**Spring 2010**
**Industry Study**

**Final Report**
***Electronics Industry***

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# ELECTRONICS 2010

**ABSTRACT**: An integral and necessary part of everyday life, the semiconductor is the heart of modern electronic technology and has enhanced globalization, increased productivity, and improved the global standard of living. Having spurred the development of a breathtaking array of goods and services, semiconductors form the foundation of both the U.S. and global economies. They are vital to U.S. national security because of their contribution to the national economy and because they are the building blocks of the nation's infrastructure, and the space, communications, and weapons systems that allow the projection of American diplomatic, information, military, and economic power. As such, the U.S. has a profound interest in maintaining influence and access to a vibrant and innovative semiconductor industry. The Industrial College of the Armed Forces (ICAF) Electronics Industry Study Seminar spent five months researching the global and domestic semiconductor industry. The seminar finds that the U.S. domestic semiconductor industry is declining compared to the global industry. The U.S. government must address this relative decline in the interest of national security. This paper defines the semiconductor industry, reviews challenges, presents an outlook, and recommends government policy to improve U.S. national security.

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# PLACES VISITED

**Domestic:**

**National Capital Region**

BAE Systems Space Systems & Electronics, Manassas, VA
Defense Advanced Research Project Agency (DARPA), Arlington, VA
ICAF Seminar
- Department of Commerce
- Department of Homeland Security (DHS), Infrastructure Protection
- Electronic Design Automation Consortium (EDAC)
- F-35 Joint Program Office (JPO), Integrated Core Process Team
- International Business Machines (IBM)
- Schweitzer Engineering Laboratories, Inc. (SEL)
- Semiconductor Industry Association (SIA)
- U.S. National Academies

Institute for Defense Analysis (IDA), Arlington, VA
- Office of the Secretary of Defense (AT&L), Industrial Policy

National Institute of Standards and Technology (NIST), Gaithersburg, MD
National Security Agency (NSA), Fort Meade, MD
Naval Research Laboratory (NRL), Washington, DC
Northrop Grumman Electronic Systems, Linthicum, MD
Virginia Semiconductor, Fredericksburg, VA

**California**

Advanced Micro Devices (AMD), Sunnyvale
Applied Materials, Sunnyvale
Defense Micro Electronics Activity (DMEA), Sacramento
Electronic Design Automation Consortium (EDAC), Sunnyvale
- Cadence Design Systems, Mentor Graphics, Synopsys

Intel, Santa Clara
Stanford University, Palo Alto

**International:**

**Taiwan**

American Institute in Taiwan (AIT), Taipei
American Chamber of Commerce, Taipei
Taiwan Semiconductor Industry Association (TSIA), Hsinchu
Industrial Technology Research Institute (ITRI), Hsinchu
Information and Communications Research Laboratories, Hsinchu
Taiwan Semiconductor Manufacturing Company (TSMC), Hsinchu
Macronix International Company, Hsinchu
ChipMOS Technologies, Inc., Hsinchu
United Microelectronics Corporation (UMC), Hsinchu
Etron Technology, Inc., Taoyuan
Inotera Memories, Inc., Taoyuan

**People's Republic of China**
U.S. Consulate General, Shanghai
Semiconductor Manufacturing International Corporation (SMIC), Shanghai
Semiconductor Industry Association (SIA), Beijing
U.S. Information Technology Office (USITO), Beijing
Chinese Semiconductor Industry Association (CSIA), Beijing
AMD Research Center, Beijing
IBM China Research Lab, Beijing

# INTRODUCTION

> *Slicing stealthily through the thin atmosphere, well above Helmand Province in Afghanistan, an MQ-1B Predator Unmanned Aerial Vehicle (UAV) closely tracks a suspected high value insurgent leader on the move. When the target vehicle stops and the insurgent enters a small structure along with a number of heavily armed men, the Predator operator and intelligence operatives confirm the target's identity. Moments prior to launching a Hellfire missile into the structure, while still awaiting authorization to attack, the Predator operator launches into a tirade of obscenities. The flight control system has failed, and the Predator spirals out of control. The Predator crashes in the mountains and the high value target survives. Subsequent investigations reveal the cause of the crash to be the failure of a substandard counterfeit semiconductor in the aileron controller circuitry of the flight control system. In response, the Department of Defense grounds all Predator UAVs until the pedigree of key electronic components can be inspected and confirmed to meet required specifications. During the 60 days this takes to complete, insurgent forces are able to assemble and plan their spring offensive with relative impunity, dramatically altering the course of the war.* –Fictional account inspired by an actual counterfeit chip occurrence in an active aircraft squadron.

Jack Kilby and Robert Noyce could not have imagined the monumental impact their devices would have on the world when they independently developed the first semiconductor integrated circuits in the late 1950s. Today, the semiconductor is an integral and necessary part of everyday life. Used in devices as mundane as toothbrushes and as exotic as the space shuttle, semiconductors are the heart of modern electronic technology. The semiconductor's impact on communication, travel, and information flows have enhanced globalization and productivity, and advanced the global standard of living. Having spurred the development of a breathtaking array of goods and services, semiconductors form the foundation of both the U.S. and global economies.

Semiconductors are vital to U.S. national security both because of their contribution to the national economy and because they are the building blocks of the nation's infrastructure and the space, communications, and weapons systems that allow the projection of American diplomatic, information, military and economic power. As such, the U.S. has a profound interest in maintaining influence and access to a vibrant and innovative semiconductor industry. Recognition of this interest led the Industrial College of the Armed Forces (ICAF) Electronics Industry Study Seminar to undertake a five-month comprehensive review of the semiconductor industry in an effort to understand industry trends, challenges, and opportunities. Informed by discussions with over 60 leading industry experts from various government and corporate laboratories; design, fabrication, packaging and testing facilities; policymaking venues and advocacy organizations, the review took full advantage of the opportunity to examine this global industry through domestic and international travel. The seminar visited sites in the National Capital Region, California (Silicon Valley), Taiwan, and the People's Republic of China. The seminar studied the industry's value chain, formulated an understanding of the innovative technology employed in these devices, examined the health of the industry both at home and abroad, and assessed the impact of industry trends, challenges, and opportunities on America's national security.

