SUPPORTING THE FUTURE OF US-BASED SEMICONDUCTOR MANUFACTURING:

Innovation, Technology Development & Translation, and Workforce Enablement

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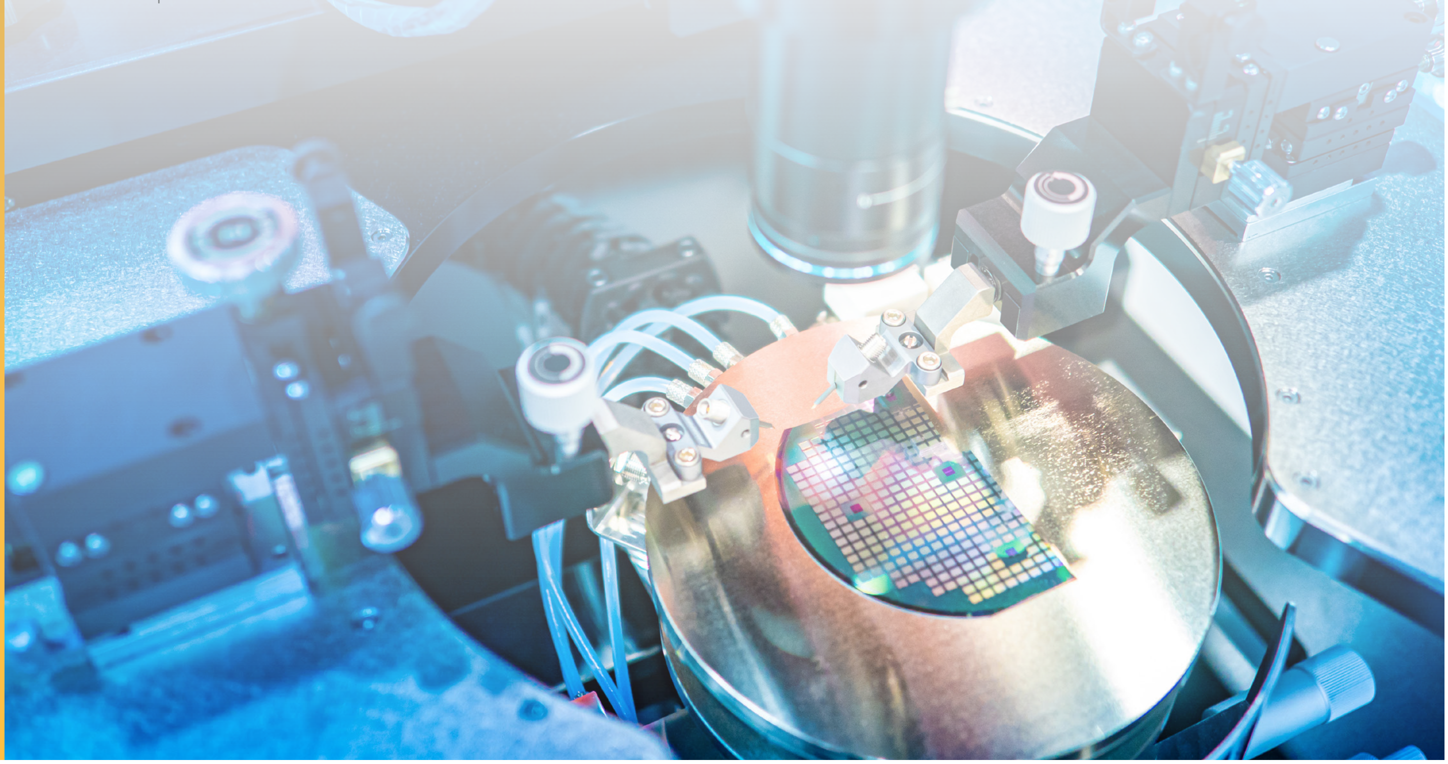
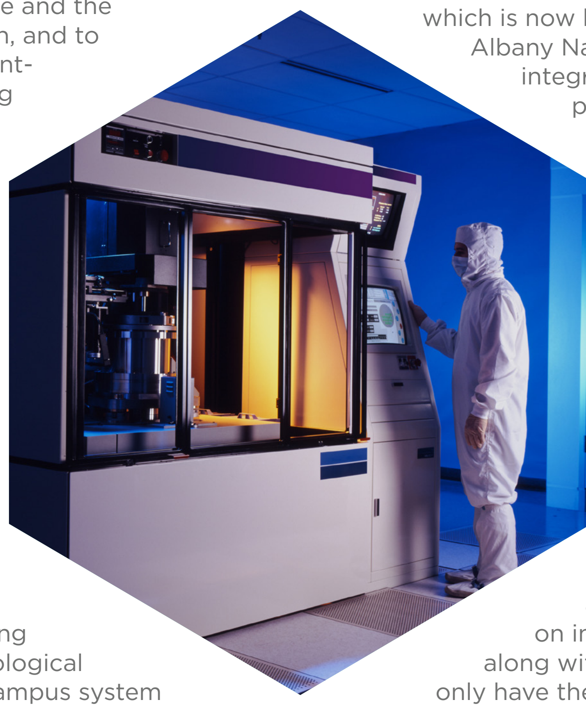


EXECUTIVE SUMMARY

We live in a world that is increasingly dependent upon data, computing power, and communication. The far-reaching impact of computing technology touches all aspects of society, and is a key driver in both the US and global economies. Heavily based on semiconductor processing technology, computer chip manufacturing is complex, expensive, and labor intensive, requiring innovative technological practices and a highly-skilled workforce. While the United States is a leader in semiconductor technology research and development, on-shore manufacturing represents only a fraction of worldwide production. There is a clear and urgent need to bolster US-based semiconductor manufacturing, to bridge the gap between the R&D pipeline and the pathway to commercialization, and to enable workforce-development-at-scale. At the time of writing this position paper, others including China, EU countries, Japan, and Taiwan are making substantial investments in science, technology, workforce training and manufacturing to bolster their positions and competitiveness in microelectronics.



