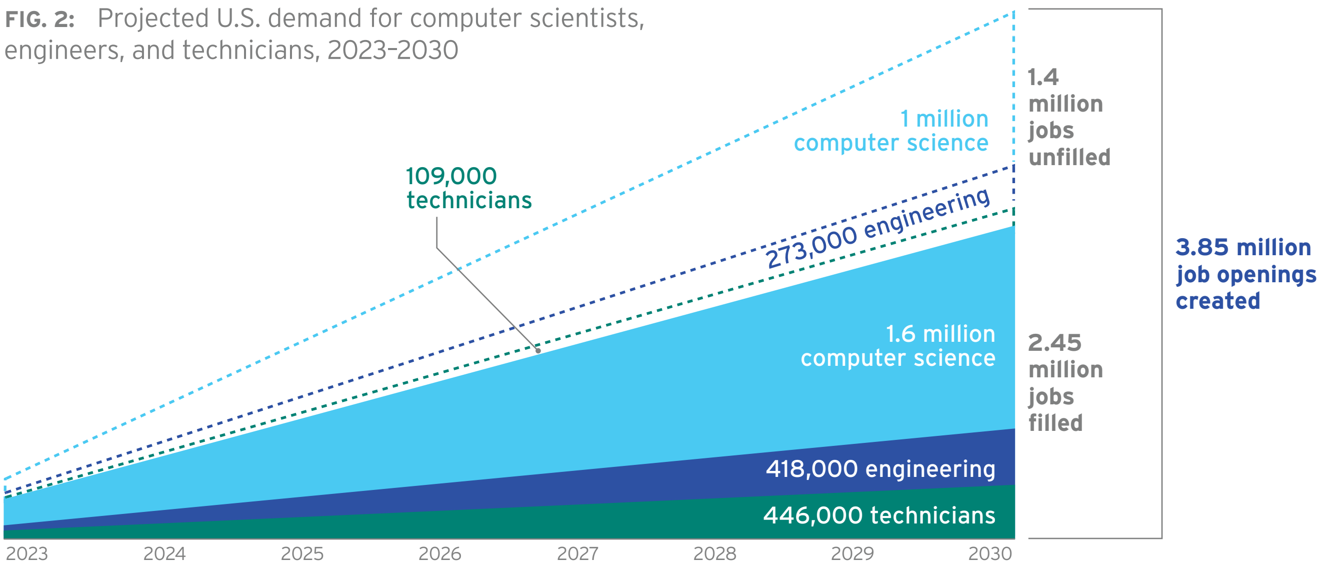
FIG. 1: Historical semiconductor workforce and projected 2023–2030 gap



The challenge facing the semiconductor industry in closing this labor market gap also confronts the U.S. economy as a whole. Other high-growth technology industries of strategic importance to the future of the U.S. and the world are facing a similar talent gap and are competing for the same pool of trained workers. These industries and technologies include clean energy, medical technology, artificial intelligence, the Internet of Things, cybersecurity, next-generation communications, aerospace, automotive, and advanced manufacturing, among others. Accordingly, the shortage of skilled workers poses a substantial challenge for both the semiconductor industry and the broader U.S. economy.

The numbers are striking. For the economy as a whole, by the end of 2030, an estimated 3.85 million additional jobs requiring proficiency in technical fields will be created in the U.S. Of those, 1.4 million jobs risk going unfilled unless we can expand the pipeline for such workers in fields such as skilled technicians, engineering, and computer science.

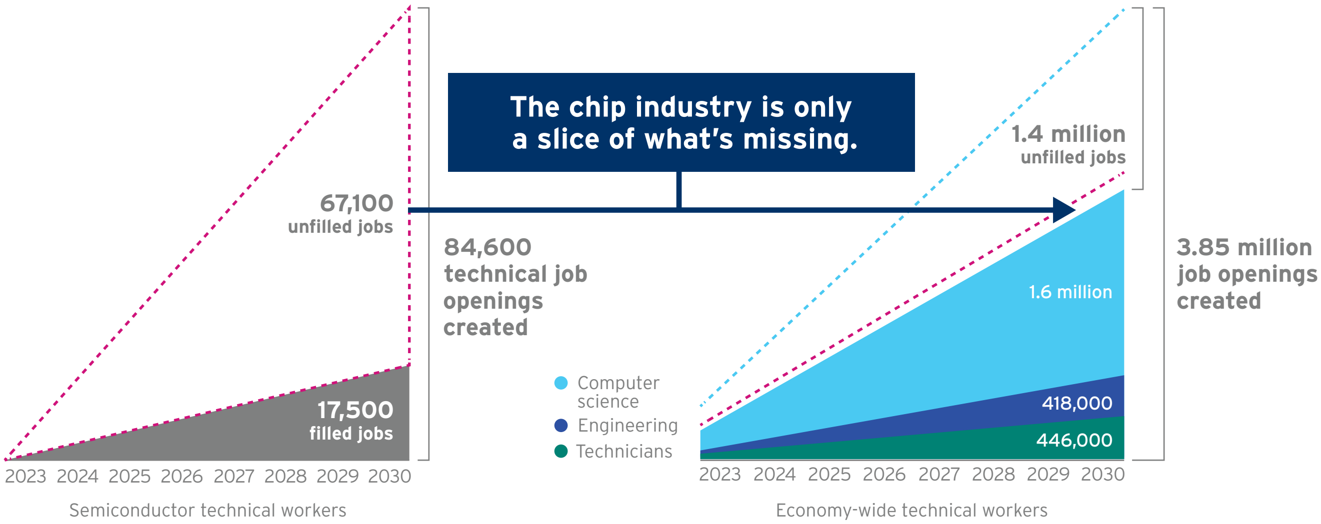
FIG. 2: Projected U.S. demand for computer scientists, engineers, and technicians, 2023–2030



Closing the talent gap is of critical importance to the success of the U.S. economy and the semiconductor industry. While the technology sector, broadly, needs to work together to address these challenges, semiconductors are foundational to virtually all the critical technologies of the future. Addressing the challenge for the semiconductor industry, first and foremost, will be central to the promotion of growth and innovation throughout the economy. But the gap in technical talent facing the chip industry is only a fraction of the overall challenge facing the economy.

The U.S. semiconductor industry has, for decades, engaged in programs to recruit, train, and employ a diverse and skilled workforce. Across the nation, chip firms have longstanding and expanding partnerships with community colleges and technical schools, apprenticeship programs, universities and laboratories, and regional education networks. As the industry grows to meet demand alongside CHIPS investments, companies are growing their workforce development footprint. At the same time, the U.S. government must work with industry and academia to prioritize measures to address the skills gap facing the broader economy and the semiconductor industry. To help achieve this goal, we present three core recommendations to strengthen the U.S. technical workforce.

FIG. 3: Projected technical worker supply gap affects semiconductor industry and the broader U.S. economy

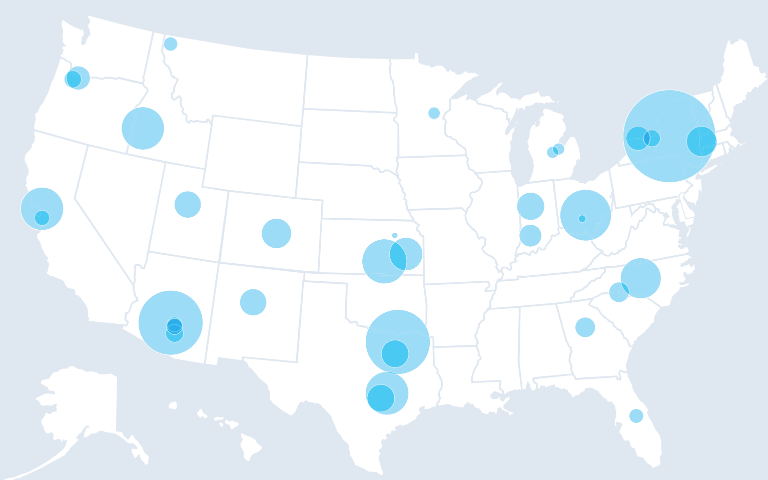


RECOMMENDATION 1: Strengthen support for regional partnerships and programs aimed at growing the pipeline for skilled technicians for semiconductor manufacturing and other advanced manufacturing sectors.

Expanding certification boot camps, apprenticeships, and other training programs at community and technical colleges located near new and expanding semiconductor fabs would be an effective means to help close the workforce gap for technicians. Curricula and education solutions tailored to the semiconductor industry will ensure students are prepared for future employment. The technician pipeline is robust and pulls from a wide variety of sources, such as high school graduates and returning veterans.

FIG. 4: New announced semiconductor supply chain jobs in the U.S.

Semiconductor companies across the nation have announced more than 44,000 new expected jobs since the introduction of the CHIPS Act.



Improving current trajectories of talent supply and demand will be an uphill battle, and companies in the semiconductor industry are already taking action. The CHIPS and Science Act also provides excellent support in closing this gap and should continue to assist industry-led efforts to bolster the technician workforce.

RECOMMENDATION 2: Grow the domestic STEM pipeline for engineers and computer scientists vital to the semiconductor industry and other sectors that are critical to the future economy.

Our analysis shows that an insufficient number of students are pursuing STEM degrees to meet the labor market demand, and many of those who graduate with STEM degrees do not enter a STEM occupation. An even smaller number of these graduates enter the semiconductor industry. Policies should be undertaken to expand this pipeline in three stages:

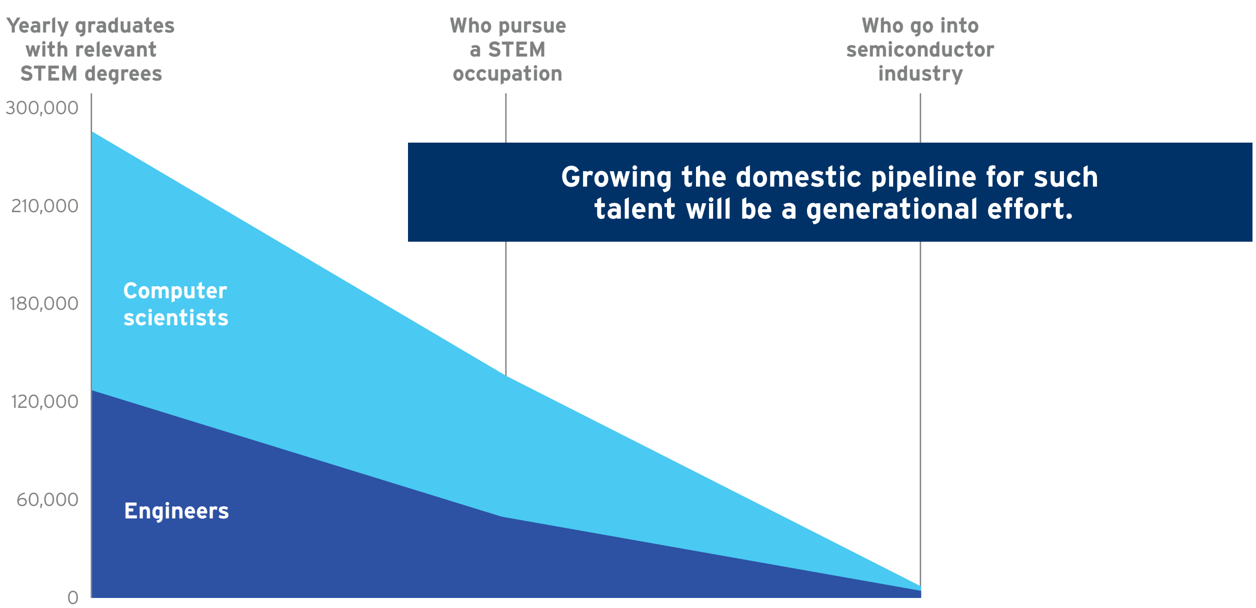
1. Attract more students to STEM disciplines.
2. Employ more STEM graduates in STEM fields.

Both of these steps will benefit the economy-wide technology talent gap, and the projected semiconductor workforce gap.

3. Attract more STEM students to job opportunities in the semiconductor industry.

The CHIPS and Science Act provides significant potential support for advancing the above three objectives by establishing the National Semiconductor Technology Center, the semiconductor-focused Manufacturing USA Institutes, the National Advanced Packaging Manufacturing Program, expanded NIST metrology research, the Department of Defense Microelectronics Commons, the National Science Foundation CHIPS Workforce and Education Fund, and other institutions. These initiatives represent an important step forward, but more

FIG. 5: Domestic pipeline of semiconductor talent



must be done. Our analysis shows that enhancing the domestic pipeline for STEM talent, especially at the master's and PhD level, is a generational challenge. The U.S. needs to act today to move forward aggressively if it is to fully meet the industry's demand for technical talent by 2030.