We found that the global industry is well positioned to recover profitability following the global economic downturn of 2008 and 2009. Furthermore, we observed a palpable desire among Asian nations that have already accumulated considerable market share to seize additional capacity in recognition of the correlation between a nation's technological capabilities and its economic vitality.[1] This intense competition has resulted in America's market share declining to such a degree that the U.S. government must take action to combat growing national security concerns.

This paper will identify and further explore these concerns following a brief definition of the electronics and semiconductor industries and current industry conditions. Next, five short essays provide additional context and background regarding these challenges, and when coupled with our outlook for the future of the industry, lead to concrete recommendations for U.S. government and industry action that will secure America's leadership in the industry and our national security.

## THE INDUSTRY DEFINED

The electronics industry is comprised of those entities creating and producing items relying on electrical circuits. Electrical circuits are devices that provide a path for electrical current to flow. An electronic good is any device that includes an electrical circuit. The global electronics industry consists of four major markets: consumer electronics, electronic equipment manufacturing, electronic manufacturing services, and semiconductors.[2]

Semiconductors are the foundation of the electronics industry and are therefore the primary focus of this paper. The semiconductor industry is global in nature and consists of all firms engaged in the design, fabrication, packaging and testing of semiconductors and related devices and processes. There are three main categories of semiconductor devices: integrated circuits, memory/logic devices, and other discrete components.[3] The activities of the semiconductor industry create value by transforming material resources, labor, capital, and entrepreneurial ability into semiconductor devices. The global semiconductor market consists of the manufacturers and sellers of semiconductors and related products. Their geographic scope includes North and South America, Asia-Pacific, and Europe.[4] U.S. firms are increasingly offshoring most manufacturing and some Research and Development (R&D) operations.

During 2009, the global semiconductor market produced revenues of $182.9B.[5] Market analysts project acceleration of the global semiconductor market from 2010 thru 2014, with the market value projected at $272.5B by the conclusion of 2014. Although U.S.-based semiconductor manufacturers operate globally and generate 81 percent of their revenue through exports, they maintain over 65 percent of their manufacturing capability in the U.S. In 2009, the industry employed an average of 207,500 individuals in the U.S.[6] The Department of Defense is not a significant consumer in the global semiconductor industry (nor are other U.S. government agencies).[7] Nevertheless, semiconductors are vital to U.S. national security because they are the electronic building blocks in the critical infrastructure and systems that enable American diplomatic, information, military and economic power. Hence, the U.S. must maintain access and influence in increasingly global semiconductor markets.

## CURRENT CONDITION

Semiconductor integrated circuit complexity and capability have increased at a phenomenal rate since the introduction of microchip technology in the late 1950s. Fostered by state-of-the-art research and development, faster and smaller microprocessors have fueled advancements throughout the electronics industry and have kept pace with Gordon Moore's 1965 prediction that semiconductor complexity, as measured by the number of components on an integrated circuit, would double approximately every 18 months, as shown in Figure 1 below. [8] Meanwhile, costs to produce these components have reduced dramatically.

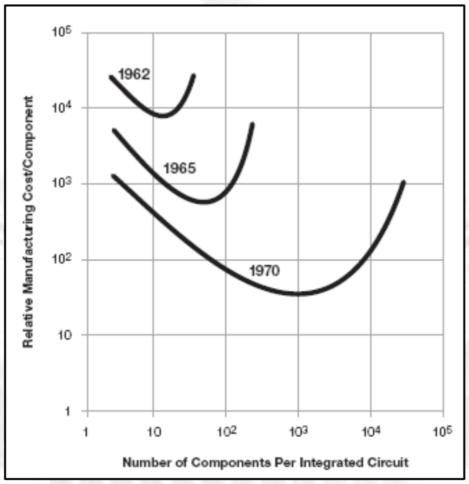


**Figure 1. Original Moore's Law**

Today, constructing a state-of-the-art semiconductor manufacturing facility (commonly referred to as a fabrication facility, fab, or foundry) can cost up to $5 billion.[9] Market forces and the incentive packages put together by governments (local, state, and federal) to attract semiconductor investments influence the decision on where to locate these expensive facilities. For example, China has used its undervalued currency, and environmental and labor laws and practices, along with government policies and supports, such as direct subsidies, preferential tax treatment, and the use of commercial offsets to foster the development and growth of its semiconductor industry.[10]

### State of Design and Manufacturing Technology

A "state-of-the-art" semiconductor chip contains more than one billion transistors. In approximately ten years, the size of electrical components and wiring on a chip, called features, will approach atomic dimensions that reach the physical limit of traditional chip design and manufacturing processes. Currently, the standard transistor size for high-volume chip manufacturers is 45 nanometers (nm). Innovative manufacturers have demonstrated feature dimensions down to 20nm, and several major semiconductor designers are planning to market 20nm chips in the next several years. The standard silicon wafer size for high-volume manufacturers is 300mm, which based on the chip size, can yield hundreds of chips.[11] Thus, an array of semiconductor chips (or "dies") on a 300mm silicon wafer featuring 45nm transistors represents the leading edge of production capability—this is considered the current "technology node" of semiconductor design and manufacturing. Discussions with semiconductor manufacturing equipment manufacturers uncovered a reluctance to design equipment capable of producing semiconductors on more efficient 450mm wafers as the mass production of 450mm wafers could quickly saturate the semiconductor market and limit the demand for manufacturing equipment.