Universities and higher-education systems provide a fertile training ground for a skilled workforce and include an established network of research centers for developing the next generation of technological breakthroughs. With its 64-campus system of 1.3 million students, 3 million alumni, $1.6 billion annual R&D expenditures, and over 7,000 principal investigators, the State University of New York (SUNY) carries a massive responsibility to create transformational research opportunities in leading edge fields and advance commercialization of its inventions for the public benefit. A sustained, well-funded national strategy is essential for the U.S. to reassert its leadership and competitiveness in microelectronics and semiconductor manufacturing; however, *its success will rely on effective regional coordination with institutions of higher education to have the requisite impact on the workforce*. Large public university systems such as SUNY have well-established transfer paths between its two-year colleges, four-year comprehensive colleges, and large research universities, have established procedures for sharing research and education infrastructure, and have existing deep connections to local and regional industry, government, and economic development efforts. The latter is critically important as it is not feasible or sustainable to place capital intensive semiconductor laboratory equipment at every college campus for student education and workforce training. Hub-and-spoke models can be intrinsically more efficient and sustainable. *This system-based approach is essential for both disseminating new academic content and teaching modalities to re-engage students with microelectronics research and manufacturing, and for expanding the diversity and inclusivity of the pool of students engaged with microelectronics careers*.

SUNY is home to the only complete university-based chip fabrication facility operating at 300mm wafer scale, Albany Nanotech, which is now known as NYCREATES. The Albany Nanotech site offers a fully-integrated research, development, prototyping, and educational facility that provides strategic support through outreach, technology acceleration, business incubation, pilot prototyping, and test-based integration support for onsite corporate partners including IBM, GlobalFoundries, Samsung, Applied Materials, Tokyo Electron, ASML and Lam Research, as well as other "next generation" nanotechnology research activities, including hands-on internships for students along with career opportunities. Not only have the top four semiconductor equipment manufacturers (Applied Materials, Tokyo Electron, ASML, and LAM) located their most advanced tools and most talented R&D teams at Albany Nanotech, but these partnerships and infrastructure have enabled major breakthroughs, such as IBM's recent development of their 2nm chip technology[1].

Facilities like Albany Nanotech are prime examples of fabrication environments that replicate an industrial fabrication facility, but also enable innovation and workforce development. Such facilities are well poised for onboarding new technologies and educating the next generation of the semiconductor workforce. The role of the university is to provide the infrastructure, host the partners/tenants and to provide an instream of students/interns, post docs/contractors to support, feed, and accelerate this virtuous cycle of innovation. SUNY is a prime example of a higher-education institution with the size, scale, student diversity, and access to cutting-edge 300mm Si fabrication facilities necessary to effectively 'move the U.S. workforce needle' to help reassert U.S. leadership and competitiveness in microelectronics and semiconductor manufacturing. Albany Nanotech represents a thriving microelectronics ecosystem that is the result of more than $15 billion in investment by New York State spanning more than two decades, with a current operating budget of approximately $300 million per year. While these types of sites and facilities take billions of dollars and decades to create, build, and operate, Albany Nanotech is already operational and positioned to scale to meet domestic demand for more computer chips. SUNY's highly unique experience pioneering this successful co-location model between industry and academia at Albany Nanotech positions it well to achieve the large-scale impact that is envisioned in the United States Innovation and Competition Act (USICA).

Strategic investments described herein will enable SUNY to realize such a large impact, in alignment with the impact that was envisioned in the 2020 National Defense Authorization Act (NDAA) and the United States Innovation and Competition Act (USICA) of 2021, which included provisions to fund research and development in the semiconductor industry from the bi-partisan CHIPS for American Act and the bi-partisan American Foundries Act.

USICA, landmark legislation championed by Majority Leader Schumer that would spark innovative collaboration between higher education, industry, and research enterprises, passed the Senate in June 2021 and included emergency appropriations to support the implementation of semiconductor R&D programs that were authorized in the 2020 NDAA. Specifically, USICA provides $12.5 billion over five years for a National Semiconductor Technology Center, a National Advanced Packaging Program, and other programs that support research, testing, and workforce development in coordination with the private sector, federal agencies, and higher education.

THE MULTI-FACETED NEED FOR SEMICONDUCTOR INNOVATION

While the United States is a leader in semiconductor technology research and development, onshore manufacturing represents only a fraction of worldwide production. The U.S. supply shortage pre-dated but continues to be exacerbated by the pandemic and weather-related disasters at international manufacturing facilities. The current computer chip shortage is already negatively impacting motor vehicle production and further shortages and increased costs are projected for everything from phones to tablets and computers. There is a clear and urgent need to bolster US-based semiconductor manufacturing, and to bridge the gap between the R&D pipeline and the pathway to commercialization.

The Semiconductor Research Corporation (SRC), which represent university researchers, government, and industry, released *The Decadal Plan for Semiconductors*[2] in November 2020. The plan was a call to action to "address a range of seismic shifts shaping the future of chip technology." These seismic shifts, identified by SRC members, involve "smart sensing, memory and storage, communication, security, and energy efficiency." The SRC called for the federal government/industry to "invest ambitiously in semiconductor research in these areas to sustain the future of chip innovation." The identified areas of focus include: 1) fundamental breakthroughs to address the "analog data deluge"; 2) growth of memory and storage demands; 3) communication capacity vs. data generation; 4) security challenges; and, 5) the need to improve efficiency and reduce the energy requirements for computation.

In its 2018 *Report of the Office of Science Workshop on Basic Research Needs for Microelectronics*,[3] the Department of Energy identified the following priority research priorities for microelectronics: 1) innovative material, device and architecture requirements driven by applications, algorithms, and software; 2) revolutionize memory and data storage; 3) reimagine information flow unconstrained by interconnects; 4) redefine computing by leveraging novel unexploited physical phenomena; and 5) reinvent the electricity grid through new materials, devices and architectures.

The common thread among these and other reports is that the US needs to: reduce power utilization

KEY ELEMENTS FOR THE FUTURE OF SEMICONDUCTOR FOR MANUFACTURING IN THE UNITED STATES

- Reduce power & improve efficiency
- Enable novel computing approaches
- Meet increasing data & communication needs
- Ensure computing & manufacturing security
- Train and maintain a strong workforce

Figure 1. *Key elements needed to address major semiconductor needs and challenges for establishing new technologies and a robust, US-based manufacturing base.*

and improve the efficiency of computation; enable novel computing approaches (devices, architectures, and beyond); meet the demands of increasing data and communication needs; ensure the security of computation and manufacturing; and, train and maintain a strong workforce (Figure 1). Although there is no question that substantial investments are needed to bolster innovation through basic science research, the monumental challenge is understanding how to bridge the gaps between what we currently see as "state-of-the-art," and what ultimately needs to be done to meet current, and anticipate future, needs from the market. Higher education has a significant role to play here but it requires both investment in research and development, as well as a paradigm shift in how R&D advancements are translated to commercialization and manufacturing.

