PURDUE UNIVERSITY

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Ensuring American Leadership in Microelectronics

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Introduction

Chairwoman Johnson, Ranking Member Lucas, and Members of the Committee, thank you for the opportunity to testify today. I am Mung Chiang, Executive Vice President for strategic initiatives at Purdue University, the John A. Edwardson Dean of the College of Engineering, and the Roscoe H. George Distinguished Professor of Electrical and Computer Engineering. Purdue University is world renowned for education, research, intellectual capital, facilities, and industrial collaborations. In 2021, Purdue's College of Engineering became the largest engineering school to be ranked among top five in the U.S., with over 15,000 students enrolled. Purdue has over 100 faculty members working in microelectronics and related fields who currently carry out research with over $110M in federal funds for research and development.

Here is a summary of the points I will make today: The U.S. must reclaim global leadership in tool development, material processing, manufacturing, and packaging of semiconductors. We need significant support from partnerships across academia, industry, national labs, and government to keep up with the pace of workforce demand for this critical industry. The ongoing discussion on legislation toward these goals has reached a critical point.

State of Semiconductors Industry in the U.S.

Our digital economy is built on silicon: microelectronic chips with up to tens of billions of transistors "printed" on feature sizes as small as one-ten-thousandth of a strand of hair. Innovative technologies, amazingly, continue to extend the life of Moore's Law: doubling the transistor density every two years, as we have seen throughout the past half-century.

For the American semiconductor industry, we are currently in the critical years. One constant reminder is the difficulty for all kinds of companies, such as the automakers, to access chip supply and continue their production. To fully understand the picture, it helps to visualize the supply chain in five steps:

- Raw materials and gases needed to make chips: some of these are rare and hard to come by.
- Hardware tools that go into the chip factories: some of these are very specialized and expensive, at over $100M per piece.

- Design of chips, as well as the software tools used in such design: many semiconductor companies have become "fabless," as they do not fabricate, or manufacture, the chips they design.
- Manufacturing: taking all of the above into a factory, the physical making of chips goes through many processes. Some factories focus on logic chips while others on memory chips.
- Assembly, Test, and Packaging: Once chips are made, they need to be packaged and integrated into the microelectronic products and eventually find their way into phones, cars, fighter jets, and more.

There remains substantial American industry leadership in certain hardware and all software tools, and in many sectors of fabless chip design. However, there is significant dependence on foreign countries for raw materials and gases.

Much of the discussion these days zooms in on the manufacturing step, and to some degree, advanced packaging. There are two very different types of business models for manufacturing:

- Make the chips designed by the same company.
- Make chips designed by other companies: the "foundry" model.

With increasing specialization in the semiconductors industry over the past three decades, many companies have chosen to rely on a foundry model. This enhances the benefits of scale and sharpens the ability to deliver cutting edge technologies, developing the service mindset and trust with foundry customers.

Along the entire semiconductor supply chain, the U.S. is now facing a pivotal moment on 3 P's: protect, promote, and partner. Protect through export control, promote through investment, and partner through on-shoring like-minded nations' technologies to America. An impactful example is the investment by Taiwan Semiconductor Manufacturing Company (TSMC) in Arizona. Since TSMC's announcement in May 2020, it has snowballed in scale and triggered an avalanche of strategic moves across the industry and governments.

Demand for chips is exploding, and chip shortages are in the news and are pinching the supply chain of other sectors of the economy. Any nation that aims to control its destiny must lead in semiconductor manufacturing, but today, the U.S. share of global semiconductor fabrication is only 12%, down from 37% in 1990, according to the Semiconductor Industry Association, despite the fact that the U.S. is the largest end-user of semiconductors, accounting for 47% of the global market.

Today, leading edge chip fabs cost more than $10B each, and designing leading edge chips can cost $500M each and require design teams with hundreds of engineers. Leading edge chips make possible the cloud computing and increasingly powerful artificial intelligence (AI) that we access through edge devices such as our smartphones. Applications like these have voracious appetites for computing, data, and communications. To realize the promise of these technologies, the performance of electronic systems must continue to improve at the pace it has for the past 60 years, during which the performance of chips was increased by making transistors smaller and smaller and placing more and more of them on a chip. New ways to increase performance at the leading edge must be found because the limits of making transistors smaller have almost been reached.

The semiconductor industry faces another challenge – one that arises from its success. Chips are becoming the critical, differentiating factor in more and more products, which is creating an urgent need for affordable, custom, product-specific electronics. Electronics used in national defense is one critical example, but an increasing number of commercial companies are also seeing the need for custom electronics that differentiates them from their competitors.

The vast majority of applications do not require custom electronics. In fact, the chip shortages that we hear about today are not at the leading edge, but rather, at so-called, "legacy technology nodes." Chips are more and more pervasive and are in more and more products, but few companies have the expertise or the ability to afford the custom, product-specific designs that are needed. To fully realize the opportunities we have, new ways to advance performance at the leading edge must be found, but the times also call for the democratization and differentiation of electronics, which will require a fundamental rethinking how electronic systems are designed, packaged, and qualified. We need to unleash U.S. creativity and innovation to make the second half of the "silicon century" even more exciting and impactful than the first half.