A major business consideration semiconductor chip design companies face is whether to maintain expensive internal manufacturing capabilities or to outsource chip production. Outsourcing manufacturing and focusing solely on semiconductor design, referred to in the industry as a "fabless" approach, presents the opportunity for firms to divest themselves from the significant capital investment and operating costs associated with advanced manufacturing operations, while allowing them to focus exclusively on semiconductor design. Although divesting foundry operations may create short-term profits, the generation of intellectual property, in the form of collaborative research and development, often follows manufacturing. Over the long term, this migration could create a significant competitive disadvantage for U.S. semiconductor design companies as their innovation capacity and talent finds better opportunities in the science parks rapidly growing throughout Asia.

## Domestic Semiconductor Manufacturing Segment

As the second largest U.S. export segment, the semiconductor industry is a major contributor to the overall economic strength of the U.S. economy and its health and advancement are vital aspects of national security.[12]

Intel Corporation is the market leader with almost 80% of the Computer Processing Unit (CPU) semiconductor market share.[13] Intel has a $123B market capitalization and generated $35B of sales in 2009. They employ 79,800 people. Advanced Micro Devices (AMD) is the other major CPU contributor with approximately 20% market share.[14] AMD divested its fab capabilities in 2008 and relies on the company it spun off, Global Foundries, for the majority of its production. Taking the fabless approach and focusing solely on the design aspect of CPU semiconductors will enable AMD to leverage its advanced design capability and return to solid financial footing.[15] International Business Machines' (IBM) semiconductors power almost all of the modern home video game controllers. Outside of this business, IBM has a unique relationship with the Department of Defense (DoD). In 2001, the DoD entered into a 10-year contract with IBM for the production of "trusted" semiconductors. The DoD provides IBM approximately $45M each year for this service.[16] This trusted foundry program supports a critical area of national security and provides the DoD with domestically produced, process-controlled semiconductors for sensitive military applications. This arrangement creates a responsive semiconductor supplier base to maintain and advance the war-winning technologies essential to national defense and combat the lack of market influence that results from the DoD only consuming 7% of the domestic semiconductor market.[17]

Texas Instruments (TI), NVIDIA, Qualcomm, and Xilinx represent niche aspects of the market. TI is the leading producer of digital signal processors and displays, many of which have applications in defense electronics. NVIDIA's primary strength is in high-end computer video controllers, but it has recently leveraged its skill at component design to begin developing motherboard semiconductors. Qualcomm is the principal producer of semiconductors for the cellular phone industry. Xilinx is the leading producer of the increasingly popular Field Programmable Gate Arrays (FPGAs), which are Integrated Circuit (IC) devices designed for reprogramming, which provides standardized, but configurable digital circuits. Thus, consumers can program the same generic FPGA to perform any number of functions.[18]

### Global Semiconductor Business Outlook

The global semiconductor market experienced significant losses during the 2008-2009 global financial downturn. The sale of integrated semiconductor products, such as CPU chips, was the most profitable portion of the market in 2009. These products generated total revenues of $144.3B and represented almost 80% of the overall market. Sales of discrete semiconductors – individual components such as transistors and diodes – created revenues of $38.6B in 2009 and represented the remainder of the market.[19] The European semiconductor market Compound Annual Growth Rate (CAGR) declined at 13% over the last 5 years, while the Asia-Pacific market declined at 2.3% during the same period. In 2009, the European semiconductor market created revenues of $26.6B while the Asia-Pacific market achieved $114.3B in revenues. The U.S. market declined 4.3% during the same period and posted $34B in revenues in 2009.[20] Asia represents 63% of the global market, followed by the U.S. with 23% market share and Europe with 14%.[21] In general, the global semiconductor industry operates competitively, is innovative, and responds to the demand of its customers. These elements create net value for the consumer while providing healthy revenues.

## CHALLENGES

Several technological and policy challenges exist for the semiconductor industry, but discussions with industry experts gives hope that most challenges are surmountable, even those presented by scaling components to the atomic level. Our review has identified the following issues for the global industry and U.S. national security policy-makers to address:

<u>Industry-wide:</u>

- Continuing Moore's Law to its natural conclusion with Complementary Metal-Oxide Semiconductor (CMOS) and going beyond with next generation technologies
- Developing/maintaining human resources and skills to ensure innovation toward smaller, faster and cheaper electronic devices

<u>National security-related:</u>

- Guaranteeing assured access to trusted ICs
- Providing extended lifecycle support of microelectronics technologies in defense systems and critical national infrastructure

These challenges will require dedicated efforts in scientific research, continued development of intellectual capital within the U.S., and incentives for U.S. businesses to lead the industry in innovation, manufacturing, and design. As technology proliferates globally, the U.S. can best ensure its national security by maintaining the lead in innovation while securing and validating the semiconductor supply chain.