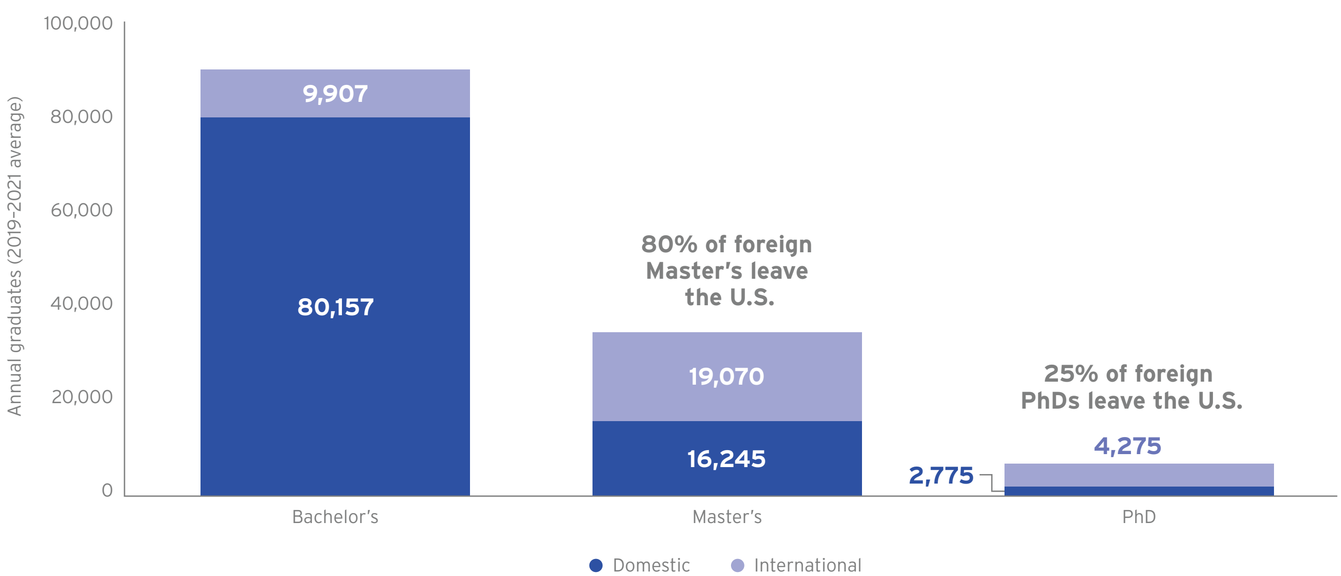
RECOMMENDATION 3: Retain and attract more international advanced degree students within the U.S. economy.

The process of growing the domestic pipeline of U.S.-citizen students pursuing advanced degrees in STEM fields will take years or decades to bear fruit. In the meantime, we estimate that approximately 16,000 master's- and PhD-level international engineers are leaving the U.S. each year. For the semiconductor industry alone, these departures contribute to a projected total gap of approximately 17,000 master's and PhD engineers by the end of the decade. Simply put, the workforce gap for individuals with advanced engineering and computer science degrees cannot be realistically addressed for the foreseeable future solely with U.S.-citizen graduates.

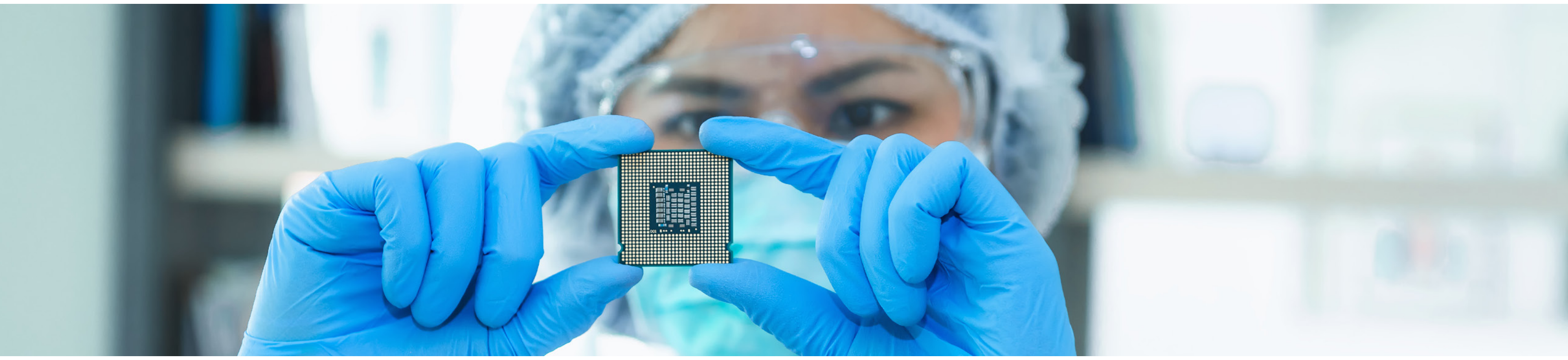
At U.S. colleges and universities, over 50% of master's engineering graduates and over 60% of PhD engineering graduates are foreign citizens. Approximately 80% of master's and 25% of foreign PhD STEM graduates from U.S. institutions do not remain in the U.S. after graduating, either by choice or because of U.S. immigration policy.

Such high shares imply that providing easier pathways to permanent U.S. residency has the potential to provide an immediate boost to the domestic talent pool available to the semiconductor industry and other technology industries of strategic importance. Reforms to high-skilled immigration policy that lower the barriers to U.S. firms seeking to recruit and retain international students with advanced degrees can help to meet near-term skills gaps facing the semiconductor and other key technology industries.

FIG. 6: Annual graduates in semiconductor-related **engineering fields** by degree level and citizenship



1. INTRODUCTION



The U.S. economy faces a significant shortage of skilled workers, which poses challenges to U.S. economic growth, technology leadership, and national security. This shortage impacts the semiconductor industry and all technology reliant industries, including key technologies of the future—clean energy, medical technology, artificial intelligence, cybersecurity, next-generation communications, aerospace, automotive, advanced manufacturing, and others. Addressing this skilled workforce challenge is a matter of national importance.

This economy-wide shortage pertains primarily to two categories of skilled professionals: (1) engineers and computer scientists with four-year degrees and advanced degrees and (2) skilled technicians with two-year degrees or less, and additional on-the-job training. The shortage is attributable to a range of complex societal and other factors:

- An insufficient number of American students pursue STEM degrees.
- Among American students who do pursue STEM fields, too few pursue advanced degrees in these fields, and many students with STEM degrees find employment in non-STEM occupations (e.g., finance, business, etc.).
- An insufficient number of American students utilize the training opportunities at community colleges and other institutions to obtain the skills needed for technician roles in advanced manufacturing facilities.
- While U.S. colleges and universities attract substantial numbers of students from around the world to study in the STEM fields, including a majority of foreign students in master's and PhD programs in STEM, U.S. companies are often unable to recruit and retain these students to work long-term in the U.S.

This paper, commissioned by the Semiconductor Industry Association (SIA), summarizes the skilled workforce challenges facing the U.S. economy as a whole, including the semiconductor industry. The paper focuses on the workforce gaps facing the U.S. semiconductor industry in light of anticipated growth in domestic manufacturing and semiconductor design through 2030.

But given the foundational role of semiconductors in driving innovations in communications, computing, healthcare, military systems, transportation, clean energy, and countless other applications, addressing this challenge for the semiconductor industry will be central to the promotion of growth and innovation throughout the economy.

2. THE ECONOMY-WIDE WORKFORCE GAP

The global competition for talent will determine leadership in the key technologies expected to drive the future economy. Industries such as clean energy, medical technology, artificial intelligence, cybersecurity, next-generation communications, aerospace, transportation, and advanced manufacturing all require a skilled workforce to promote innovation.

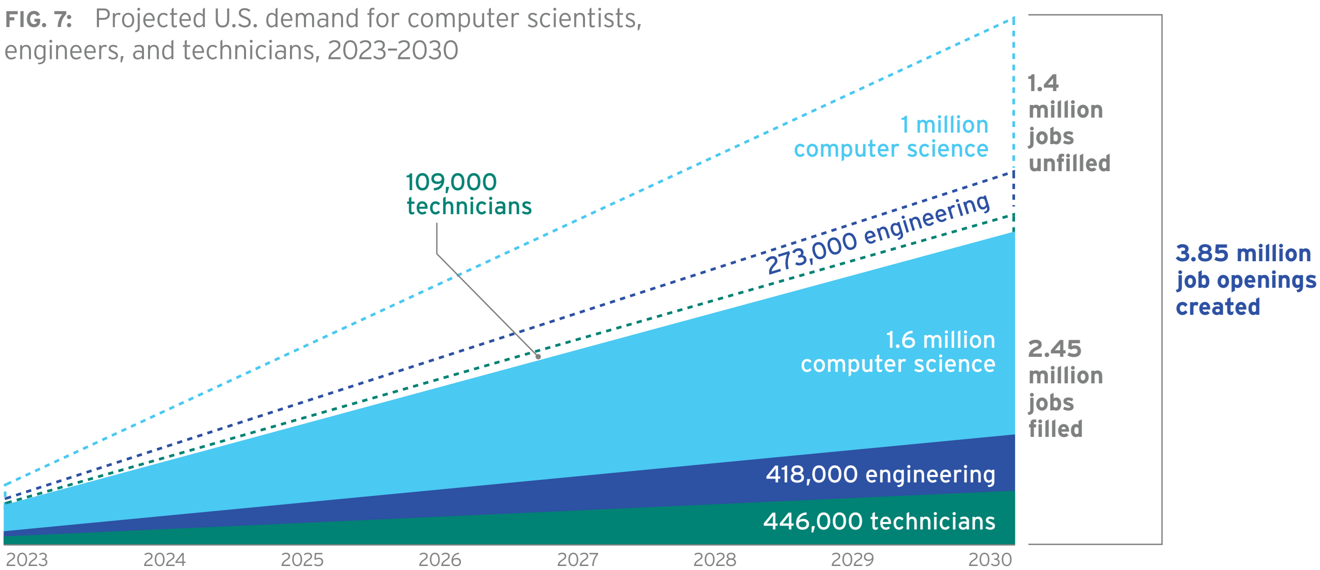
The U.S. faces a significant shortage of skilled and highly educated workers in three primary occupational groups: technicians, engineers, and computer scientists.

Based on an economy-wide gap analysis described in the appendix, we estimate a workforce gap for technicians of 20%, meaning that the estimated supply for these occupations represents only 80% of the estimated demand. For both engineering and CS, we estimate a 39% workforce gap.

These gap percentages are derived from an economy-wide gap analysis, which compared the supply of graduates from relevant technician, engineering, and CS academic programs. The demand of new and replacement job openings in these three occupational groups is based primarily on the Bureau of Labor Statistic (BLS)'s 2021–2031 employment projections. Adjustments were made to account for foreign students who depart the U.S. following graduation, and for workers whose broad occupation category does not align with their broad degree field. See the appendix for more detail on the gap analysis.

The gap between the supply and demand of workers with the requisite training and education to fill the jobs in advanced technology industries poses risks to the competitiveness of the U.S. economy and to U.S. national security. Unless the U.S. takes steps to address this talent gap, it risks falling behind global competitors in the race for economic leadership and technology innovation.

FIG. 7: Projected U.S. demand for computer scientists, engineers, and technicians, 2023–2030

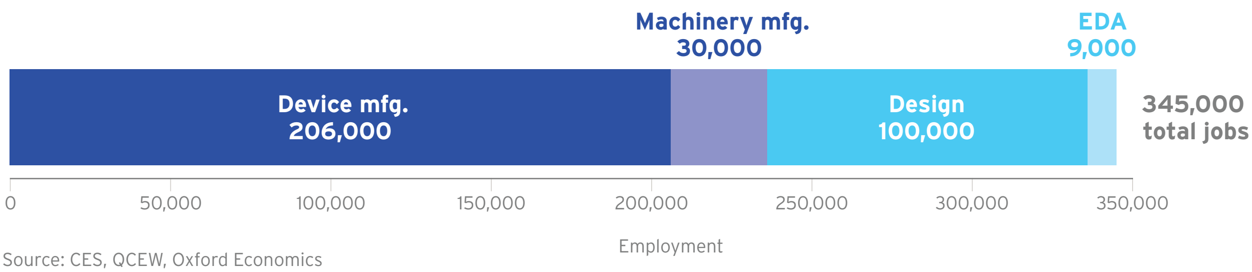


3. THE SEMICONDUCTOR WORKFORCE GAP

3.1 Current employment in the U.S. semiconductor industry

We estimate that the semiconductor industry employs approximately 345,000 workers in the U.S. as of the start of 2023. Approximately two-thirds (68% or 236,000) of this workforce were engaged in semiconductor manufacturing, either fabricating semiconductor chips themselves or manufacturing the specialized machinery used in semiconductor fabrication. The remaining 32% of the workforce (109,000) were design workers, either designing semiconductors themselves or developing the specialized software tools used in design (EDA).[1]

FIG. 8: U.S. semiconductor industry employment by segment, 2023[2]



Source: CES, QCEW, Oxford Economics

The semiconductor workforce is primarily comprised of technicians, engineers, and computer scientists ("the technical workforce"), alongside other supporting occupations (e.g., management, administrative, HR, sales, etc.). We estimate that approximately three-quarters of the industry works in one of the technical occupations, with the remainder (26%) in the "other" support category.