Universities have three unique roles to play:

- One is to help create synergy with companies large and small to bridge fundamental research advances with commercially deployable technologies. Innovation ecosystem works best when we create synergy across major companies in manufacturing and in design, small to medium disrupters with their venture capital investors, and researchers and teachers at universities.
- A second role is educating and retraining larger numbers of engineers, technicians, and operators. Ideally, universities can create jobs and knowledge together, and generate both new positions and the talent needed to fill the positions.
- Universities, especially land grand institutions such as Purdue, have an obligation to serve as an economic driver for the state and there is no greater opportunity today than in microelectronics. Purdue is proud to be a partner with the State of Indiana developing strategies and providing a talent pool to fill the jobs of the future.

Workforce for Semiconductors Industry

For the future of chips, the ultimate supply chain is that of human talent.

In just the next five years, at least 42,000 semiconductor engineers need to be trained and ready nationwide. And the number will continue to climb well into the next decade. The first critical factor in re-shoring and re-energizing the U.S. microelectronics industry is to attract the most talented and energetic young people to careers in semiconductors. Today, there are not enough science, technology, engineering, and math (STEM) students in the U.S. The demand for engineers in fields such as artificial intelligence is exploding, and smaller numbers of students are choosing to pursue careers in microelectronics, further leading to a growing gap between the supply and demand for microelectronics engineers. This gap exists across the spectrum from skilled technicians and operators with associate and bachelor degrees to those with advanced degrees such as Master's and Ph.D.'s. This gap is especially acute in the defense sector where more U.S. citizens are needed.

Growing U.S. microelectronics manufacturing from its current level (12% of global revenue) and maintaining our strong position in design and software tools (80% of global revenue) will require a much larger workforce. This is a grand challenge that universities, companies, and government must address together in a coordinated way.

Students today are aware of the excitement and opportunities in fields such as machine learning, data science, autonomous systems (which are critically dependent on rapidly advancing electronics), but they tend to view microelectronics as an old, mature, and not very exciting field. We must find ways to make students aware of the opportunities for careers in microelectronics, the need for creative new solutions, and the impact they can have on society. They should understand that they are not entering the tail end of a maturing industry, but the beginning of a new era in electronics. Some specific steps that should be taken now are:

- Revise, re-invigorate, and expand microelectronics curricula for a new era by offering new certificates, minors, and degrees dedicated to semiconductors, both to students and to practicing engineers who need to be constantly upskilled.
- Expand partnerships with community colleges and universities to increase the supply of skilled technicians, augment internships with national labs, and increase funding for these programs from agencies such as NSF, DOD, DOE, and DOL.
- Universities should work with industry to define the types of hands-on training that is necessary for the different types of careers in microelectronics. A plan for online and "virtual hands-on" education should be developed so that students at any university or community college in the U.S. can prepare for careers in semiconductors.
- A strategy for stronger industry engagement in workforce development should be developed. For example, students studying microelectronics should be able to find internship opportunities as easily as students studying computer science. More courses should be taught with, or taught by practicing microelectronics engineers.

Purdue Is Leading the Way: New Degrees and Online Courses, Defense Workforce Preparation, Hands-on Training, and Nation-wide Partnerships

Aspiring to be the pinnacle of excellence at scale, Purdue confers over 3,000 BS, MS, and PhD engineering degrees every year, while the undergraduate program ranks among the top 10, the graduate program among the top 4, and the online graduate program top 3 in the U.S.

Purdue University's Elmore Family School of Electrical and Computer Engineering announced two months ago that it is introducing America's **first suite of degrees and credentials dedicated to semiconductors**. This includes a new Master's degree in semiconductors and microelectronics (to be offered both residential and online), an undergraduate minor degree, and several online certificates. Students will learn both the manufacturing and design of chips, as well as the entire supply chain: the chemical engineering of gas reaction, the mechanical engineering of tool development and packaging, the material engineering of new manufacturing materials, and the industrial engineering of supply chain and logistics optimization. Courses will be supplemented with hands-on learning in one of the largest clean rooms in academia, and virtual simulation projects. The first students will be able to enroll starting next spring semester in some of these offerings.

Purdue is also a leader in **online education**. An example is the nanoHUB, the premier open and free platform for computational research, education, and collaboration in nanotechnology and related fields. Through the nanoHUB site, Purdue offers a rapidly growing collection of courses and simulation tools that run in the cloud. This platform will be expanded to scale up relevant courses for microelectronics and make them available to academic and industrial partners.

Purdue leads **SCALE, a 12-university consortium** that received a five-year, competitive award from the Department of Defense through Indiana's NSWC Crane, to educate the next generation of BS, MS, and PhD graduates, especially for defense applications. This microelectronics workforce development initiative blends classroom instruction with hands-on training and introduces students to concepts of secure and trusted microelectronics. A significant research investment through SCALE will not only add to the knowledge base but provide enhanced training for the students and add value for their future employers.