Rapidly advancing technology poses a particular challenge as CMOS based microcircuits become exceedingly more complex and achieve reduced scaling to 20nm, 15nm, or even smaller feature sizes. As leading U.S. manufacturers begin 32nm production this year and continue development of smaller scale technology, they will require advanced lithography capabilities, computational scaling, and new materials in order to achieve production quality products.[22] As scaling continues over the next 10-15 years, the physical constraints of the atom as it behaves in CMOS substrates will limit semiconductor manufacturing by causing excessive signal leakage and heat.[23] To overcome these roadblocks, the industry will require a new switching technology to replace the current CMOS-based transistor and continue receiving the benefits of smaller, faster, and cheaper electronic devices, thereby preserving American quality of life and productivity advances.[24]

In addition to the technological issues facing the industry, several policy issues need attention in order to ensure the continued health of the industry and guarantee continued U.S. leadership in semiconductor innovation and manufacturing. Of critical importance in the near term is strengthening the foundation for retaining intellectual capacity for U.S. manufacturing and design firms. Two particular trends are troubling and require correction. First, the performance of U.S. K-12 students places them below the average of their foreign peers in math and science, reducing the pool of qualified U.S. applicants for undergraduate engineering degrees. Second, the decline of undergraduate degrees in electrical engineering has led to a shortfall of post-graduate expertise in semiconductor related sciences.[25]

The decline in U.S. semiconductor manufacturing has led to an insecure supply chain and loss of high-technology jobs. Although several manufacturers indicated a preference to operate in the U.S. during our discussions, high corporate tax rates combined with incentives from foreign governments have provided motivation for the industry to move manufacturing capacity offshore. Retaining sufficient domestic design, manufacturing, packaging, and testing capability to supply trusted ICs would ensure an added layer of protection for classified and critical components. Creating a favorable business environment for semiconductor manufacturing to return to the U.S. would help overcome this challenge.

Integration of reduced scale microcircuits will continue to challenge the industry and DoD. The insatiable appetite for advanced electronics in the commercial market drives innovation, but defense systems in particular cannot keep pace with the rapid timeline of advancing technology. As a result, defense systems are not incorporating the latest microchip technologies, but are relying on older, larger scale 65nm, 90nm, or larger scale chips, many of them Commercial Off-the-Shelf (COTS) products. The heavy reliance on COTS products for defense platforms reduces the need for government-sponsored innovation. Furthermore, Diminishing Manufacturing Sources (DMS) based on an average 2-year lifecycle of next-generation commercial products complicates sustainment for military platforms that typically exceed a 20-year life cycle. Although COTS products provide the shortest development-to-fielding cycle available, manufacturers must make them compatible for military use, which increases costs for fielding and life cycle sustainment.

These challenges, although daunting, are surmountable, but their resolution will require a dedicated, cooperative effort by both industry and government. In the sections that follow, five short essays will provide the background and context of the issues and challenges as we prepare to offer recommendations for the U.S. government and industry action to secure America's leadership in the industry and our national security. The first three essays dissect the semiconductor industry from three different perspectives (globalization, innovation, and education). The final two essays focus on DoD acquisition.

## ESSAYS ON MAJOR ISSUES

### Industry Major Issue - Globalization

Globalization has made national boundaries porous by allowing a worldwide flow of goods, people, and capital. The semiconductor industry reflects this trend. A combination of market forces and government policies contributed to the offshoring of the U.S. semiconductor industry, which occurred in three distinct phases characterized by moving assembly, foundries, and design activities abroad.[26] From the 1960s to the 1980s, U.S. semiconductor firms first moved their labor-intensive assembly operations, and later their testing and packaging activities to various locations in Asia, such as Hong Kong, Malaysia, and Taiwan.[27] By 1978, about "80% of U.S. semiconductor production was assembled abroad," and by 2005, that figure was "probably above 95%."[28]

The strategy of designing, manufacturing, and assembling semiconductors in different countries has led many firms to specialize in a certain market segment such as semiconductor design, fabrication, or product assembly in order to stay competitive. Since 2001, many major semiconductor manufacturers have eliminated their fabrication capability and have turned to firms specializing in wafer fabrication for their chip production.[29] The U.S. is building only one of the 16 new foundries in the world that began construction in 2009.[30]

During the 1980s to the 2000s, U.S. firms contracted with these capital-intensive foundries in Taiwan to produce wafers, while keeping design activities in the U.S. and other developed countries.[31] Throughout this period, U.S. firms "continued domestic fabrication, but Asian countries increased their share of overall production—with Taiwan expanding as a major supplier of fabrication services and China emerging as a new source in the late 1990s."[32] As for design activities, "some design has been done offshore since at least the 1970s, [and] the pace of offshoring has noticeably increased in the last few years."[33] Through the 1970s, U.S. firms generally confined offshoring of design activities to Japan and Western Europe, but "[b]y the mid-1980s, a handful of offshore design investments had been made in Hong Kong, Taiwan, [and] Singapore."[34]

Because of the globalization of the semiconductor industry, the U.S. is starting to lose its competitive edge in key aspects of semiconductor development and manufacturing. The U.S. share of world spending on semiconductor research, development, and manufacturing capacity fell 15 percent since 1998.[35] In addition, U.S. share of leading-edge semiconductor manufacturing capacity fell from 36 percent to 11 percent in the past 7 years as the majority of new 300 mm wafer fabs moved offshore.[36] For instance, Texas Instruments has stopped the in-house manufacturing of advanced semiconductors at the 45nm and smaller feature size.[37] The firm now relies on partnerships with overseas foundries to develop advanced processors, resulting in worker layoff in various manufacturing facilities throughout Texas. The Bureau of Labor Statistics estimates that U.S. semiconductor manufacturing will lose 146,000 jobs over the coming decade—a decline of 34 percent.[38]

***Key Factors Contributing to Globalization***

Globalization of semiconductor manufacturing capability is due to several factors. Production and labor costs encouraged U.S. firms to offshore their production as a way to cut costs in order to stay globally competitive. In response to higher costs, overseas production of "U.S.-designed chips [occurred] mainly on an outsourced basis," to foundries in other countries created with the assistance of foreign government financed programs and subsidies.[39] For example, offshoring and the growth of indigenous semiconductor manufacturing in several Asian countries caused the share of worldwide wafer fabrication capacity in the U.S. to decline from 42 percent in 1980 to 16 percent in 2007.[40]