[1] The U.S. semiconductor industry workforce gap analysis presented here focuses exclusively on the direct labor force of the semiconductor industry itself and does not consider the broader labor force needs of the semiconductor industry's domestic supply chain (what economists refer to as indirect employment). In our previous work, *Chipping In*, Oxford Economics estimated the scale of this broader supply chain impact, along with the industry's induced impacts (economic activity supported out of direct and indirect workers' spending), as a total (direct plus indirect plus induced) industry economic footprint of almost 1.9 million workers across the U.S. economy in 2020, 277,000 of whom were considered direct. See Oxford Economics (May 2021). "Chipping In." https://www.semiconductors.org/chipping-in-sia-jobs-report/. Note that the semiconductor machinery manufacturing and EDA jobs, which are included as part of the semiconductor industry's direct employment in the present report, were instead classified as part of the industry's indirect employment in the previous report.

[2] Device manufacturing and machinery manufacturing are based on CES and QCEW data respectively. Design employment is based on Oxford Economics' estimate of 92,000 semiconductor design workers in 2020 (May 2021 "Chipping In") adjusted for 2020–2023 industry growth. U.S.-based EDA employment is based on company reports from Synopsys and Cadence, focusing on U.S.-based employment.

SCOPE OF THIS REPORT

There are many key segments to the semiconductor design and manufacturing process, along with the production of other specialty equipment, software, and materials used in the semiconductor industry.[3] For purposes of this report, we included in our labor force estimates the following **industry segments** of the semiconductor industry:[4]

Manufacturing

- **Semiconductor fabrication** refers to the front-end process of manufacturing silicon chips in a semiconductor fab. Back-end semiconductor manufacturing for assembly, test, and packaging with the same job codes are included in the scope of this report.
- **Semiconductor machinery** manufacturing refers to the manufacture of the specialty equipment used in semiconductor fabrication.

Design

- **Semiconductor design** refers to the complex process of building a computer model of a new chip, ensuring it is free from errors and meets the design rules necessary for manufacturing.
- **Electronic Design Automation** (EDA) refers to the programming of and support for specialized software tools used in semiconductor design.

This report only investigates the labor shortage facing the *technical* workforce that drives innovation in the semiconductor manufacturing industry, which includes the following three **occupational categories**:

Semiconductor technicians operate, maintain, and troubleshoot equipment used in the manufacturing of semiconductor components.

Semiconductor engineers research, develop, and improve semiconductor devices and fabrication processes, playing a crucial role in innovation in both fabrication and chip design.

Semiconductor computer scientists apply computational principles and algorithms to design and develop software and hardware solutions for semiconductor-based systems and technologies, primarily in the chip design sector.

This report excludes job positions that are not semiconductor-specific and have less tailored academic feeder programs (the "other" category in Fig. 9, which includes management, administrative, sales, logistics etc.). It is important to note that many of these "other" job categories may also require an engineering degree—in the semiconductor industry, many sales jobs, for example, require technical engineer expertise.

The report methodology is available in the appendix.

3 Following the convention in the government data upon which these estimates are primarily based, a worker's industry segment is assigned based on the establishment at which they work, not the company they work for.

4 Our estimate excludes other parts of the semiconductor ecosystem, such as the materials (e.g., industrial gases, process chemicals, metals) used in the manufacturing process and back-end assembly, test, and packaging (ATP). While these are vital inputs into the fabrication process and the production of a finished chip, the job categories in these fields have significant overlap with other industries and were outside the scope of this report.

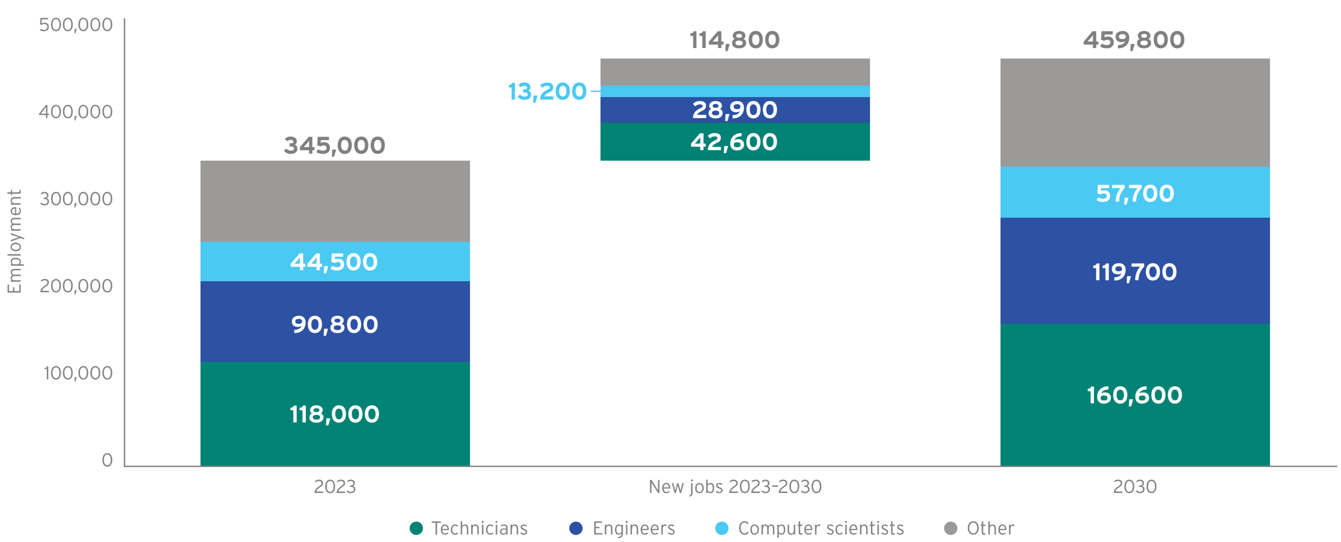
3.2 Expected growth in the U.S. semiconductor industry

The semiconductor industry in the U.S. is expected to experience healthy growth over the remainder of the decade. As digitization and connectivity continue to drive virtually all aspects of the economy and modern life, demand for chips is projected to grow. The 2022 revenue of the global chip industry is currently $574 billion, and this revenue is expected to nearly double by the end of the decade, reaching $1 trillion by 2030.[5]

Due in part to passage of the CHIPS and Science Act, the U.S. semiconductor industry is poised to capture a strong share of this growth. According to SIA, over 50 projects in the semiconductor industry have been announced throughout the country in anticipation of CHIPS Act funding, accounting for 44,000 additional jobs.[6] Other projects will likely move forward as the funding under the CHIPS Act begins to flow, and still others are likely to advance due to the incentives of the CHIPS advanced manufacturing tax credit.

This growth in the U.S. semiconductor industry will result in a corresponding increase in the number of jobs. We project that the industry will grow by nearly 115,000 jobs by 2030, from approximately 345,000 jobs today to approximately 460,000 jobs by the end of the decade (a 33% total increase), representing our mid-growth estimate of 4.2% annual growth. Among new job openings in the technical workforce (85,000), we project that half will be for technicians (42,600), 34% will be engineers (28,900), and 16% will be computer scientists (13,200).

FIG. 9: Semiconductor industry employment and 2023–2030 new job growth by occupation group[7]



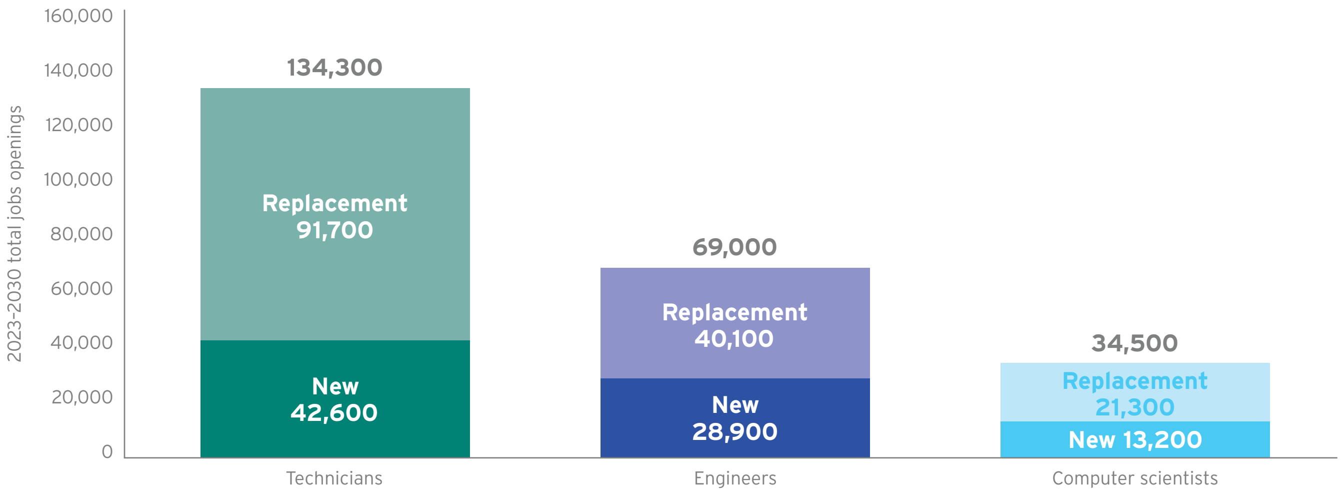
[5] McKinsey & Company, The semiconductor decade: A trillion-dollar industry, https://www.mckinsey.com/industries/semiconductors/our-insights/the-semiconductor-decade-a-trillion-dollar-industry#/

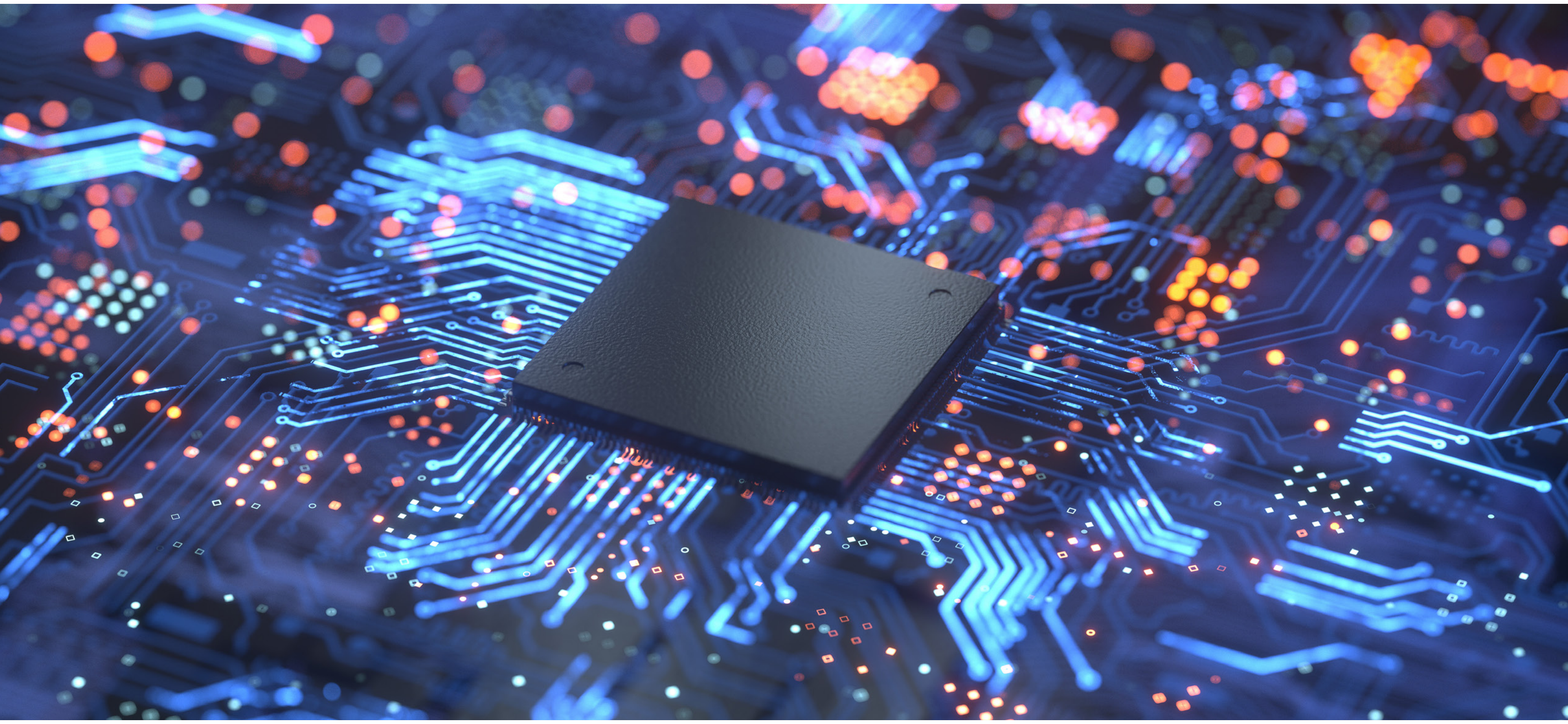
[6] Robert Casanova, SIA, The CHIPS Act Has Already Sparked $200 Billion in Private Investments for U.S. Semiconductor Production, https://www.semiconductors.org/the-chips-act-has-already-sparked-200-billion-in-private-investments-for-u-s-semiconductor-production/

[7] Occupational assumptions for the semiconductor manufacturing and design segments were developed based on BLS Occupational Employment and Wage Statistics data and expert opinion. For manufacturing: technicians (50%), engineers (20%), CS (5%), other (25%); for design: engineers (40%), CS (30%), and other (30%).