THE ROLE OF UNIVERSITIES & HIGHER EDUCATION

The importance of this work and the consequences of inaction cannot be understated—strategic investments here are directly tied to the health (and comparative strength) of the US economy and well-being of its citizens. When research and development lag, there is a corresponding decline in jobs along with resources (i.e. tax receipts) to fund social programs including healthcare, education, and infrastructure, to name a few. Two Nobel prizes were given to studies that concluded that as much as 85 percent of the long-term growth in America's economy is ascribed to advancements in science and technology.[4] China is projected to become the world's largest economy when measured by GDP by 2030. By 2026 (the 250th anniversary of the United States), China's strategic plan calls for it to be well on its way to becoming the unchallenged world leader in science, technology, and innovation. These developments are perilous for America and a tipping point in its R&D position.[5]

The State University of New York (SUNY) is the largest comprehensive system of public higher education in the United States. Unique among U.S. university systems in its scope and range, SUNY comprises distinguished research universities, academic medical centers, liberal arts colleges, community colleges, technology colleges, and recognized centers of excellence. SUNY's 64 campus system of 1.3 million students, 3 million alumni, $1.6 billion annual R&D expenditures, and over 7,000 principal investigators carries a massive responsibility to create transformational research opportunities in leading edge fields and advance commercialization of its inventions for the public benefit. Through innovative academic/industry partnership led by the SUNY Polytechnic Institute (SUNY Poly) campus in Albany, New York known as Albany Nanotech,[6] SUNY has also become an internationally recognized hub for microelectronics and semiconductor manufacturing.

THE ALBANY NANOTECH COMPLEX IS HOME TO SUNY POLY'S COLLEGE OF NANOSCALE SCIENCE AND ENGINEERING.

It is imperative that a robust response to address innovation and competitiveness in science and technology, technology translation, and workforce enablement is implemented and well-resourced, now. This can be accomplished through investment in human capital, knowledge capital, an ecosystem conducive to innovation, and financial capital; all hallmarks of the University research and development infrastructure.

Universities and higher-education systems provide a fertile training ground for a skilled workforce and include an established network of research centers for developing the next generation of technological breakthroughs.

Key to reducing administrative barriers and supporting innovative partnerships, SUNY also has the largest comprehensive university-connected research foundation in the country. The Research Foundation of SUNY (SUNY RF) provides essential business services that enable faculty to focus on the education of students and the performance of life-changing research. SUNY RF proudly powers SUNY's technology transfer and commercialization activities, including managing a technology and innovation portfolio of 1,828 patents, 848 active licenses, 130 operational startups, 18 technology and business incubators, and a startup equity portfolio with a total fair value of over $500 million.

BRIDGING THE GAPS

A critical challenge to furthering innovations that impact manufacturing advances is to address known gaps that are preventing innovations in research laboratories, higher education institutions, and small businesses from translation into manufacturing and commercialization.

In industry, the so-called "valley of death" describes the difficulty in maturing technologies through the demonstration and validation stage, which ultimately leads to a failure to transfer many new technologies to industry.[7]

Thus, we need major investments to accelerate R&D in key areas (Figure 2) and to build the bridges needed to translate promising technologies and innovations from the discovery stage all the way through commercialization.

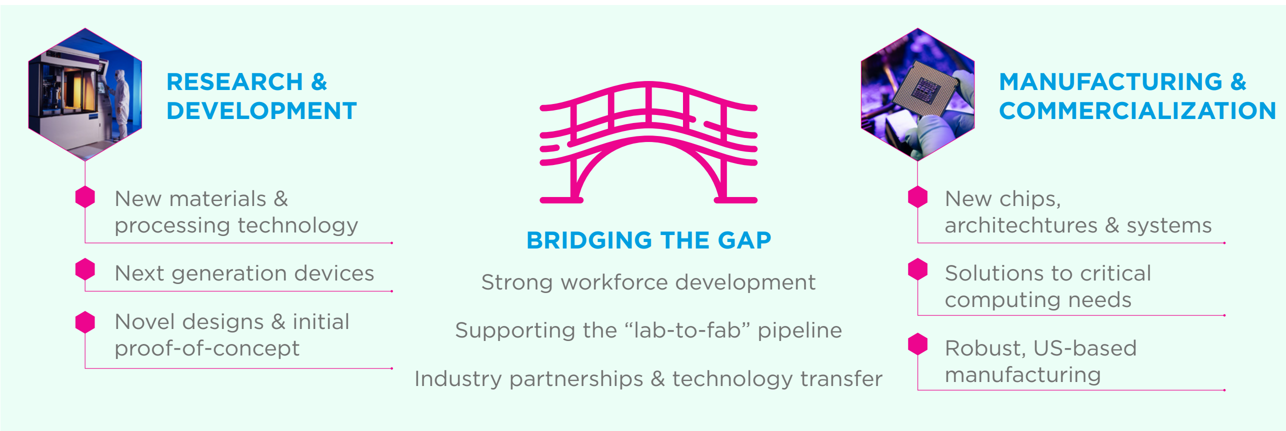


Figure 2. *Major gaps between R&D and ultimate manufacturing and commercialization of technologies yield a "valley of death" and lead to the failure of many innovations. By supporting the pipeline between the laboratory and fabrication/ manufacturing, investing in partnerships and technology transfer, and establishing a strong workforce, it is possible to bridge these gaps.*

SUPPORTING THE TECHNOLOGY PIPELINE

To address the key elements for semiconductor and microelectronics manufacturing in the US, there must be strong support for research and development that will lead to technological breakthroughs. This includes investment in basic research on: 1) new materials and processing technologies; 2) next generation devices; and 3) novel approaches to design, from the chip level to entire systems. With advances in each of these areas, intellectual property can be more efficiently and effectively transitioned from university laboratories and research centers to industry partners for manufacturing and commercialization. Simply increasing R&D output, however, is not enough. Bridging the aforementioned valley of death will require new investment in infrastructure as well as initiatives to transition technologies and practices.