Furthermore, shifts in manufacturing historically resulted in the migration of research and design capabilities, which achieve synergy by being close to manufacturing facilities. This synergy allows firms to quickly push innovations into production and maintain a competitive advantage. "[T]he primary reasons for opening offshore design centers are the need for closer contact with customers, access to specialized skilled labor, and cost reduction."[41] Moreover, as the fabrication of semiconductors becomes more complex, it is "important to develop close relationships among design and manufacturing activities, so as to enable feedback discussions."[42]

During the early 1980s, the U.S. offered the most attractive R&D investment incentives in the world following the enactment of the R&D tax credit.[43] However, as other countries have implemented generous tax credits, grants, and other incentive measures to attract semiconductor manufacturing and R&D investment, R&D spending by U.S. semiconductor firms has decreased by 8.4 percent over the last decade.[44] Moreover, U.S. semiconductor firms may continue to reduce investments in research and design activities if the U.S. government continues to maintain one of the highest corporate tax rates in the world while other countries offer a combination of lower tax rates, investment tax credits, and other tax incentives. Because of the incentives in other countries, research and design activities may continue to migrate to Europe and Asia.

Finally, U.S. export controls have inhibited U.S. competitiveness in the electronics industry. The U.S. government designed export control laws and regulations to prevent the unauthorized and illegal export of sensitive equipment, materials, or technology. However, 50 years have passed since these controls originated, and they are hindering global competitiveness by U.S. firms in the electronics industry. Export controls on dual-use technology that have both commercial and military applications are excessively complicated, contain many redundancies, and try to protect too much.[45] Consequently, export controls deter global trade with the U.S. Foreign customers are seeking foreign suppliers and U.S. companies are seeking foreign partners in order to avoid export control restrictions.

***Globalization Implications and Conclusions***

The semiconductor industry plays a strategic role in the U.S.'s ability to remain competitive and a technological leader by fostering innovation. For this reason, a strong U.S. semiconductor industry forms the foundation for U.S. national security. Officials from the intelligence community have stated that relying on integrated circuits fabricated outside the U.S. is not an acceptable national security option.[46] These officials have pointed out that the manufacturing of semiconductors chips in some countries, particularly China, raises the risk that low quality, counterfeit, or tampered electronic devices may make their way into the market and into U.S. defense systems and other strategic infrastructures (electrical grid, financial systems, transportation systems, etc.).[47] Although the DoD has worked with industry to maintain a trusted foundry, the cost to build and maintain current state-of-the art facilities is significant and likely unsupportable.[48] As a result, the future may challenge the U.S. to obtain reliable semiconductor chips and other electronic products. Long-term competitiveness in the semiconductor industry is essential for the U.S. to achieve domestic economic growth, maintain its economic advantage in productivity, innovation, and technology, and meet national security requirements.

## Industry Major Issue – Technological Leadership in the Semiconductor Industry: An Imperative for U.S. Economic Vitality

***Introduction***

The U.S.'s technology driven economy underpins its national power and global influence. Its economic strength derives from its unique competitive advantages of entrepreneurial spirit and capacity for technological innovations that ultimately produce transformational technology. This transformational technology is essential to the nation's economic vitality that is crucial to improving both the nation's wealth and standard of living for its citizens. A key transformational technology was the invention of the transistor in 1948. This remarkable innovation sparked the entire semiconductor industry that continues to influence nearly all sectors of the economy, either directly or indirectly. The U.S. economy is also one of the most productive in the world.[49] Productivity gains in U.S. manufacturing sectors in the past several decades would not have been possible without industrial automation equipment based on essential semiconductor components.

The semiconductor industry has matured into a highly competitive global marketplace with new competitors emerging from developing nations. It is widely recognized by developing nations that there is a correlation between a nation's technological capabilities and its economic vitality.[50] Although not the largest element of the U.S. GDP, the semiconductor industry has been its first or second export over the past six years.[51] The U.S. semiconductor industry employs over 207,500 workers[52] with annual sales of $115B[53] in the U.S. The domestic industry, however, is in a steady decline.[54] Over the last decade, this trend has become evident as semiconductor firms migrate to overseas locations taking with them some of their R&D capabilities.[55]

***China's Rise and its Impact to the U.S. Semiconductor Industry***

China's strategy to generate economic growth relies on high technology manufacturing as a strategic element to achieve its ambition for global leadership in technological innovations.[56] To achieve this, China has pursued national policies supporting investments in science and technology infrastructures, educational facilities, and research and development.[57] Indeed, the Chinese government provides substantial financial incentives such as tax holidays and subsidized infrastructure to foreign and domestic semiconductor firms.[58] China's national focus has promoted high technology manufacturing as a key pillar of its economy and has allowed its semiconductor manufacturing section to attain capabilities that are within one or two generations of the current leading semiconductor technology.[59]

China's policy to promote economic growth has also established a sizable emerging "middle class" consumer base.[60] This consumer base will drive the demand for products associated with the "middle class," which in turn will influence a shift in economic influence from the West to the East.[61] Furthermore, this particular demographic will be younger and more willing to purchase durable goods compared to the developed nations.[62] These factors are attracting U.S. technology firms to expand into China in order to facilitate access to this huge consumer base. As U.S. and other western firms establish operations in China, the migration of technical skills and capabilities to indigenous Chinese technology companies is inevitable. This technology transfer from western firms could enable Chinese firms to become competitive peers in the semiconductor industry as they strive to become an innovative country by 2020.[63]