In addition to these **new** job openings as a result of industry expansion from 2023–2030, the semiconductor industry will also need to hire additional **replacement** workers to fill in for the regular turnover of the existing labor force.[8]

FIG. 10: Semiconductor industry technical job openings by occupational group, 2023–2030 total





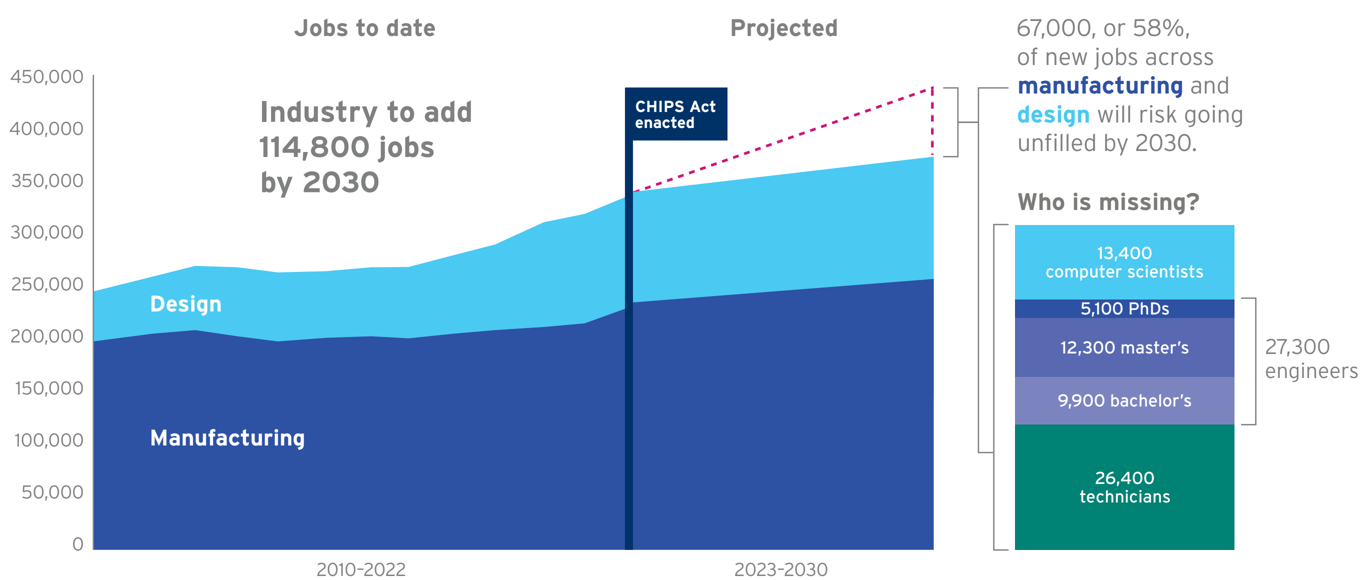
[8] Replacement jobs by occupational group are estimated as the current occupational employment multiplied by annual occupation-specific replacement rates for labor force exits and occupational transfers from the Bureau of Labor Statistics' (BLS)'s 2021-2031 Employment Projections. See https://www.bls.gov/emp/. The overall replacement rate was 11% for technicians, 6% for engineers, and 7% for computer scientists.

3.3 The gap in skilled semiconductor workers

The semiconductor industry is not immune from the workforce challenges facing the broader economy. Just as other key sectors face a shortage of workers with the necessary skills and education to fill the jobs of the future, the semiconductor industry is subject to these same trends.

While the industry is expected to grow by nearly 115,000 jobs by 2030 (Fig. 9), we estimate that roughly 67,000 risk going unfilled at current degree completion rates, or 58% of projected new semiconductor industry technical jobs. These 67,000 unfilled jobs also represent approximately 80% of the projected new jobs in technical occupations (technicians, engineers, and computer scientists).[9]

FIG. 11: Historical semiconductor workforce and projected 2023–2030 gap



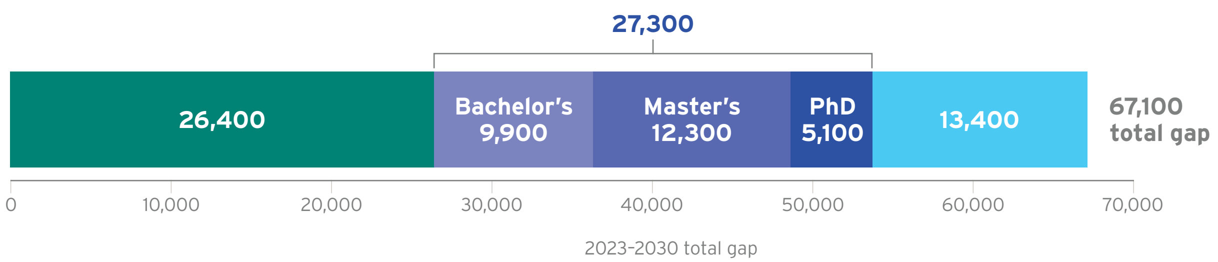
Of this total estimated semiconductor technical workforce gap of 67,000 by 2030, we estimate that approximately 39% of the gap (26,400 jobs) will be in technician occupations, 41% (27,300 jobs) in engineering occupations, and 20% (13,400 jobs) in computer science. Technician positions typically require 2-year degrees or less, while computer science positions most often require four-year degrees. Of the 27,300 gap in engineering, we estimate that about 36% (9,900 jobs) will be at the bachelor's level, 45% (12,300 jobs) at the master's level, and 19% (5,100 jobs) at the PhD level.[10]

9 These gaps are calculated by applying the economywide gap rates of 20% for technicians and 39% each for engineers and computer scientists to the total (new and replacement) 2023–2030 semiconductor job demand (Fig. 10).

10 This breakout of the overall engineering gap of 27,300 by education level was estimated by performing three separate engineering gap analyses by degree level, each similar to the analysis described for engineering as a whole in the appendix. The total semiconductor industry demand for engineers (69,000—see Fig. 10) was then apportioned by degree level using data from the American Community Survey (ACS), and the gap shares were applied to these demands. The sum of the gaps across the three degree levels was then scaled to the overall engineering gap of 27,300.

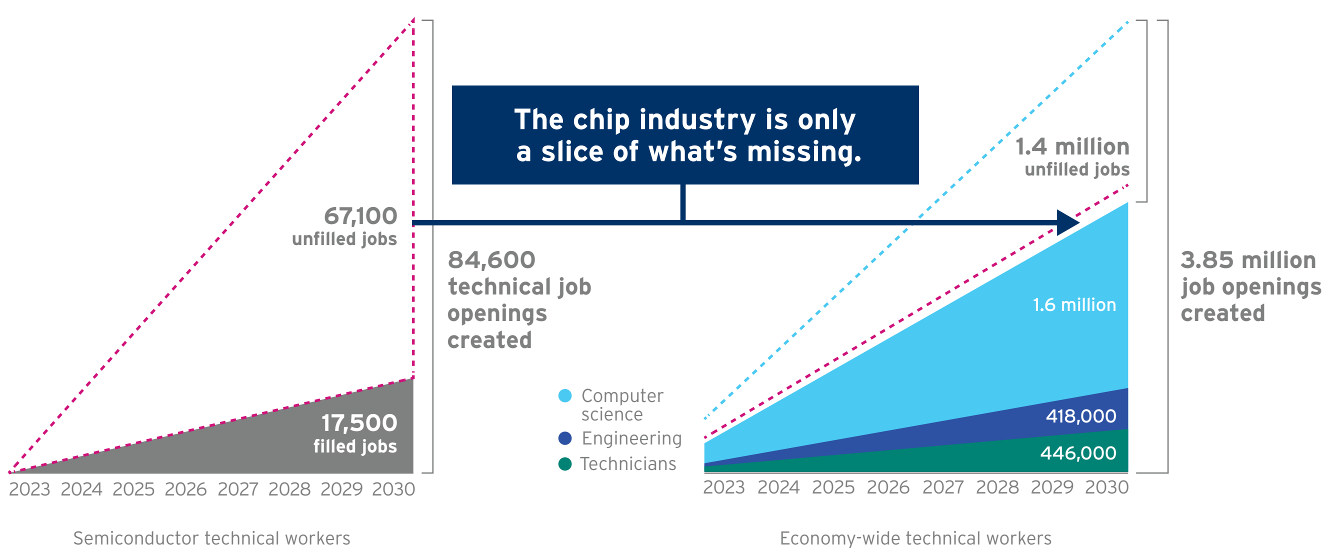
The workforce gap facing the semiconductor industry is only a slice of the shortage of jobs facing the economy as a whole. As discussed at the top of this chapter, the broader U.S. economy is expected to create an estimated 3.85 million additional jobs requiring proficiency in technical fields by the end of 2030. Of these new jobs, 1.4 million jobs risk going unfilled unless we can expand the educational pipeline for such workers. As shown in Fig. 13, the semiconductor industry represents a fraction of the projected shortage facing the entire U.S. economy.

FIG. 12: Semiconductor workforce gap, 2023–2030 total



Accordingly, the workforce challenge facing the semiconductor industry in the U.S. cannot be viewed in isolation, as it is part of a broader talent gap facing the broader economy. This challenge is most pressing among the technologies of the future that will drive future economic growth, all of which depend on semiconductors as a foundational technology for innovation. Thus, the need to educate, recruit, and retain more skilled workers is imperative for the semiconductor industry and the nation as a whole.

FIG. 13: Projected technical worker supply gap affects semiconductor industry and the broader U.S. economy



4. POLICY RECOMMENDATIONS

Addressing the shortage of trained and educated workers—both throughout the broader economy and in the semiconductor industry in particular—is a matter of national importance. At stake is the U.S.'s continued economic and technology leadership, its global competitiveness, and its national security.

The enactment of the CHIPS and Science Act provides a unique opportunity to pursue new efforts to close the projected workforce gap in technician, engineering, and CS talent. This will require multiple strategies in order to increase the supply of relevant graduates in technician, engineering, and CS fields of study; to better attract graduating talent to the semiconductor industry in particular through spreading awareness and capturing student imagination; and to strategically target top international talent to enhance the high-skilled U.S. semiconductor workforce.

The U.S. semiconductor industry has, for decades, engaged in programs to recruit, train, and employ a diverse and skilled workforce. Across the nation, semiconductor firms have longstanding and expanding partnerships with community colleges and technical schools, apprenticeship programs, universities and laboratories, and regional education networks. As the industry grows to meet demand alongside CHIPS investments, companies are growing their workforce development footprint. At the same time, it is important for the U.S. government to work with industry and academia to prioritize measures to address the skills gap facing the broader economy and the semiconductor industry.

To help achieve this goal, we present three core recommendations to strengthen the U.S. technical workforce. The first recommendation focuses on technicians, and the latter two on engineers and computer scientists.

Editor's note: *This report contributes to a substantial and growing body of programs, literature, and innovation in assessing and addressing workforce challenges in the semiconductor industry. The recommendations presented below are not designed to be all-encompassing, but offer a roadmap for the categories of where leaders in industry, government, and education should focus their attention: scaling programs for technicians, growing the U.S. innovation workforce pipeline, and securing international semiconductor talent. Specifically, readers should consider the recommendations of the National Semiconductor Economic Roadmap (NSER), the American Semiconductor Academy (ASA) Initiative, the CHIPS Industrial Advisory Committee's Subcommittee on Workforce, and others.*

RECOMMENDATION 1: Strengthen support for regional partnerships and programs aimed at growing the pipeline for skilled technicians for semiconductor manufacturing and other advanced manufacturing sectors.