In the semiconductor industry, the principle of scale is important on many levels. As the individual transistors and device elements on chips continue to scale smaller and achieve higher density, the size of silicon wafers and the magnitude of manufacturing facilities (fabs, cleanrooms) has continued to grow. While university research laboratories and start-ups can demonstrate new materials and devices using relatively small-scale equipment (typically on 100mm - 200mm wafers or even wafer pieces), major equipment suppliers and chip manufacturers are focused on high volume manufacturing on a 300mm wafer substrate, in equipment optimized to deliver high throughput. *This dichotomy between research scale proof-of-concept and the reality of high-volume manufacturing is a significant contributor to the "valley of death."*

HOW DO WE ADDRESS THE MISMATCH BETWEEN RESEARCH-LEVEL ACTIVITIES AND MANUFACTURING-LEVEL PRODUCTION?

First, investments must be made to keep university and other key research laboratories up to date with state-of-the-art fabrication tools and equipment; however, this does not imply that university-based facilities should try to replicate and maintain a complete CMOS-capable process flow or toolset. The cost of maintaining such equipment and the lack of availability of state-of-the-art, small wafer (100-200mm) tools makes such an approach untenable. *Goals here are much better accomplished by using* *an industry-university co-location model, similar to what has been established in Albany, New York at the SUNY Poly campus* (detailed below).

As such, universities need targeted investments in processing equipment (e.g., deposition, etch, lithography, metrology) that enable the next generation of discovery in materials, devices, packaging and testing. For example, atomic layer processing tools (e.g. deposition, etch, selective area growth) are needed to support extremely small-scale device development efforts and novel material stacks for emerging devices. As 2D and topological materials continue to demonstrate promise, there must also be investment in tools/toolsets that can support the processing, and in some cases transfer of these materials for wafer-scale fabrication. Likewise, cutting-edge metrology tools are needed to keep pace with aggressive device and materials scaling. Finally, investments are needed to support these research activities, not just the purchase of equipment and expansion of infrastructure. Basic funding to support the research programs (personnel, materials, tool time, etc.) is critical, and must be focused on research areas that support key semiconductor manufacturing and innovation needs (Figures 1 & 2).

WHAT IS NEEDED TO TRANSITION TECHNOLOGIES FROM LAB TO FAB?

Lab-scale demonstration of materials and devices on wafer pieces and small silicon wafers (100mm - 200mm) ultimately needs to be translated to fabrication in a high-volume manufacturing (HVM) environment. This typically means transition to a 300mm wafer platform. There is considerable mismatch, however, between the processing capability, materials compatibility, controls, and the overall process flow when moving from a research-level fabrication facility to HVM. Industry co-location facilities like Albany Nanotech are good examples of fabrication environments that replicate an industrial fabrication facility, but also enable innovation. Such facilities are well-poised for onboarding new technologies — but not without significant investment in "bridge" tools and infrastructure. To effectively demonstrate process and materials compatibility with 300mm "fabs" or "foundries," a dedicated set of tools and processing capability is needed. This is especially important in the areas of materials deposition, etch, and planarization, where novel materials and processing steps could negatively impact (and even shut down) a standard semiconductor production line. A bridge facility and set of equipment would enable unique processing capability in parallel to the strictly controlled 300mm process line, and would provide a unique "proving ground" for translating lab-based materials and process innovations into a manufacturing-ready, 300mm toolset. Such a facility would also constitute an efficient interface to established university-based research centers across the U.S. Current examples at SUNY institutions include New York State's university-based Centers of Excellence program; in particular, SUNY Poly's Center of Excellence in Nanoelectronics and Nanotechnology, Binghamton University's Small Scale Systems Integration and Packaging Center, Stony Brook University's Center of Excellence in Wireless and Information Technology, and the University at Buffalo's Center of Excellence in Materials Informatics. In addition, SUNY works closely with Empire State Development, New York's economic development arm, which deploys over $60 million annually to support a network of 70+ state-supported university research centers, incubators, and other advanced technology innovation assets. As part of this network, NYSTAR had been designated by the National Institute of Standards and Technology (NIST) Manufacturing Extension Partnership as the lead for all of New York, supporting a statewide center and ten regional centers.

WHAT WOULD A "BRIDGE" FACILITY AND TRANSLATIONAL PIPELINE LOOK LIKE?

Establishing a "bridge" facility requires a dedicated toolset in close proximity to a standard 300mm fabrication facility (co-location model), as well as a pipeline of processing innovation and metrology from distributed research-scale facilities/fabs. Placing flexible tools within, or in close proximity to a standard 300mm fab enables the seamless transfer of wafers back and forth to the "bridge" facility for unique process development. In effect, the "bridge" becomes a parallel loop for unique material and process development, and a sandbox for innovating and translating novel technologies onto the standard 300mm wafer platform. By including encapsulation tools (to protect/cover incompatible materials), as well as wafer cleaning and inspection tools (to remove and detect potential contaminants), wafers can ultimately proceed from the "bridge" space back into the standard fab (process line). This approach requires dedicated space and dedicated tools, in order to allow for processing and materials flexibility, and to limit impact on the function and throughput of the standard fabrication facility. It also requires a pipeline of processing developments from research-level laboratories and fabrication facilities. A strong network of partners developing novel materials and processes must be able to perform initial proof-of-concept, which can then be translated to the "bridge" facility.

Examples of such technology development and translation that are enabled by the 300mm fabrication facility capabilities at Albany Nanotech include US Department of Defense-sponsored research programs in advanced radiation hardened and 2D material-based nanoelectronic devices[8] and integration of novel resistive switching devices with CMOS for neuromorphic computing and artificial intelligence applications[9]. In addition to individual projects, the Albany Nanotech 300mm fabrication capabilities are currently enabling multiple project wafer (MPW) programs that incorporate unique circuit designs from multiple research groups from across the country onto a single chip, saving cost and accelerating development time.

EDUCATING, TRAINING, AND MAINTAINING A STRONG WORKFORCE

U.S. colleges and universities are at the heart of the education and workforce engine that has supported the microelectronics and semiconductor ecosystems since the inception of the transistor. Reassertion of U.S. leadership in microelectronics and cutting-edge microelectronic manufacturing must begin with sustained reinvestment in the U.S. college and university-based workforce enterprise; not only to maintain and expand the continued knowledge creation and innovation that has advanced existing semiconductor R&D for the last 50+ years, but to enable onshoring of key manufacturing capabilities necessary for U.S. economic and national security.