***Innovation, Manufacturing, and Economic Vitality***

The U.S. has been at the forefront for producing and exploiting transformational technology. Its leadership in technology is fostered by a free market environment and supporting infrastructure that includes world-class universities, an efficient capital market, and intellectual property protection. There are worrisome trends, however, for the U.S. semiconductor industry. The U.S. share of leading-edge semiconductor manufacturing fell from 35% in 2001 to 11% in 2006 as the majority of new 300-millimeter wafer fabs moved offshore.[64] Furthermore, the U.S. global share for semiconductor research and development has fallen from 45% in 1998 to less than 30% in 2005 indicating increased competitive efforts by other nations.[65] U.S. based firms now spend 22% of their R&D budgets overseas compared to 14% from the previous decade.[66] Although most of this budget is outside of China,[67] there is a trend for locating R&D centers there to facilitate entry into its enormous potential market.[68]

The decline in U.S. semiconductor manufacturing capacity has negative consequences for the industry's capabilities to continue innovating.[69] There are significant benefits from the synergistic effects of co-locating production lines, labs, and suppliers.[70] As manufacturing declines, associated supply chains, support firms, capital investment and, most importantly, related research and development atrophies. The U.S. could eventually lose its leadership in innovating new products, which is necessary for qualitative economic growth, if this trend continues.[71]

Manufacturing capabilities are critical for generating real economic growth.[72] Productivity is a good measure for standard of living and the trends in recent years are troubling.[73] After averaging annual 2.7% productivity growth from 1995 through 2002, annual growth of productivity in the non-farming business sector has slowed to just 1.7% in 2005, 1.0% in 2006, and 1.4% in 2007.[74] This new average rate of less than 1.4% suggests it would take nearly 52 years for average U.S. living standards to double, versus just 26 years at the earlier average.[75] Signs of this slowdown are apparent, particularly in the declining competitiveness of U.S. manufacturing sectors like automobiles and electronics.[76]

Intense competition in the global economy and emerging country's national strategies for fostering economic growth should persuade the U.S. to consider policies supporting domestic industrial capabilities, particularly in high technology sectors and policies, to encourage technological innovations. These are key strategic requirements to maintain economic vitality through transformational innovations. To attain this, the U.S. must have a combination of national will and supportive policies to shape the semiconductor market environment in support of the nation's interests.

***Conclusion***

It is crucial for the U.S. government to consider the strategic importance of industries vital to the nation's interests, such as semiconductors, and enact national policies to promote them. These policies must promote higher education in the Science, Technology, Engineering, and Math (STEM) disciplines, reform corporate tax policies to enable U.S. manufacturers to stay globally competitive while operating domestically, and encourage private and government R&D investments in transformative scientific research.

The world has focused a great deal of attention on China's economic rise, and China deserves great credit for its tremendous progress in just a few decades. However, the U.S. must not cede its leadership in technology and innovation. The U.S. economy still has the competitive advantage of being the largest and most innovative in the world because of a free market system that rewards an entrepreneurial and creative culture. A growing Asian consumer base is driving a global market shift, which presents fabulous market opportunities for U.S. firms. By utilizing its unique competitive advantages for generating innovations, the U.S has tremendous opportunities in this new market. U.S. economic vitality will continue as long as it can still lead in innovation, particularly in the semiconductor industry.

## Industry Major Issue – Building and Maintaining a Skilled Workforce

***Introduction***

The semiconductor industry requires individuals who excel in the STEM disciplines. In 1998, the Semiconductor Industry Association (SIA) established the Semiconductor Workforce Strategy Committee in response to what they saw as the U.S.'s inability to provide the industry with the highly skilled and educated workforce it needed.[77] Twelve years later, the industry still has the same concerns.

Although lower wages were a key factor in the decisions of U.S. firms to move their labor-intensive assembly operations to various locations in Asia when offshoring first began,[78] access to a skilled labor force is of greater importance today. Hence, when companies consider new locations, a significant concern is the long-term availability of skilled labor.[79] For example, the availability of educated and skilled workers influenced location decisions by both Texas Instruments and Hexaware in their expansions to the Philippines and Mexico respectively.[80]

***The Importance of Education***

Almost all of the officials the seminar met with, including academics from a leading engineering college in the U.S., noted the importance of having a highly educated and skilled workforce in order for the semiconductor industry to continue to innovate and push the envelope of technology. Furthermore, several officials from semiconductor firms, both in the U.S. and overseas, explained that a key factor in a semiconductor company's decision of where to locate is the availability of an educated and skilled workforce. They stipulated that the availability of skilled labor overseas has been a factor in the decision of some U.S. semiconductor firms to offshore part of their operations.

At the same time, almost all of the U.S. officials we met expressed concern over the U.S. education system's ability to produce sufficient numbers of skilled technical workers needed for the U.S. to continue as a leader in the semiconductor industry. Although the number of graduate students in the science and engineering fields has grown since 2000, the latest data available showed that U.S. engineering graduates decreased by 20% from 1985 to 2004, while China, Japan, and South Korea engineering graduates have increased 120% during this same period.[81] Today over 50 percent of the students graduating from U.S. universities with master's degrees and over 70 percent of those graduating with doctorate degrees in science and engineering fields are foreign nationals.[82] Current immigration policies, however, which result in long waits for permanent residence status, have deterred many talented scientists and engineers from remaining in the U.S. after graduation.

To benefit from foreign talent pools, U.S. semiconductor firms have established research centers outside of the U.S.[83] Furthermore, several of the officials we met feared that additional offshoring would occur if the U.S. education system does not produce a sufficient number of students with the skills necessary to conduct innovative research and design work.