We estimate a gap of 26,400 technicians for the semiconductor industry by the end of the decade if remedial steps are not taken. In this time period, technician occupations will grow by a projected 42,600, in addition to the need to replace an additional 91,700 technician positions.

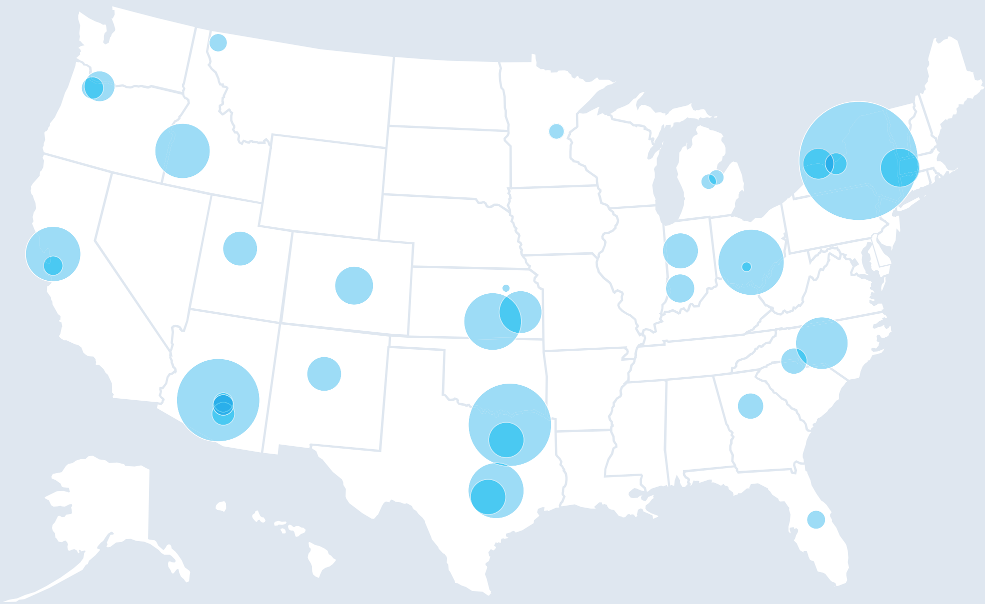
Relative to the job market for engineers, that for technicians is typically more local in nature, most technicians are trained at educational institutions in the same region as the fab. Investments in human capital for these jobs are smaller (nearly 80% of technicians are credentialed for six months to two years via a certificate or associate's degree program—see Fig. 14), and, relatedly, the turnover rate for these occupations is higher, as seen in BLS data and reflected in the high replacement demand. The higher turnover rate for these positions also helps to encourage recurring hiring relationships between industry and academia.

FIG. 14: **Technician** graduate supply by degree level, 2019–2021 annual average

Expanding certification boot camps, apprenticeships, and other training programs at community and technical colleges located near new and expanding semiconductor fabs (see Fig. 15) would, therefore, be an effective means to help close the workforce gap for technicians. Curricula and education solutions tailored to the semiconductor industry will ensure students are prepared for future employment. The technician pipeline is robust and pulls from a wide variety of sources, such as high school graduates and returning veterans. The CHIPS and Science Act provides support in closing the technician workforce gap, which will continue to assist industry-led efforts to bolster the technician workforce.

FIG. 15: New announced semiconductor supply chain jobs in the U.S.

Semiconductor companies across the nation have announced more than 44,000 new expected jobs since the introduction of the CHIPS Act.



MARICOPA SEMICONDUCTOR TECHNICIAN QUICK START PROGRAM

Phoenix, AZ, area is one of America's major semiconductor hubs, and the 10-campus Maricopa County Community College District (MCCCD) is innovating new ways to educate future semiconductor workers in the region's growing fab cluster.

In July 2022, MCCCD introduced a new Semiconductor Technician Quick Start program, an intensive 10-day program designed to give motivated students real-world exposure to the intensive environment of semiconductor manufacturing.[11] Successful students receive a NIMS Technician Certification upon completion. Students who pass the certification exam can have their tuition fees refunded, making the program free.

In its first year (July 2022 – June 2023), the program enrolled 684 students, with 589 certificates awarded. Of those who completed the certificate, 69% were students of color, 34% were women, and 53% first generation college goers. Over 3,000 prospective students are currently on the waiting list for enrollment.[12]

In addition to the need for facilities and faculty, developing semiconductor technician programs requires a great deal of technical expertise. According to MCCCD representatives, participation from industry was crucial in getting the Quick Start program started. When workers at a nearby fab were asked to participate, 149 applied to teach in the program. As of February 2023, 29 had been hired as part-time instructors. This direct engagement between current employees gives students a better understanding of their future work, and direct connections to potential future colleagues; and also gives industry a window into potential future workers before they enter the production fab.

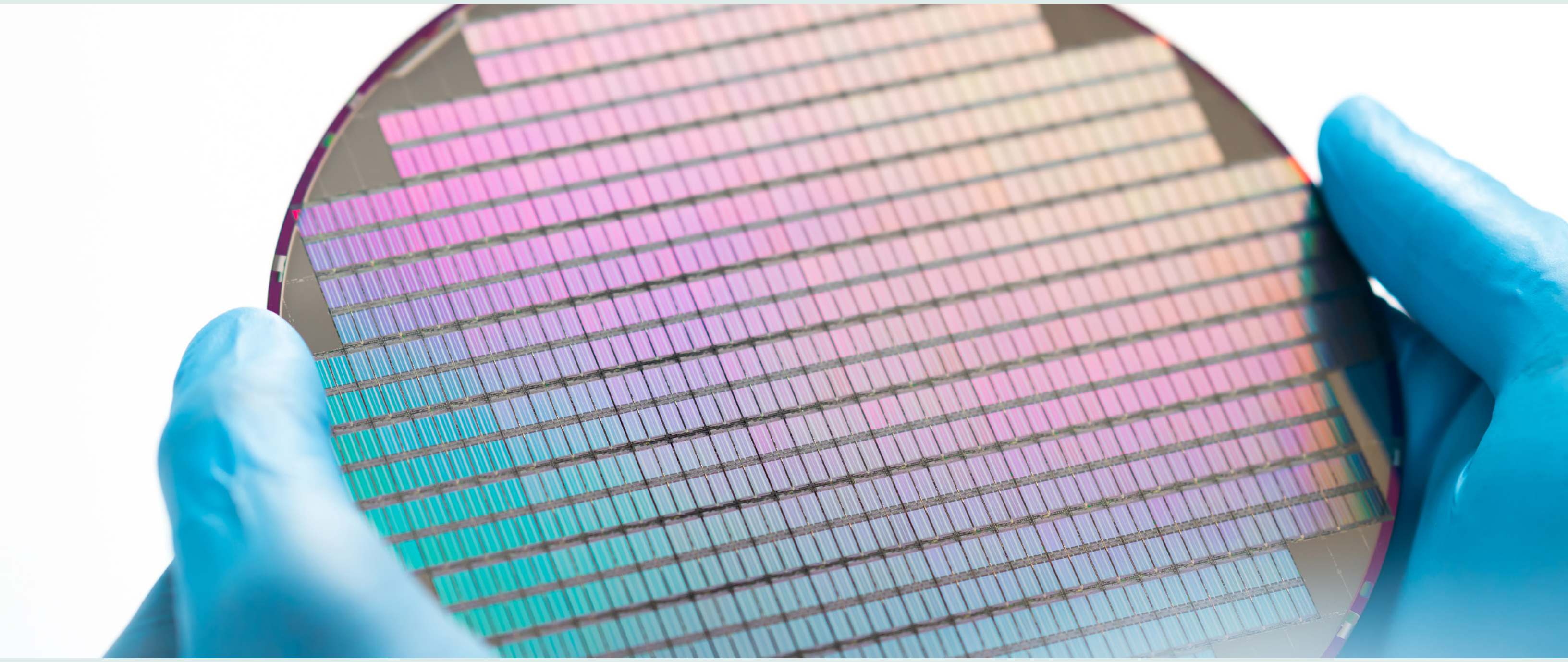
While the 10-day Quick Start Program is not going to replace longer certificates and associate's degrees for most technician positions, programs like it can certainly raise awareness of the opportunities in the semiconductor industry, and spur students to further educational and workforce opportunities.

11 See https://info.maricopacorporate.com/semiconductor.

12 These statistics were provided directly by representatives of MCCCD.

NIIT—GAINS REGISTERED APPRENTICESHIP

The National Institute for Innovation and Technology (NIIT) currently operates a Department of Labor Registered Apprenticeship Program called GAINS (Growing Apprenticeships In Nanotechnology and Semiconductors). The GAINS program offers an industrial manufacturing technician apprenticeship, giving students the ability to learn on the job while building experience and skills through working with industry partners. Numerous semiconductor and semiconductor equipment manufacturers offer training opportunities through GAINS.



VETERANS IN THE SEMICONDUCTOR INDUSTRY

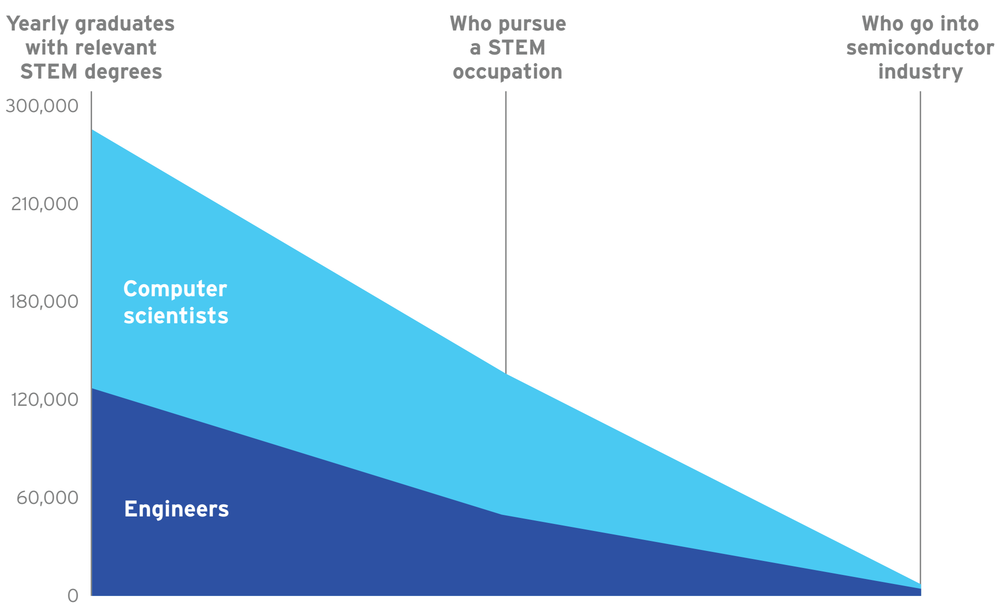
Each year, more than 200,000 U.S. service members leave the military and enter civilian life. Semiconductor manufacturing has long been a destination for employment of veterans, many of whom come to the industry with transferable skills, experience, and know-how related to microelectronics from their time serving. Ongoing recruitment of veterans is key to strengthening the semiconductor workforce.

One Texas chipmaker has earned a "We Hire Vets" designation from the Texas Workforce Commission for its success in employing a workforce composed of at least 10 percent military veterans. Acquiring veteran talent will continue to be a key part of the workforce in the semiconductor manufacturing and semiconductor equipment manufacturing industries.

RECOMMENDATION 2: Grow the domestic STEM pipeline for engineers and computer scientists vital to the semiconductor industry and other sectors that are critical to the future economy.

Engineers and computer scientists in the semiconductor industry typically have four to 10 years of post-secondary education. Addressing workforce gaps, therefore, will require a long-term, broad approach to 1) grow the pool of STEM students, 2) encourage more of these STEM students to pursue STEM careers, and 3) inspire more STEM professionals to choose to work in the semiconductor industry. At each of these intervention points, even marginal growth in talent supply could have meaningful, long-term impacts on meeting the necessary demand.

FIG. 16: Domestic pipeline of semiconductor talent



Growing the domestic pipeline for such talent will be a generational effort.