Semiconductor manufacturing in the U.S. employed nearly 200,000 people in 2019 in 20 fabs across the nation. This employment has decreased by more than 100,000 from 2001 due, in large part, to automation and offshoring.[10] While regional partnerships between individual employers and educators have long existed to support the workforce needs of individual fab facilities (e.g. SUNY partnerships with IBM and GlobalFoundries) a broader strategic approach is needed for substantial and sustained expansion of the number of STEM students pursuing careers in semiconductor manufacturing necessary to support a revitalized U.S. microelectronics sector.

Ironically, the ubiquity of semiconductor technology has, to some degree, disconnected many STEM students from the science and technology necessary to maintain global leadership in microelectronics. The pervasive availability and performance of integrated circuits have driven an explosion in computational, communication, and bio-related disciplines which have played no small role in the substantial increase of STEM-based degrees in the U.S. over the last decade (Fig. 3). However, enrollment in STEM degree programs that have typically supplied the semiconductor R&D and manufacturing workforce (Electrical Engineering, Materials Science, Physics, etc.) has remained flat or declined. Fears that the subject matter is too difficult, perhaps because of lack of exposure in the nation's P-12 system, exacerbates the decline in interest in semiconductor-related STEM careers among America's youth.[11] The enrollment decline compounds the historic lack of diversity in these programs. The United States systematically fails to attract Americans of diverse backgrounds into STEM careers, whether this is measured by gender, socioeconomic status, religion, sexual orientation, geographic location within the U.S., or disability.[12]

A key contributor to this decline of interest is a growing disconnect between students' perception of socially impactful 'tech' careers versus career pathways in microelectronics R&D and manufacturing. In other words, students are not seeing how a future career in microelectronics and semiconductor technology and manufacturing can address many serious global social and environmental issues. Compounding this has been a lack of engagement with younger students. While middle school and high school 'coding camps' and robotics competitions have grown dramatically across the US, priming interest in the fields of computer science, robotics, and autonomous systems, there has not been a meaningful analogous engagement platform for microelectronics and integrated circuits to raise awareness of the world-changing impacts intrinsic to such careers for younger students.

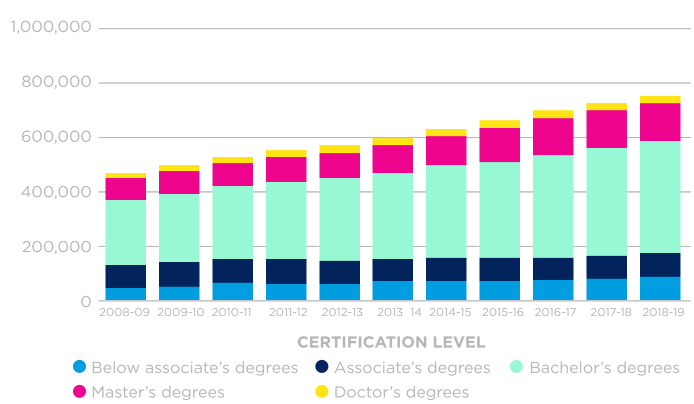


Figure 3. *Number of STEM degrees conferred by U.S. institutions, by degree level 2008-2019*

These systemic shortcomings must be addressed holistically, and at a meaningful scale of investment in U.S. higher education to promote a resurgence of student interest and career engagement in both microelectronics R&D and semiconductor manufacturing. Moreover, *the microelectronics workforce is hardly monolithic*. The R&D workforce is largely populated by those with bachelor's, master's, and doctoral degrees while the larger manufacturing workforce is dominated by two-year, associate degree recipients. Thus, a realistic approach to effective and impactful microelectronics education and workforce development must engage community colleges, comprehensive (four-year) colleges and research universities on a sufficiently large scale to 'move the needle.' No individual institution alone can have the required impact.

A sustained, well-funded national strategy is essential for the U.S. to reassert its global leadership and domestic competitiveness in microelectronics and semiconductor manufacturing; however, its success will rely on effective regional coordination with institutions of higher education to have the requisite impact on the workforce. This naturally favors large public university systems such as SUNY that have well-established transfer paths between its two-year colleges, four-year comprehensive colleges and large research universities; have existing and deep connections to local and regional industry and economic development efforts; and have established procedures for sharing research and education infrastructure. The latter is critically important as it is not feasible or sustainable to place capital-intensive semiconductor laboratory equipment at every college campus for student education and workforce training. Hub-and-spoke models can be intrinsically more efficient and sustainable. *This system-based approach is essential for both disseminating new academic content and teaching modalities to re-engage students with microelectronics research and manufacturing, and for expanding the diversity and inclusivity of the pool of students engaged with microelectronics careers*.

SUNY's diverse 64-campus system (including two-year colleges, four-year comprehensive colleges, technology colleges and research universities) serves nearly 400,000 students in for-credit degree and certificate programs, as well as its Educational Opportunity Centers (EOCs), and Pathways in Technology Early College High School (P-TECH) program, and a growing population of students in micro-credential and shorter-term certificate programs. SUNY campus leaders serve in senior roles on local regional economic development boards throughout New York State and many are very familiar with the workforce needs of the U.S. microelectronics industry.

In addition, SUNY's broad reach into the for-credit and not-for-credit education and training arenas for the trades, HVAC, environmental health and safety (EH&S), and industrial support career paths is equally important. In many regions of the U.S., the need for engineers and graduate level R&D positions at chip fabrication facilities is dwarfed by the need for process operators, maintenance technicians, facilities personnel, EH&S, and administrative operations staff. A successful workforce strategy must include these sectors as well.

SUNY is a prime example of a higher-education institution with the size, scale, degree diversity, student diversity, and access to cutting-edge 300mm Si fabrication facilities necessary to 'move the U.S. workforce needle' to help reassert U.S. leadership in microelectronics and semiconductor manufacturing.