Another major concern mentioned by officials the seminar met with, is whether the U.S. K-12 educational system produces sufficient students with sufficient ability in the STEM disciplines. In the latest published survey from the National Center for Education Statistics, the U.S. currently ranks number 33 in math and number 28 in science competencies of the 57 countries that participated in the survey.[84]

***Industry Steps In***

In 1998, SIA created a program to focus on K-12 education. A recent SIA survey found that in the 3 years prior to 2008, spending by SIA member companies on K-12 programs was over $275 million.[85] SIA used these funds to train or support over 310,000 teachers, and reached more than 14.5 million students.[86] SIA is also one of 15 organizations that, in 2005, created a program called "Tapping America's Potential," which seeks to double the STEM graduates at the baccalaureate level.[87] One example of the type of programs the industry has invested in is the Workforce Development Institute, which provides two-day programs for high school teachers to help learn methods to engage students in STEM studies.[88] Texas Instruments is another member of "Tapping

America's Potential" and is a national sponsor of MATHCOUNTS—a program for 7th and 8th graders that attempts to bring some of the same competitive excitement seen on school sports fields to math classrooms.[89]

***Conclusions***

Moving operations overseas is one option a company can exercise when there is a shortage of skilled labor. The U.S. has two primary options for increasing the supply of skilled labor needed to maintain its technological lead in the semiconductor industry and to ensure the U.S. can produce the critical components needed for our national security. The short-term opportunity is to create incentives for post-graduate students from other countries to remain in the U.S. after their studies are completed. The long-term opportunity is for the U.S. to increase the number of its citizens majoring in the STEM disciplines. Although the status of the U.S. K-12 educational system has raised a number of concerns about its ability to attract or produce sufficient numbers of students interested in the STEM disciplines, the U.S. is still widely recognized as having the leading higher education system for STEM disciplines, as evidenced by attracting doctoral and post-doctoral students from other countries.

The semiconductor industry has long recognized its dependence on an educated workforce in order to accelerate innovation. Moreover, innovation is what will keep the U.S. on the leading edge of the semiconductor industry. Hence, the semiconductor industry needs an educated workforce to remain successful.

## National Security Major Issue – Trust and Counterfeiting

***Introduction***

The 2005 Report of the Defense Science Board (DSB) task force on high performance microchip supply concluded, "[the] DoD and its suppliers face a major IC supply dilemma that threatens the security and integrity of classified and sensitive circuit design information, the superiority and correct functioning of electronic systems, system reliability, continued supply of long-system-life components, and special technology components."[90] The DoD is keenly aware that it is susceptible to embedded malicious manipulation of ICs through venues such as kill switches that turn off entire systems remotely, Trojan horses that could allow unauthorized access to DoD systems, and reliability based Trojans that prematurely end the life of critical electronic components. The 2010 Commerce Department study titled, "Defense Industrial Base Assessment: Counterfeit Electronics," states that the Naval Air Systems Command "suspected that an increasing number of counterfeit/defective electronics were infiltrating the DoD supply chain and affecting weapon system reliability."[91]

The "Trusted Foundry" program was initiated in 2004 prior to the DSB report, but in response to the same IC concerns. The Defense Advanced Research Project Agency's (DARPA) "Trusted IC" program is set to address the need for a capability to assess "trust" of ICs, especially those not manufactured at a trusted foundry. The Trusted IC program includes the ability to test the integrity of Application Specific Integrated Circuits (ASICs) and Field Programmable Gate Arrays (FPGAs) in order to guard against the potential for malicious manipulation of ICs.

***Trust***

The 2009 National Defense Authorization Bill states the Secretary of Defense "shall verify the trust of semiconductors procured by the Department of Defense from commercial sources for use in mission critical components."[92] When discussing both Trusted Foundries and Trusted ICs, it is helpful to define what trust means when put into context with national security and ICs. The National Security Agency (NSA) established tTThe Trusted Access Program Office (TAPO) "to provide a path for the DoD and the Intelligence Community to have guaranteed access to trusted microelectronics technologies for their critical system needs now and into the future."[93] According to TAPO, trust is defined as "the confidence in one's ability to secure national security systems by assessing the integrity of the people and processes used to design, generate, manufacture, and distribute national security critical components.TT" [94] National Semiconductor, a participant in the Trusted Foundry program, states, "When the government's microelectronics suppliers aren't certified [as] 'Trusted' suppliers then there is a serious risk of device tampering or counterfeit parts being introduced into their products."[95] DARPA's Trusted IC program has taken the point of view that someone may have tampered with an IC, so you should not tailor trust towards the production process, but instead towards verifying that the final product is void of tampering and free from corruption.

***Trusted Foundry / DARPA Trusted IC Program***

The Trusted Foundry program is a valuable tool to help ensure the trust of critical ASICs, but it does not cover all ICs. This includes many COTS products that use ASICs and FPGAs, and FPGAs purchased for DoD specific use that are manufactured in Asia.[96] As the first Trusted Foundry in the U.S., IBM is the only provider of commercially equivalent state of the art trusted ICs, which means that DoD builds many systems with older and potentially less capable technology. Unless new U.S. policies reverse the offshoring trends, there is a danger that the U.S. will be unable to maintain state of the art trusted IC foundries in the U.S.

DARPA designed the Trusted IC program to verify the trust of ICs after the manufacturing process, regardless of where the manufacturing occurred. DARPA is developing test methodologies to detect tampering as compared to a known "un-tampered" design or "gold standard" of an ASIC or FPGA. The next phase of the Trusted IC program will be to detect tampering in COTS products. DARPA's program will not eliminate the need for trusted foundries because the DoD has requirements for ASICs not found in the commercial industry. One example is the need for radiation hardened ICs for use in items such as satellites and missile systems. Trusted Foundries produce these ICs in relatively small quantities at various defense contractors throughout the U.S. Another example is ICs that are no longer at the cutting edge, thus not commercially available, but still critically needed for replacement parts in legacy DoD systems.