A variety of interventions can help further these three objectives, including targeted recruitment and education campaigns, scholarships, research fellowships, hands-on experiences, support for university engineering programs, new facilities and opportunities, and more. The CHIPS and Science Act provides significant potential support for achieving these three objectives by establishing the National Semiconductor Technology Center, the semiconductor-focused Manufacturing USA Institutes, the National Advanced Packaging Manufacturing Program, expanded NIST metrology research, the Department of Defense

Microelectronics Commons, the National Science Foundation CHIPS Workforce and Education Fund, and other institutions. Importantly, our analysis shows that enhancing the domestic pipeline for STEM talent, especially at the master's and PhD level, is a generational challenge, and any effort needs to begin today to fully meet the industry's demand for technical talent by 2030.

The STEM pipeline ranges from kindergarten to PhD. Programs that grow interest in STEM for K–12 students are of particular importance, especially in technology and semiconductor-related subjects, especially as the industry works to expand its workforce from underrepresented backgrounds. This will be crucial to growing the overall pool of talent.

FIRST ROBOTICS AND K–12 STEM EDUCATION

The *FIRST* Robotics Competition aims to inspire and energize high school students interested in STEM fields. The five-to-six-week program brings together teams of students from all over the world with coaches and mentors, engaging their creative, technical, and entrepreneurial capabilities as they build task-oriented robots. The competition provides an opportunity to for students to balance teamwork with healthy doses of competition as they develop their critical thinking and engineering skills. Many of the coaches come from the technology and semiconductor industry, which allows students to receive mentorship from industry professionals at an early age.

Initially a modestly sized event with 28 teams in 1992, the *FIRST* Robotics Competition has rapidly grown in the last 30 years with 3,225 teams from 26 countries participating in the 2022 competition. *FIRST* brings the camaraderie and excitement of sports to the academic world of science and technology for younger generations. *FIRST* specifically targets inequities in STEM fields, with an emphasis on engaging women and minorities in the program, encouraging their development and inclusion in STEM from an early age.

According to research from a multi-year study completed by *FIRST*, the organization and its programs have led to increased interest in STEM fields that go beyond piquing student interest and translate into higher rates of students pursuing an education or career in a STEM field. Compared to their peers, *FIRST* alumni are more likely to declare a major in engineering or computer science at 68% (vs. a peer group at 29%). Moreover, female alumni of *FIRST* are also more likely to declare a major in engineering or computer science at 51% (vs. a peer female group at 16%).[13]

As STEM-focused programs such as the *FIRST* Robotics Competition engage the next generation of the U.S. workforce from a young age, students are better equipped to make informed decisions regarding their education and career paths. Similar programs that address this demand for high skilled technical workers through targeting and investing in young children will not only close this gap but also enable and equip tomorrow's leaders for success.

13 See https://www.firstinspires.org/sites/default/files/uploads/resource_library/impact/stem-boosting-engagement.pdf.

SEMICONDUCTOR-SPECIFIC DEGREE PROGRAMS AND HIGHER EDUCATION NETWORKS

Recognizing the growing importance of preparing students for employment in the chip industry, educational institutions across America are adopting programs tailored to semiconductor jobs.

Purdue University, for example, launched its Semiconductor Degrees Program, offering a range of credentials, including a Master of Science degree, stackable certificates at post-graduate level, a Bachelor of Science minor, and associate degrees through a partnership with Ivy Tech Community College in Indiana. The Purdue programs are interdisciplinary, featuring coursework in chemicals, materials, semiconductor manufacturing equipment, manufacturing, packaging, and more. Students engage in a suite of learning options beyond the classroom, including online platform nanoHUB and virtual labs, co-ops/internships, and design-to-fab team projects.

Within the past year, new higher education semiconductor regional networks have been established, facilitating collaboration between institutions on semiconductor research, curriculum, opportunities and assets, and other solutions and efforts. More than 65 U.S. higher education institutions representing 18 states are members of either the Midwest Semiconductor Network, the Northeast University Semiconductor Network, or the Northwest University Semiconductor Network.

The Semiconductor Research Corporation currently prepares about 20% of all PhD electrical engineers and electrical and computer engineers in the semiconductor industry through its programs and partnerships with industry, universities, and government agencies. Broadening participation in these semiconductor-specific programs would supplement the talent pipeline and encourage pursuit of a microelectronics career.

RECOMMENDATION 3: Retain and attract more international advanced degree students within the U.S. economy.

The process of growing the domestic pipeline of U.S.-citizen students pursuing advanced degrees in STEM fields will take years or decades to bear fruit. In the meantime, we estimate that approximately 16,000 master's- and PhD-level international engineers are leaving the U.S. each year. For the semiconductor industry alone, these departures contribute to a projected total gap of approximately 17,000 master's and PhD engineers by the end of the decade. Simply put, the workforce gap for individuals with advanced engineering and computer science degrees cannot be realistically addressed for the foreseeable future solely with U.S.-citizen graduates.

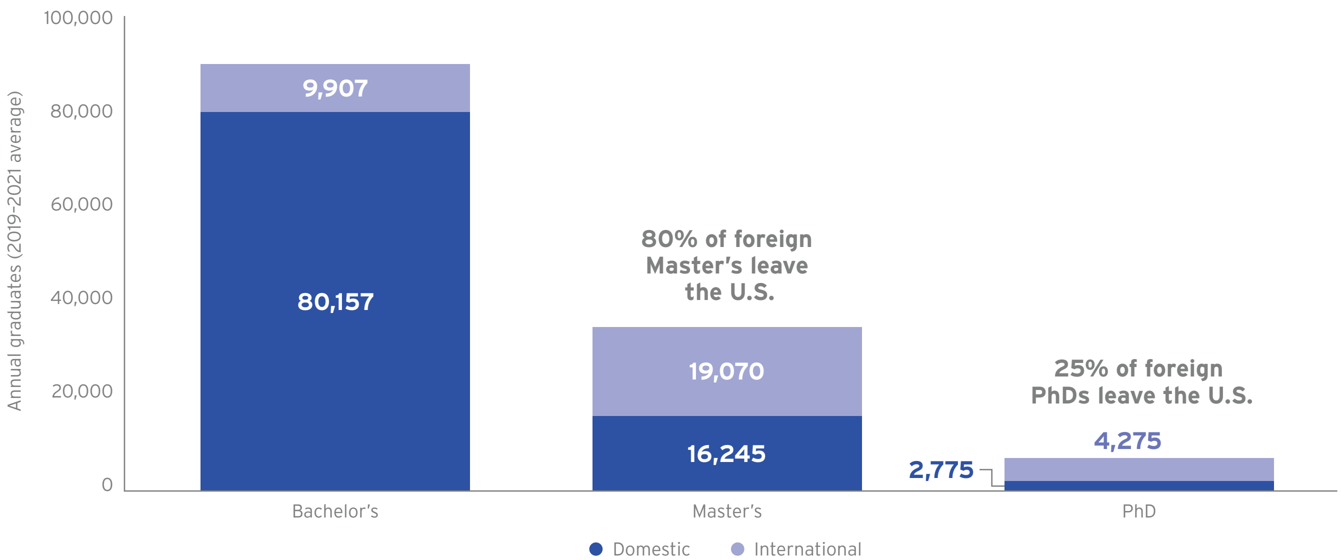
At U.S. colleges and universities, over 50% of master's engineering graduates and over 60% of PhD engineering graduates are foreign citizens.[14] Approximately 80% of master's and

[14] These statistics refer to the supply of semiconductor-related engineering graduates identified in the appendix, and are based on IPEDS data. Foreign graduates here refers to those who are not U.S. citizens or permanent residents.

25% of foreign PhD STEM graduates from U.S. institutions do not remain in the U.S. after graduating, either by choice or because of U.S. immigration policy.[15]

Such high shares imply that providing easier pathways to permanent U.S. residency has the potential to provide an immediate boost to the domestic talent pool available to the semiconductor industry and other technology industries of strategic importance. Reforms to high-skilled immigration policy that lower the barriers to U.S. firms seeking to recruit and retain international students with advanced degrees can help to meet near-term skills gaps facing the semiconductor and other key technology industries.

FIG. 17: Annual graduates in semiconductor-related **engineering fields** by degree level and citizenship



Economy-wide, we estimate that 24,133 foreign engineering graduates depart the U.S. annually.[16] Meanwhile, we project an annual economy-wide workforce gap of 26,642 engineers. For the semiconductor industry, which represents approximately 15% of this gap, accessing an annual 3,900 international engineering graduates (15% of the annual departures) would almost entirely address the projected shortage, especially for the 2,500 master's- and PhD-level engineers that the semiconductor industry is short each year. Most foreigners who complete advanced degree programs in the U.S. want to stay and work in the U.S., but are ultimately unsuccessful in the H-1B lottery following a period of time in the Optional Practical Training (OPT) program. This results in exceptional, foreign, U.S-educated talented individuals returning to their home countries or seeking employment in another country that will offer residence. Many of these graduate students have worked on projects funded by the U.S. government or U.S. semiconductor companies, underscoring the importance and benefit of retaining such expertise and experience. In the time it takes to grow the domestic engineering pipeline, reforms that address this urgent shortage would be extremely effective at addressing these challenges.

Long-term policies aimed to retain more foreign nationals, such as easing the path for foreign STEM graduates to obtain long-term work authorization and residence in the U.S., including a "green card stapling" program or reserving a subset of annual H-1B visas

15 See source notes relating to the adjustments to engineering supply in the appendix (footnote 18).

16 See Fig. 21 and related text in the appendix.

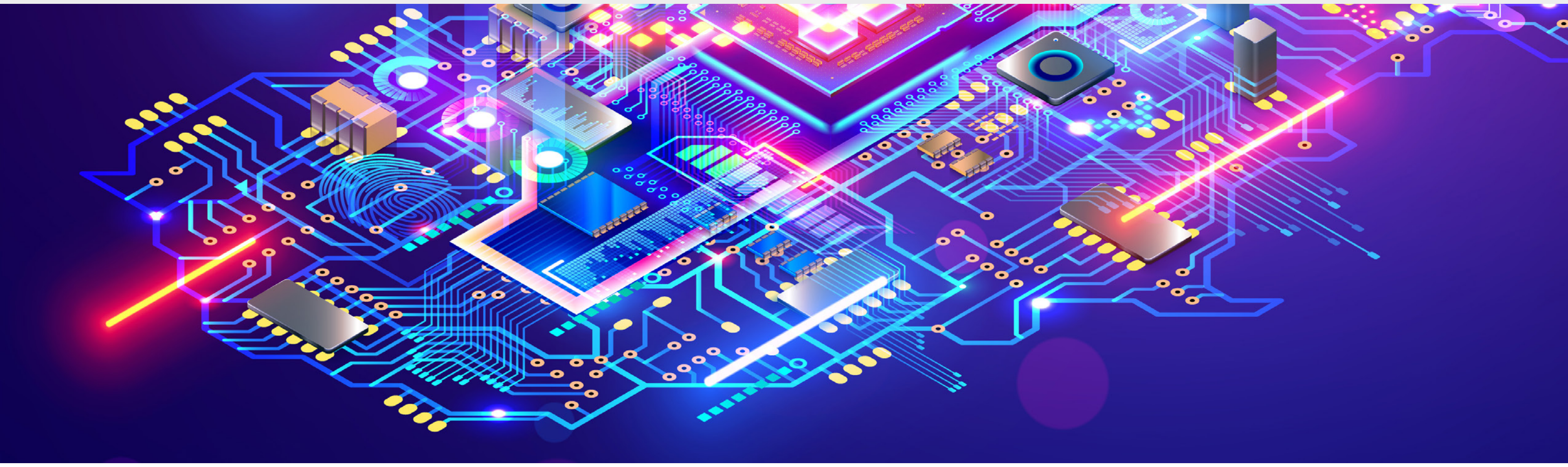
for semiconductor innovators, could go a long way to closing this gap. Additionally, some immediate regulatory changes could include preservation of the Optional Practical Training program, improvements to the H-1B registration system, a beneficial visa revalidation pilot program, and reductions in PERM wait times in the green card system.

Importantly, alongside efforts to increase retention of foreign STEM graduates, some positions requiring an advanced engineering degree must be filled by a U.S. citizen because the position involves national security-related work. This includes some roles within the semiconductor industry—designing chips for advanced weapons systems, for example. While most job roles for advanced technical workers do not need to be filled by U.S. citizens, critical demand related to these national security-related positions depletes an already small pool of U.S. citizen graduates from advanced engineering programs, increasing the need to recruit the remaining talent, which is disproportionately foreign.