KEY ELEMENTS OF A SUCCESSFUL EDUCATION AND WORKFORCE STRATEGY FOR MICROELECTRONICS AND SEMICONDUCTOR MANUFACTURING

A successful strategy to support an effective workforce for the U.S. microelectronics and semiconductor manufacturing industry must be multi-pronged and financially well-supported for long-term success. Key elements include, but are certainly not limited, to the following seven-point approach:

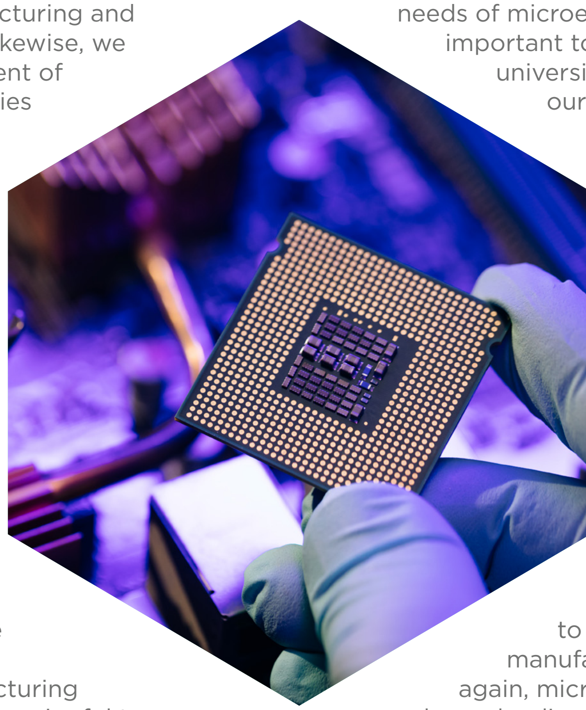
1. **Pre-college student engagement:** Meaningful, career and skills-oriented summer academies, workshops and bootcamps for incoming two-year and four-year college students to introduce microelectronics career pathways and associated academic programs. These would include 'design and fab' academies, 'chip manufacturing' bootcamps, and 'emerging technology' career workshops or similar.
2. **Access to Design-Fab-Test experiences at the undergraduate level:** Student educational access to introductory electronic and photonic integrated circuit design tools (i.e., electronic design automation (EDA/EDPA) software tools) in courses and workshops that allow students to submit their own designs to multi-project wafer (MPW) tape-outs, fabrication, and packaging. This should be coupled with access to chip-testing facilities for students to complete the design/fab/test cycle. Long a staple of graduate research, this access needs to be pushed deep into undergraduate curricula to stimulate innovation and career interest. It is essential to leverage facilities with proven and scalable MPW capabilities, such as Albany Nanotech's 300mm Si prototyping facility, to engage students with multiple technologies, e.g. traditional CMOS, photonic integrated circuits (PICs), ReRAM, power electronics, biochip, and quantum-computing architectures. Designing and testing basic chip-based sensors or rudimentary neural network circuits is well within the grasp of a wide-range of undergraduate students. Providing

such ‘innovation platforms’ directly to students is essential. It is also worth noting that various manufacturing innovation institutes, including SUNY’s AIM Photonics Institute, have already shown the efficacy of this approach for their educational outreach efforts.

3. **Expanded experiential learning:** Increased undergraduate participation in microelectronics R&D is clearly a key strategic component and requires expansion. However, a meaningful impact on the microelectronics manufacturing workforce requires a parallel expansion in experiential learning opportunities associated with advanced manufacturing, automation, machine learning, data literacy and Industry 4.0 principles. This is especially critical for the skilled technical workforce (e.g. those with A.S., A.A.S, and A.O.S. degrees) necessary for onshoring of microelectronics manufacturing and packaging technologies. Likewise, we must expand the engagement of students in advanced facilities management and the trades which support microelectronics fabrication facilities. Access to a university-based 300mm Si fab facility for experiential learning opportunities, which could be bundled with coursework in the form of micro-credentials—for two-year engineering tech students and four-year engineering students—is critical for all these sectors of the workforce. Such experience enables direct transition to the semiconductor manufacturing workforce in a timeframe meaningful to employers, while still putting students on a pathway to an initial or advanced degree.

4. **Expanded industry internships/co-ops:** Sustained support for a dramatic expansion in industry internships, co-ops and mentoring of students is likewise a key component. Although typically made available to upper-level undergraduates and graduate students, we must expand this engagement to include lower-level undergraduates (two-year/four-year) and, where appropriate, the trades to stimulate interest in microelectronics-related degrees, certificate programs and career pathways.

5. **Expanded initiatives in student diversity:** At each level of student engagement, the importance of sustained support for a diverse student pool cannot be overstated. A prime reason for the lack of growth in enrollment in microelectronics degree programs, whether at the technician, engineer, or R&D research professional level is the shrinking student pool. Entire sectors of our incoming student body have little connection to microelectronic career pathways. Tapping into these segments of our student body promises a rich and talented pool from which to rebuild our semiconductor workforce. A successful strategy will focus on embedding microelectronics and semiconductor manufacturing engagement activities (as outlined above) within specific institutions with diverse student populations.



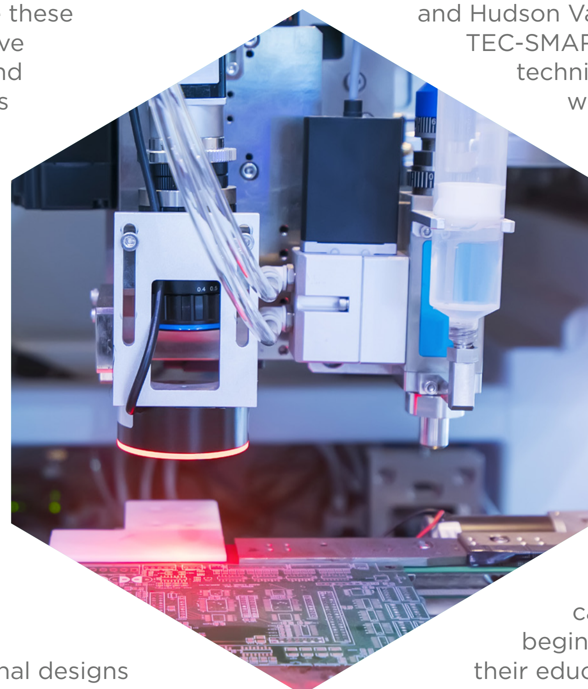
6. **Incumbent worker training and Department of Defense transition assistance program support:** Colleges and universities are traditionally driven by enrollment of students in ‘for-credit’ courses and programs. To rapidly respond to the workforce needs of microelectronics it is equally important to support colleges and universities in reskilling and upskilling our current workforce. Flexible delivery and engagement mechanisms must be developed to leverage the same content and facilities available to registered students to support our incumbent workforce. Nowhere is this more important than supporting transitioning military personnel. The more than 200,000 highly diverse military personnel transitioning out of service every year bring ready-made skills and experience to our microelectronics manufacturing workforce. Here again, micro-credentials, in which SUNY plays a leading role nationally, could be a beneficial toolset. Supporting student access to custom education and training modules in microelectronics will hasten their transition to such career paths but give them credit toward a certificate or degree.