Purdue is home to the **Birck Nanotechnology Center (BNC**), an interdisciplinary research infrastructure for 160 affiliated faculty members and their research groups from 36 academic units at Purdue. The 187,000 sf facility includes a 25,000 sq. ft. ISO Class 3-4-5-6 (Class 1-10-100-1000) nanofabrication cleanroom - the Scifres Nanofabrication Laboratory. This is the largest clean room of this quality in a U.S. university. This is the place where quality hands-on training occurs for hundreds of students, a much-needed feature for microelectronics workers. Despite how critical this facility is for training, the upgrading and maintenance is a challenge, equipment is expensive and quickly becomes obsolete. It is imperative to receive more support to maintain competitivity and train the next generation workforce on current, relevant technologies, rather than equipment dated decades ago.

Purdue is also creating **workforce development programs with Ivy Tech**, a state-wide community college with over 70,000 students, to train technicians and production workers needed in semiconductor foundries, and to create a significant pipeline of students from community colleges to a university degree.

No single university can do everything in semiconductor workforce development. Purdue understands that solutions to workforce problems have to be developed in partnership across sectors to deliver excellence at scale. In a **workshop** organized by Purdue on November 12, 2021, representatives from industry were joined by representatives from the U.S. Departments of Commerce and Defense, the National Science Foundation, national labs, and academia, to discuss scaling-up educational programs; online and hands-on training; knowledge and skills for technicians, BS, MS, and PhD graduates; special programs for trusted and assured electronics; and funding opportunities for comprehensive workforce development programs. This is just the first event in a series that will bring together the right stakeholders to solve the semiconductors workforce development issues and ensure the U.S. is the rightful leader in the field.

Purdue is also part of the **American Semiconductor Academy (ASA),** a partnership of 50 American universities and community colleges. The ASA initiative aims to secure America's global leadership in semiconductor manufacturing by encouraging universities to collaborate with each other through a distributed network across the country with diverse sources of talent, partner with companies to attract and develop talent, and foster innovation to fuel the growth of semiconductor manufacturing in the U.S.

Semiconductor fabs are expensive to build and operate, but they are still fundamentally a manufacturing facility. Various states in the U.S. have maintained their manufacturing DNA in their workforce. The State of Indiana has targeted the semiconductor industry for continued growth and has scaled up their efforts led by Governor Holcomb and Commerce Secretary Chambers. I am honored to **serve as the technology advisor to the state**, and together we are working to on a strategy to recruit industry and build a workforce to meet their needs and the needs of our nation.

We also launched the **Center for Tech Diplomacy at Purdue (CTDP)**, an independent think tank at the intersection of technology and U.S. foreign policy. There is a gathering, bipartisan appreciation of the impact of technology on national security, human rights, economic growth, democracy, and liberty. CTDP brings deep engineering expertise and training to policymakers in an understandable and relevant way that demonstrates the inextricable links between technology and policy.

The Moment Is Now

Universities cannot solve alone the R&D and workforce problems that the microelectronics industry faces today. Significant investment from the government is needed on four fronts:

1) scale up the educational programs including hands on training and online learning,
2) substantially increase the number of scholarships for undergraduates and fellowships for graduate students in areas related to the semiconductors supply chain,
3) fund research and development programs that push the boundaries of science, and
4) facilitate translation of new discoveries into applications.

A highly skilled, creative, innovative, and substantially larger microelectronics workforce is a critical factor in the nation's strategy to re-shore and re-energize U.S. microelectronics. There is a serious gap today in the supply and demand for microelectronics technicians and engineers, and the shortage of talent will grow even larger as we build microelectronics facilities in the hundreds of billions in the U.S. this decade.

Action is needed now. Every day that passes makes the U.S. more vulnerable to risks in the supply chain, gaps in defense technologies, and a dire shortage of qualified workers. Passing the United States Competition and Innovation Act (USICA) this month will be a crucial and timely win for the national security, economic security, and job security in our country.

Dr. Mung Chiang

Dr. Mung Chiang is the Executive Vice President of Purdue University for strategic initiatives, the John A. Edwardson Dean of the College of Engineering, and the Roscoe H. George Distinguished Professor in the Elmore Family School of Electrical and Computer Engineering.

Dr. Chiang's research on communication networks received the 2013 Alan T. Waterman Award, the highest honor to scientists and engineers under the age of 40 in the U.S. He is a recipient of the Terman Education Award conferred by the American Society for Engineering Education, the Kiyo Tomiyasu Technical Achievement Award conferred by the Institute of Electrical and Electronics Engineers, and a Guggenheim Fellowship. He is a fellow of the National Academy of Inventors and a foreign member of the Royal Swedish Academy of Engineering Science.

Dr. Chiang founded the Princeton EDGE Lab in 2009, which bridges the theory-practice gap in edge computing and co-founded a few startup companies with products used by tens of millions of people worldwide. His textbook "Networked Life," popular science book "The Power of Networks," and online courses have reached hundreds of thousands of students.

Most recently Dr. Chiang founded the Center for Tech Diplomacy at Purdue, which intends to bring engineering expertise to policymakers in a way that demonstrates the inextricable links between technology advances and national interests.