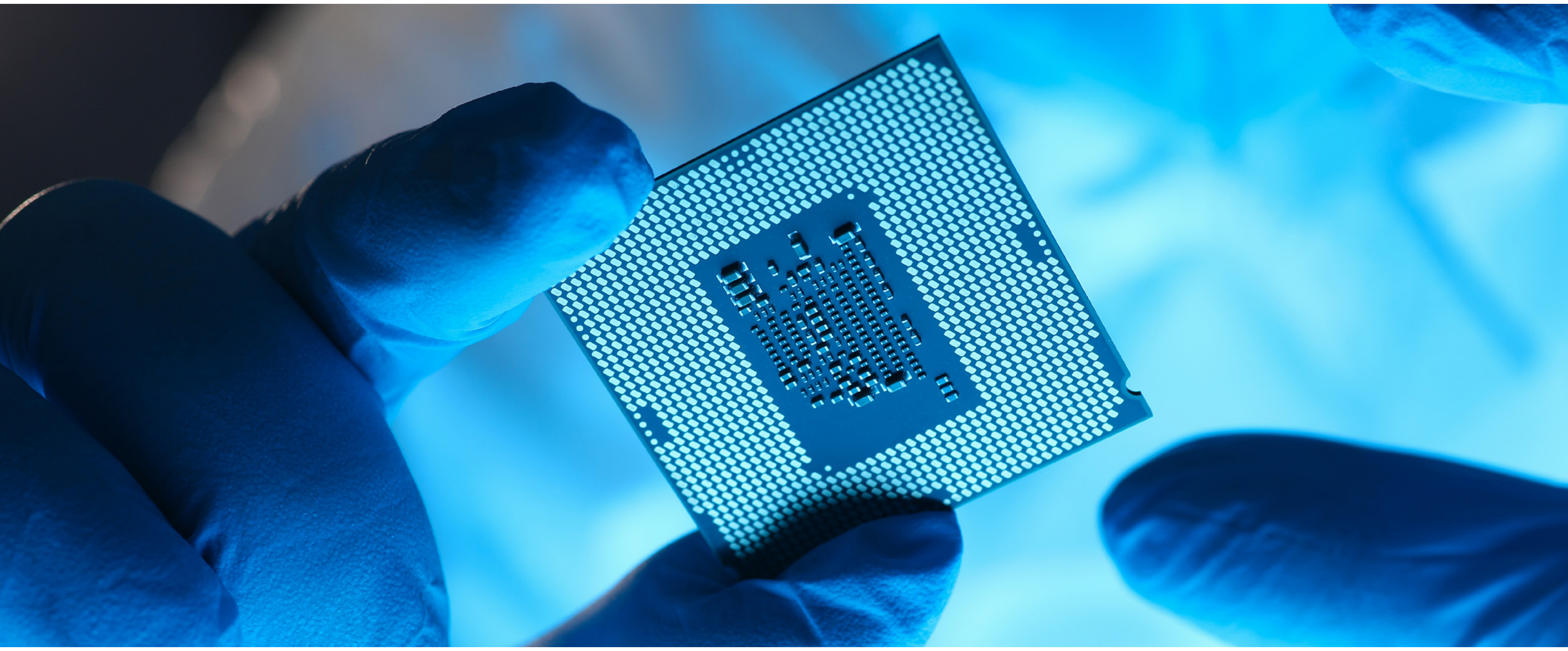
NATIONAL SECURITY INDUSTRIES AND THE NEED FOR U.S. CITIZEN ENGINEERS

Many federal agencies, such as the Department of Energy, the Department of Defense, and Homeland Security, require employees to have security clearance. Additionally, private companies that engage with the U.S. government through contracted work, such as those within the aerospace industry, share the same requirement for security clearance. Only workers that have obtained this clearance are able to handle classified information related to national security, and without it, cannot be employed for these positions. Additionally, only U.S. citizens are eligible for certain types of security clearance, further decreasing the supply of workers eligible to apply for these roles.

U.S. government agencies are already facing a supply shortage and struggling to fill STEM positions (especially at the doctoral level). Finding applicants for these roles that are technically qualified but also U.S. citizens eligible for security clearance poses an even greater challenge. As the majority of PhD degrees in STEM fields are earned by non-U.S. citizens, this creates a structural mismatch between supply and demand in the labor market.



5. CONCLUSION

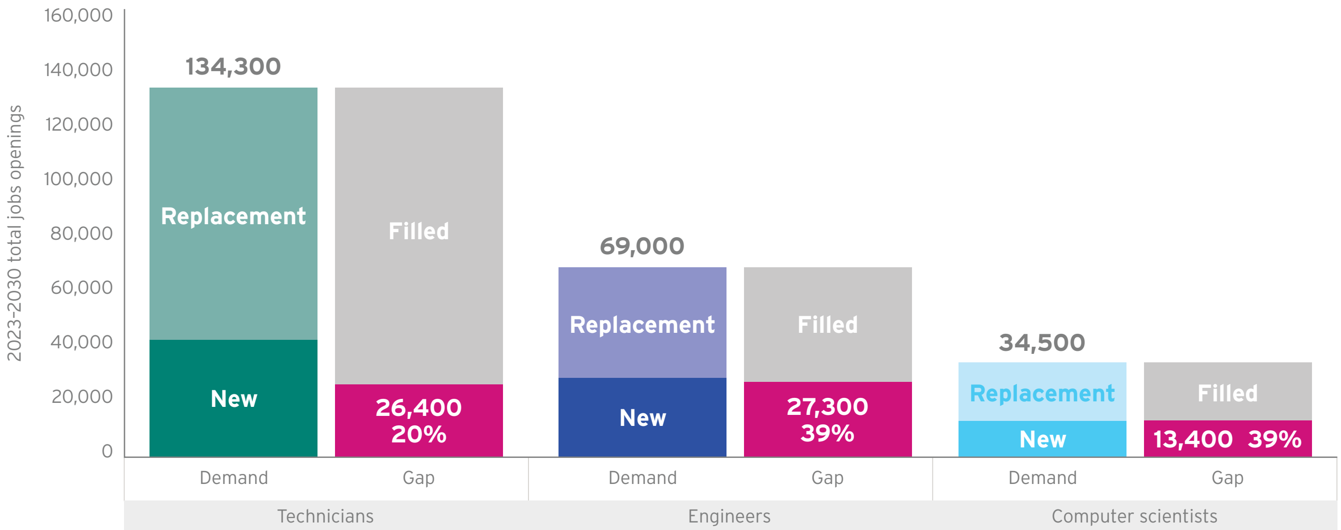


The U.S. semiconductor industry is poised for rapid growth through the end of the decade and beyond, spurred by the increased need across all sectors of the economy for cutting-edge technology that relies on semiconductors and the enactment of the CHIPS and Science Act. As a result, the industry will need to grow its domestic workforce as companies expand and open new manufacturing fabs and semiconductor design and R&D establishments. In the absence of action to address the gap in workers with the requisite skills and credentials to fill the jobs resulting from this growth, the U.S. may fail to achieve the full potential of the capacity growth, supply chain resiliency, and technology innovation leadership expected in the coming years.

According to our projections, the U.S. semiconductor industry workforce is poised to grow by about a third through 2030, adding approximately 115,000 jobs, of which 85,000 are for technical roles (technicians, engineers, and computer scientists). This is in addition to hiring replacements for 153,000 current technical positions, totaling 238,000 hires by 2030. Filling this demand will be a challenge, especially in light of competition from adjacent industry for qualified and diverse talent at all educational levels and skills.

This report estimates a labor market gap for the semiconductor industry of 67,100 workers from 2023–2030: 26,400 technicians, 27,300 engineers, and 13,400 computer scientists.

FIG. 18: Semiconductor occupational demand and gap summary, 2023–2030 total



This report recommends scaling existing educational programs to train technicians, with a particular focus on regions with significant increases in demand. With 80% of technicians credentialed in 6–24 months, semiconductor companies are already moving forward to develop and expand programs to recruit and skill new workers.

In the case of engineers and computer scientists, where postsecondary education programs typically take between four and ten years, a more broad-based effort to expand the STEM pipeline is necessary. Closing these gaps requires a comprehensive STEM strategy, starting with boosting student interest in STEM opportunities at the K–12 level. At the college level, these students should be encouraged to work in a STEM profession, as well as to be made aware of job opportunities in the semiconductor industry. Industry, educational institutions, government all have important roles to play in making the benefits of these opportunities more apparent.

Boosting the supply of engineering and CS graduates among U.S. citizens, especially at the master's and PhD level where most graduates are foreign nationals, is essential for both economic and national security goals. In the short to medium-run, however, given the long timescale needed to train this talent, it will be essential to retain more foreign graduates from U.S. institutions.

A sustainable and predictable supply of technicians, engineers, and CS professionals across all industries is vital for U.S. national security, competitiveness, and innovation—and to guarantee the supply of the end products American consumers and businesses demand. The success of U.S. semiconductor manufacturing, design, and R&D depends on leadership from industry, government, and education to rise to the challenge and maximize the generational opportunity that lies ahead.

6. APPENDIX: GAP ANALYSIS METHODOLOGY

The gap shares presented in the body of the report (20% gap for technicians, and 39% gap each for engineering and CS) are based on economy-wide gap analyses for these three categories of workers.

A gap analysis compares labor market supply, primarily measured in terms of academic completions by field of degree, with labor market demand, seen in terms of job openings by occupation. This supply and demand are linked by a crosswalk aligning fields of academic completions with occupations. In the case of engineering and CS, adjustments are made to reflect the departure of foreign graduates and the misalignment between workers' occupations and their degree fields. Finally, the gap is calculated between the supply and the demand.

Supply (academic completions)

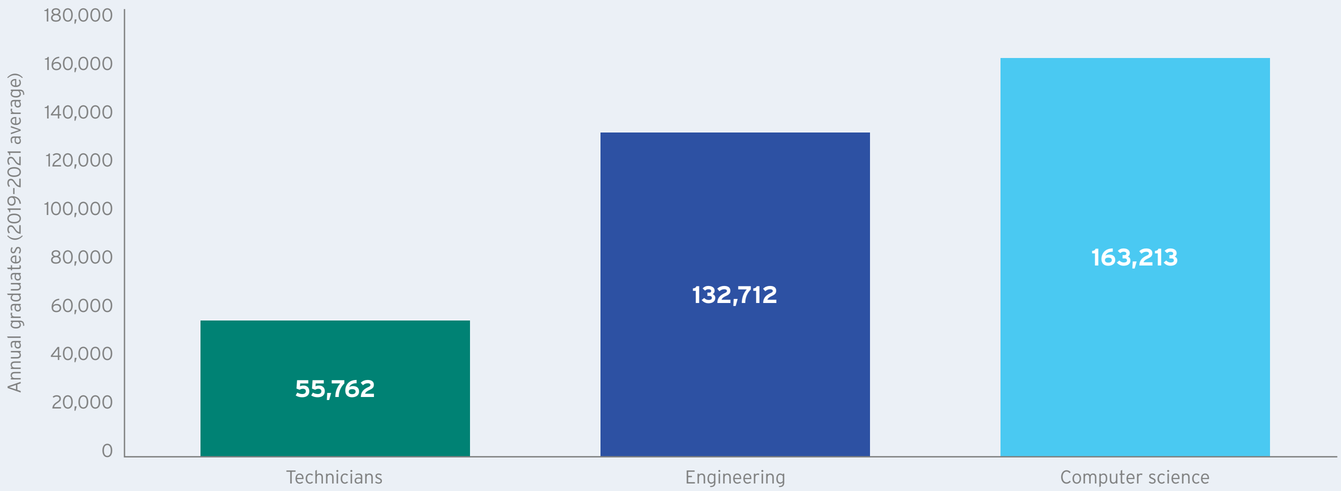
Labor market supply was measured in terms of academic completions (which we will refer to as "graduates") by field of degree/certificate, classified according to Classification of Instructional Programs (CIP) codes. Academic completion data were compiled from the Integrate Postsecondary Education Data System (IPEDS). For each of the three focus subjects (technicians, engineering, and CS), a set of relevant CIP codes was selected based on the occupational profile of the semiconductor and related devices manufacturing industry in the Occupational Employment and Wage Statistics (OEWS), along with expert opinion.

It is important to note that the supply of graduates in these fields does not represent all technician, engineering, and computer science graduates, but rather those graduates in CIP fields most relevant to semiconductor manufacturing. For example, the engineering supply excludes graduates in fields such as biomedical or aerospace engineering.

Fig. 19 summarizes the supply of technician, engineering, and CS graduates used in the gap analysis.

The semiconductor technician-related CIP fields represented in this report include: industrial production, electromechanical, electrical engineering, environmental control, electrical maintenance, mechanical engineering, and other. The semiconductor engineer-related CIP fields represented in this report include: mechanical engineering, electrical engineering, computer engineering, chemical engineering, industrial engineering, engineering (general), and other engineering. Of CS graduates, 51% are at the bachelor's level, 23% at the master's level, and 1% at the PhD level; with the remaining 23% at the certificate or associate's level.