7. **Microelectronics career transitioning:** While colleges and universities have long supported the transitioning of their students from the classroom to the workforce, a national microelectronics education and workforce initiative must also include an innovative approach to connect the highly qualified students with employers. Graduating students (or incumbent workers/transitioning DoD service members) should be able to construct a digital profile of their knowledge, skills, and abilities that can be made available to employers if they so choose. There

are novel approaches to do just this such as IBM's personal skills blockchain concept and SEMI's SEMI-Works® talent hub portal. These approaches should be scaled nationally to give graduating students and newly trained workers the ability to communicate verified details of their skills to potential employers — and for potential employers to highlight the knowledge, skills, and abilities they value the most for their future employees. SUNY's own Credential as You Go national effort can inform priorities in this area, as can SUNY's experience with open source digital badges.

8. **SUNY Microelectronics Workforce and Education Hubs:** To enable these key elements for an effective and impactful education and workforce strategy requires a system-level approach to avoid redundant and unsustainable infrastructure investment while providing the broadest possible access to a diverse student population.

For example, expansion of Albany Nanotech's 300mm Si prototyping facility to support large-scale educational MPW fabrication will create a design-fab hub where two-year/four-year/grad students from across the system and beyond can submit educational designs for fabrication. These designs would then be distributed back to fully equipped testing and application labs at SUNY research university centers, four-year comprehensive colleges, and community colleges to complete the student design-fab-test cycle and prepare students for direct entry into the microelectronics R&D and semiconductor manufacturing workforce. This MPW approach has been used successfully in SUNY Poly's AIM Photonics 300mm Si-wafer integrated photonics process flow for students from SUNY Poly, Rochester Institute of Technology, University of Rochester, University of California Santa Barbara, University of Arizona, Rensselaer Polytechnic Institute (RPI), and Massachusetts Institute of Technology (MIT).



The same 'hub and spoke' model would support critically important experiential learning models for the larger technician and engineer workforce. Leveraging workforce development facilities at SUNY community colleges (e.g. the Finger Lakes Workforce Development Center at Monroe Community College in Rochester, NY, the SUNY Erie Workforce Development Centers in Buffalo, NY, and Hudson Valley Community College's TEC-SMART facility, in Malta, NY), technician and engineering students would gain key hands-on technical experience before participating in 'capstone' internship experiences at SUNY Poly's 300mm Si Prototyping facility to enable transition directly into the U.S. 'fab' workforce.

A successful microelectronics and semiconductor manufacturing education and workforce development strategy must engage students with innovation and career pathways from the very beginning — and at each stage of their educational decision making — to prevent the broad pipeline of students entering higher education from becoming a modest trickle of entrants into microelectronics and semiconductor careers. *Such a coordinated resource model is highly scalable across the U.S. and represents a cost-effective approach to build a more diverse and better-trained semiconductor and microelectronics workforce.*

TECHNOLOGY TRANSFER AND INDUSTRY PARTNERSHIP

Translation from lab to fab, and eventually into the market, for most microelectronics technologies requires capital and time, as well as a combination of academic, government, and industry collaboration throughout various phases of the commercialization lifecycle. In order to maximize public dollars invested at the earliest stages of microelectronics research and technology development, and to increase the potential for the successful commercialization of these innovations, it is imperative that academic institutions engage and build strong relationships with the full spectrum of entities that operate across the various microelectronics industries and supply chains. Synergies across academic institutions can effectively accelerate the commercialization pathways for microelectronics innovations at scale by actively guiding and supporting the strategic and scientific vision for government-supported technology development centers and related clusters dedicated to these activities.

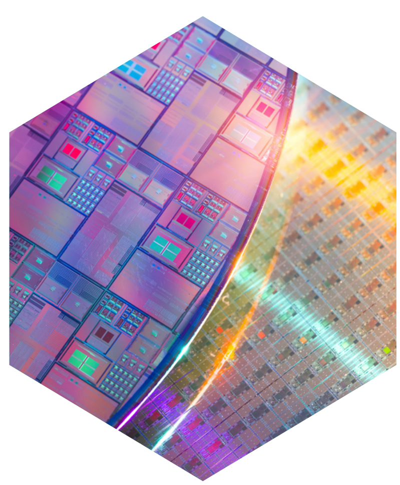
Universities are home to nascent and seasoned researchers, entrepreneurs, and startup companies that bring new microelectronics innovations to market. These innovators and entrepreneurial ventures, which are tackling some of the toughest problems facing the microelectronics industry, are critical to boosting innovation and increasing the nation's competitiveness. Academia is also critical in driving additional investment in technology and talent by larger, established corporations from the US and abroad, which in turn organically catalyzes more innovation and investment in the space. Further, to the betterment of all, there is clear recognition and existing commitment at the university level that program development in the microelectronics sector must be oriented to developing and attracting an inclusive, diverse, and high-performing workforce that draws from all segments of society and reflects the diversity of our increasingly global community.

New startup companies and growing small businesses developing and scaling breakthrough microelectronics innovations and processes from prototype to manufacturing require access to expensive and unique equipment, tools, and specialized facilities that are typically only available through a limited subset of academic, government, or industry partners. Providing affordable, straightforward, and streamlined access to these critical resources for qualified researchers, startups, and established small businesses that do not have the financial resources due to their stage of development or other factors will improve their likelihood for commercial success and spur more innovation domestically.

Established large companies that have a vested interest in the development and advancement of new microelectronics technologies and manufacturing techniques must be engaged by academic institutions with relevant research and commercial capabilities so they have a line of sight into the latest research and innovations being developed outside their walls. It also provides a natural opportunity to align interests between relevant startups or small businesses and willing large established companies, using the academic institutions as the common thread and vehicle for collaboration, at least initially. When executed correctly, this process opens up additional opportunities for more engagement between academia, government, and industry to advance the beneficiary researchers, startups, or small businesses, including joint development, non-recurring engineering, talent development and matchmaking, investment, licensing, access to customers or supply chain partners, etc.