FIG. 19: Annual economy-wide supply of graduates in semiconductor-related fields



Source: IPEDS, Oxford Economics

Demand (new and replacement job openings)

Job openings for technicians, engineers, and computer scientists are estimated by occupation, classified by Standard Occupation Classification (SOC) codes. Job openings are derived from the annual average economy-wide (i.e., across all industries) new and replacement job demand for selected occupations in the Bureau of Labor Statistics (BLS)'s 2021–2031 employment projections. New jobs represent the expansion of occupational categories and can be negative for contracting occupations; replacement jobs represent openings to replace turnover from labor market exits and occupational transfers.

Because the BLS employment projections assume minimal (<0.2% per year) growth for the semiconductor manufacturing industry, new semiconductor jobs (see Fig. 10) are added to the BLS demand described above, while replacement semiconductor jobs are already part of the BLS's estimated economy-wide replacement job demand.

In our projection of new semiconductor industry jobs, we modeled high-, mid-, and low-industry growth scenarios. This report selects the mid-growth outcome, but a high-growth outcome is also reasonably likely to occur and would exacerbate the challenges highlighted in this report. A low-growth outcome, based on available projects and facility announcements, is unlikely to occur.

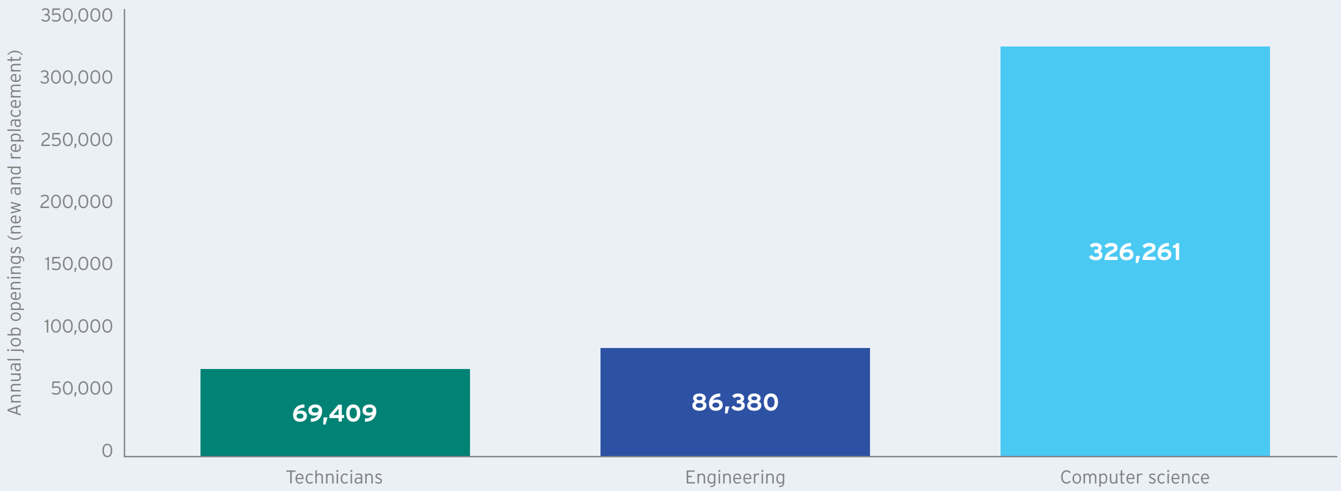
A high-growth estimate of 5.7% compound annual growth (CAGR) would result in about 165,000 new jobs by 2030 (48% total increase from 2023), bringing the industry's total employment to 510,000. A mid-growth estimate of 4.2% CAGR would result in about 114,800 new jobs by 2030 (33% total increase). A low-growth estimate of 2.1% CAGR would result in about 53,900 new jobs by 2030 (16% total increase).

Graduates by degree field were aligned to job openings by occupation using a crosswalk between CIP and SOC codes developed by the National Center for Education Statistics (NCES) and BLS.

As explained above, for each of the three gap analyses, the relevant population was defined on the supply side by quantifying the graduates in degree fields relevant to the semiconductor industry. The economy-wide demand for this supply was then estimated based on job openings in occupations matched to the supply using the NCES crosswalk.[17]

Fig. 20 summarizes the demand for technicians, engineers, and computer scientists, measured in new and replacement job openings, used in the gap analysis.

FIG. 20: Annual economy-wide hiring demand in semiconductor-related occupations



Source: BLS 2021–2031 employment projections, Oxford Economics

Adjustments

The gap between occupational demand and educational supply is calculated by subtraction. Since demand is measured in job openings, and supply in graduates, this implicitly assumes a one-to-one relationship between these two quantities; that is, each job opening is assumed to be filled by one graduate in a relevant field.

Clearly, this assumption is imperfect. An individual filling a job may have multiple (relevant) degrees—an engineer may have both a bachelor's and a master's degree in engineering, for example—or they may have no (relevant) degrees or certificates—a technician might be hired into an apprenticeship program out of high school, for example.

In the case of technicians, the final gap is simply the gap between the supply and demand numbers presented above.

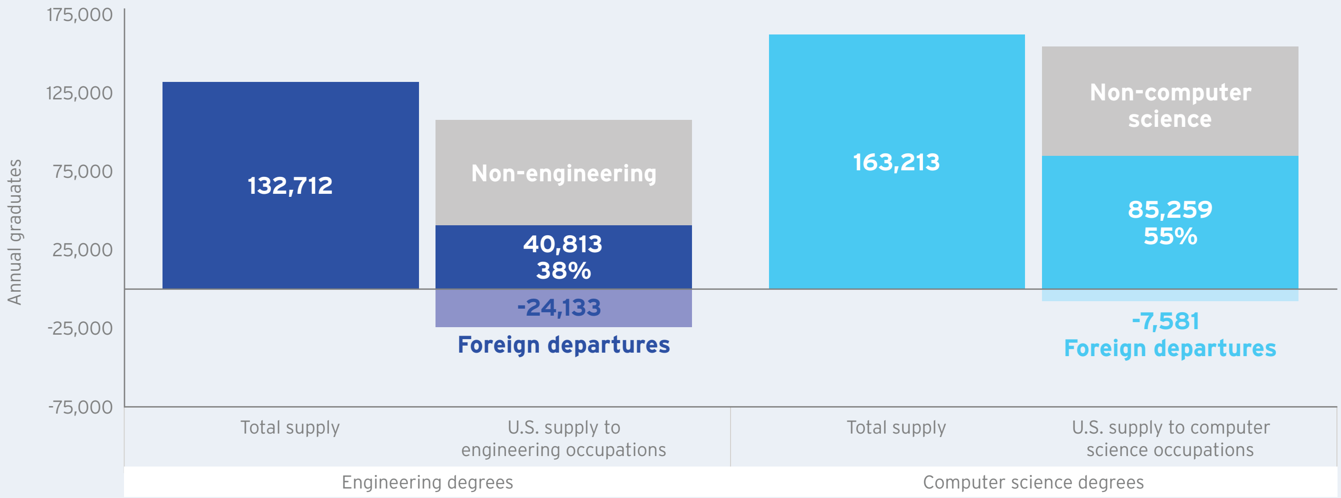
17 Occupational matches were restricted to the major occupational categories of focus. For example, the supply of engineering graduates was allowed to match only to demand in engineering occupations; crosswalk connections between engineering degree fields and occupations in other major occupational categories such as management were suppressed. Where a given occupation was linked in the crosswalk both to academic fields included in the identified supply as well as to excluded fields, a share of the total occupational demand was allocated proportional to the aggregate number of completions of the different academic programs. For example, the occupation of aerospace engineer is cross-walked both to aerospace engineering, an excluded degree field, as well as mechanical engineering, an included field, so a share of the total new and replacement demand for aerospace engineers is included in the demand based on the number of completions in these respective programs.

In the case of engineers and computer scientists, we apply two adjustments before calculating the gap to better align supply and demand:

- The supply of graduates is adjusted downward to reflect foreign graduates who depart the U.S. after graduation. Specifically, we assumed in the gap analysis that approximately 25% of foreign PhD-level STEM graduates depart the U.S. after graduation (this value is also reported in Fig. 6 and Fig. 17), and 80% of foreign STEM graduates at the master's-level.[18]
- Both the supply of graduates and the demand of job openings are adjusted to account for misalignment between workers' degree field and their occupation. These adjustments are based on data from the National Survey of College Graduates (NSCG) on the relationship between workers' occupations and the field of their highest degree.
  - The **engineering demand** was adjusted down from 86,380 job openings to 67,455 to reflect the 78%[19] of workers in engineering occupations whose degree field is in engineering.
  - The **CS demand** was adjusted down from 326,261 job openings to 139,502 to reflect the 43% of workers in CS occupations whose degree field is in CS.
  - The **engineering supply** and the **CS supply** are adjusted downward, after the adjustment for foreign departures described above, to reflect the share of workers with engineering degrees who work in engineering occupations (38%), and the share of workers with CS degrees who work in CS occupations (55%).

The demand-side adjustments are fully specified in the text immediately above. The supply-side adjustments are summarized graphically in Fig. 21.

FIG. 21: Engineering and CS supply-side adjustments



[18] The departure rate for foreign STEM PhD graduates used in the modeling is 23%, which is based on survey data from NCSES—see, for example: Okrent, Abigail and Amy Burke "Where are they now? Most early career U.S.-trained S&E doctorate recipients with temporary visas at graduation stay and work in the United States after graduation." https://ncses.nsf.gov/pubs/nsf21336. The rate for foreign STEM master's graduates, which we apply in the gap analysis to foreign STEM bachelor's graduates as well, is based on the results of Beine, Michel, Giobanni Peri, and Morgan Raux (2022), "International college students' impact on the U.S. skilled labor supply." https://www.nber.org/system/files/working_papers/w30431/w30431.pdf.

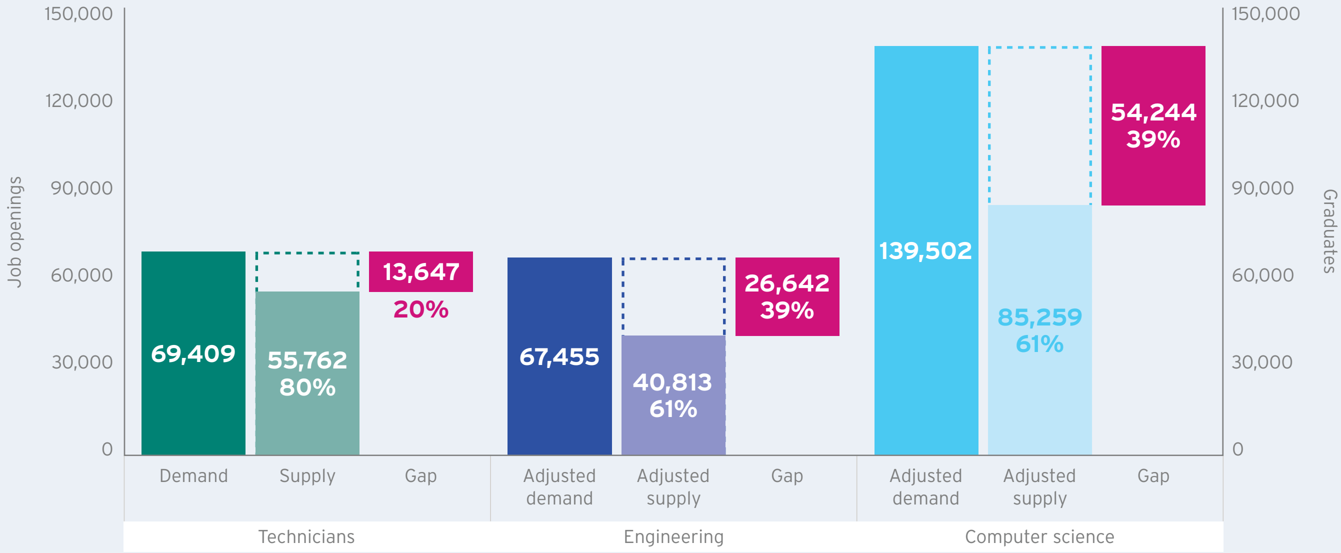
[19] The percentages referenced in this list are all based on the NSCG data.

Gap

The gap between the estimated demand for technicians (measured in occupational job openings) and the estimated supply of technician graduates is 20%, meaning that 20% of the overall demand is unmet by the available supply. After the adjustments described above have been applied, the gap between the estimated demand for engineers and supply of engineering graduates was 39%. The gap between the adjusted demand for computer scientists and the adjusted supply of CS graduates was also 39% (see Fig. 22).

These gap shares are those that are applied to the semiconductor industry's new and replacement demand to estimate the industry gap (see Fig. 18). These gap shares are also applied to the economy-wide demand by occupational group summarized in Fig. 20 to obtain the economy-wide gaps shown in Figs. 2, 3, 7, and 13.

FIG. 22: Economy-wide gap results



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