The SUNY system, with grant and technology commercialization activity managed by the Research Foundation of SUNY, is uniquely positioned to be a leader and partner in serving this critical technology translation role between academia, government, and industry. SUNY's long track record (across its campuses) of providing accessible and affordable education and training opportunities for all New Yorkers on a massive scale (1.3 million students and nearly 3 million alumni), accessible via a single source, SUNYRF, has already demonstrated a proven ability to remove barriers in training and cross-fertilization and to facilitate connection to industry and academic partnership.

A truly impactful and thriving domestic microelectronics innovation ecosystem will require targeted investment by the public sector in the form of large, multi-institutional technology development and manufacturing centers or clusters focused on specific technology areas as well as record levels of non-dilutive government funding for technologies, companies, and projects. Based on previous periods of growth in government funding, like the investments made as part of the recovery from the great recession in 2008, it is highly likely similar investments in microelectronics research and education will lead to the mobilization of private investment across all categories, from equity investment to project capital and other debt financing. Those academic institutions operating centers focused on the advancement of microelectronics research, commercialization, manufacturing, and workforce development will need to offer wrap-around entrepreneurship and technology scaling support for their various stakeholders — students, faculty, startups, small companies, large established players, and the general public. This includes everything from basic training and advanced educational programs for innovators and entrepreneurs at all levels to business development mentoring and coaching support, subsidized access to shared facilities and bridge tools up to 300mm, and access to the pre-seed/seed-stage investment needed for technology de-risking, validating target markets, and building initial teams early on.

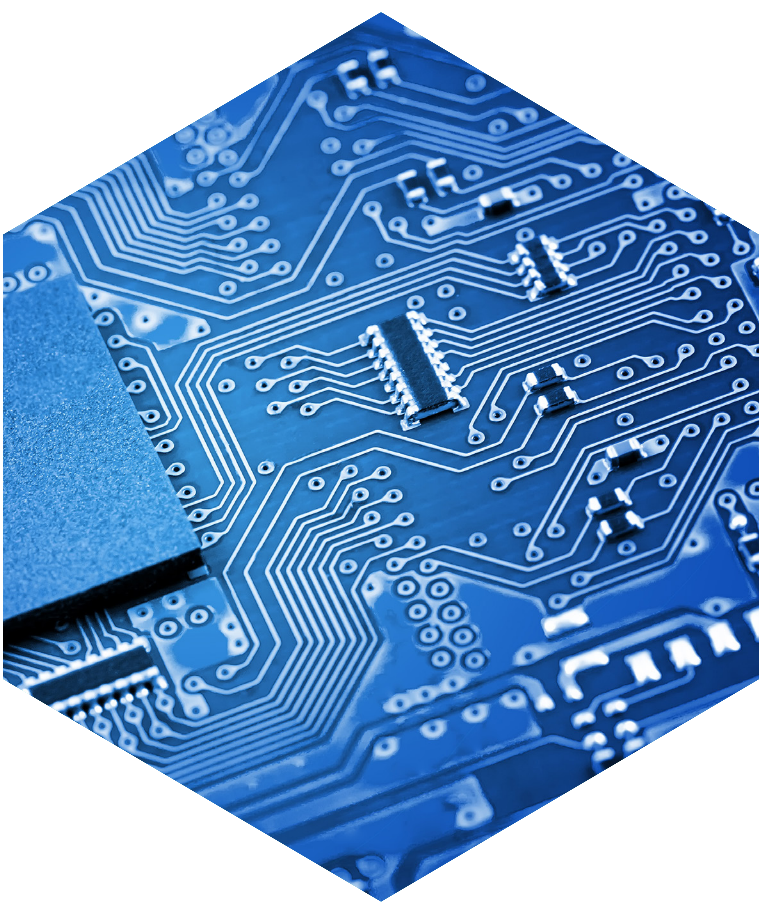


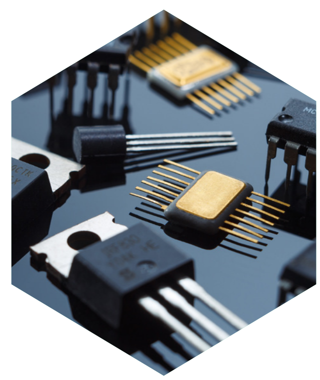
CONCLUSION

The nature of education and workforce training for microelectronics and semiconductor R&D and manufacturing is intrinsically challenging. Technology continually pushes the envelope of our fundamental understanding of materials and the very nature of information and communication itself. However, despite the complex and advanced nature of SUNY's enterprise we cannot demand students undertake an arduous career of study, only to be engaged with actual career pathways at the very end of their experience.

A successful microelectronics and semiconductor commercialization, manufacturing, education and workforce development strategy must engage students with innovation and career pathways early in their academic careers, and at each stage of their educational decision making, to prevent the broad pipeline of students entering higher education from becoming a modest trickle of entrants into microelectronics and semiconductor careers. *Industry-academia co-location facilities like Albany Nanotech are great examples of fabrication environments that replicate an industrial fabrication facility, but also enable innovation and workforce development*. Such facilities are well-poised for onboarding new technologies — but not without significant investment in "bridge" tools and infrastructure. SUNY's world-class microelectronics characterization, analysis, and fabrication facilities and capabilities make it a natural development partner and destination for global businesses of all sizes operating in the microelectronics industry. The public/private co-location model pioneered by SUNY Poly and partners at Albany Nanotech where a university campus, faculty, and students are co-located in the same facilities as industry partners, was focused exclusively on the microelectronics space. Investments here and in similar ventures to enhance opportunities for researchers, startups, and small businesses to connect and collaborate with industry players will result in more market-facing, commercially viable research and foster accelerated technology translation and commercialization from lab to fab for the domestic microelectronics industry.

Outlined in this document, we have put forward key elements of a successful innovation, technology translation, and education and workforce strategy for bolstering the U.S. microelectronics and semiconductor manufacturing of today, tomorrow and in the future. SUNY, with its integrated network of 64 campuses, premier 300mm facilities and bridge tools, and successful track record in workforce development and education, offers a proven model for the kind of scale-up strategy that the U.S. needs to retain leadership and competitiveness in the global microelectronic industry envisioned in USICA.





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