***Conclusion***

America's national security requires that we have trust in the integrated circuits that we use in defense systems. This trust is critical because the DoD is a technology driven organization that utilizes semiconductors in wide array of critical military equipment that must always work in times of peace and especially in war. As IC manufacturing continues to migrate from the U.S. to Asia, the DoD loses its ability to apply oversight to the manufacturing process. The Trusted Foundry program is a valuable tool to help ensure the trust of critical ASICs, however, it does not cover all ICs used. DoD must plan for the real possibility that the U.S. will lose its domestic innovative microchip manufacturing capability if current offshoring trends continue. DARPA's Trusted IC program can resolve this issue by ensuring trust after the manufacturing process regardless of the place of fabrication. Regardless of the success of the Trusted IC program, there will always be a need for the Trusted Foundry program to provide critical IC components such as radiation hardened ICs and critical legacy IC replacement parts.

## National Security Major Issue – IC Life Cycle, DMS, COTS Implications

### *Introduction*

As Moore's Law continues, the enormous improvements in capability of microelectronic circuits has very beneficial effects for the DoD and national security including greater computing capability, enhanced data fusion, more precise targeting, increased communications capability, and many others. However, Moore's Law also presents challenges for the nation. The rapid evolution of integrated circuitry greatly outpaces the slow march of government-procured products, particularly within the DoD acquisition process, in which major defense acquisition programs are procured over the course of decades rather than years. Although acquisition leaders have attempted to incorporate measures that can take advantage of Moore's Law, such as spiral development and open system architecture approaches, current weapons platforms are relying on older generation IC technology. That technology, while critical to mission accomplishment, will be increasingly difficult to sustain as industry moves to more advanced ICs that may not be compatible with older technology.

Additionally, as the industry approaches the physical limits of microchip scaling—CMOS is the current industry standard for semiconductor substrate—new materials or switching technologies will be required to evolve to the "next step" in integrated circuit design. That "next step" is likely to require a deliberate effort from DoD acquisition planners to incorporate it into defense platforms because the "next step" technology may not be compatible with CMOS technology. Future designers of defense systems must consider the impact of "next step" technology on their designs to minimize obsolescence problems for next generation platforms.

### *Life Cycle, DMS, and COTS*

The defense acquisition process is, by nature, a time-consuming activity. Pre-system and system acquisition phases leading to full operational capability (FOC) can take several years for a major defense acquisition program such as a submarine, an armored vehicle, or an aircraft. The most difficult and resource-consuming DMS issue is that upon reaching FOC, a system will enter many years of sustainment and encounter decades of obsolescence issues.

Non-availability of parts during a program's extended life cycle is the most challenging aspect of microelectronics DMS problems. First, since defense requirements account for roughly one percent of the global semiconductor market,[97] manufacturers are reluctant to commit resources to technologies that are no longer commercially viable. With only a marginal share of the market, military-specific applications are no longer the driving force behind innovation and creative development. The commercial markets, with insatiable appetites for newer, more capable electronics, are driving innovation. As such, research and development funding in the private sector for the past decade has far exceeded government funding for microelectronics.[98] This driving force has exacerbated the DMS dilemma by requiring DoD to rely on COTS products in many military subsystems. Manufacturers, however, do not design COTS products for military use, and in many cases, COTS products are not survivable in military environments.[99]

***Conclusion***

Several potential solutions exist to resolve electronics obsolescence issues for DoD systems including some promising emerging technologies that DoD may incorporate into future platforms. According to the Defense Micro Electronics Activity (DMEA), "the only real solution to microelectronics obsolescence is having the capability to produce on demand form, fit, and functionally equivalent integrated circuits."[100] The U.S. must develop processes to manufacture components or to have those components available on demand by several different means as outlined in the policy recommendations section below.

## OUTLOOK

The global economy will pull out of the 2008–2009 recession and return the global semiconductor industry to profitability in 2010. Industry experts have predicted continued industry growth through at least 2014, assuming the global economy continues its recovery. Semiconductors will become even more prevalent in society as developers find new and innovative uses for semiconductors in a wider range of consumer products. Semiconductor firms will continue the trend of outsourcing device manufacturing by going fabless, increasing the importance of these fabrication companies to the industry as a whole and causing manufacturing capacity to continue its migration to low cost centers.

The U.S. segment of the industry will retain leading edge technology node design and manufacturing capability in the near future, but will face serious challenges to its dominance as American companies transfer manufacturing and research and development activities offshore to take advantage of foreign government enticements, pursue human capital, and benefit from proximity to the largest markets for their products. The enormous capital expenditures required to maintain leading edge capabilities will concentrate the leading edge technology in the hands of a very few companies. U.S. industry leaders have affirmed their commitment to retain the most advanced technology node design and manufacturing capability in the U.S., at least for the near term, but have acknowledged that the forces outlined above continue to enhance the business case for offshoring more of their activities. Our review of the industry has led to conclusion that combating this trend will require prompt and effective government action to motivate American companies to retain their capabilities in the U.S. over the long term. If we fail, the industry's ability to support national security resource requirements will be at risk.

On the technology front, leading semiconductor manufacturers will produce chips at the 32nm feature size this year, and will transition to 20nm and smaller technologies by the end of the decade. Industry leaders the seminar met with confidently predicted that they would be able to maintain Moore's law at least through this period. Beyond the next ten years, however, most industry and government experts expect to reach the finite bounds of contemporary CMOS-based semiconductor capability based on approaching power and heat limitations. As a result, we expect the industry to continue turning its attention toward developing the next generation switching technology such as carbon-based nano-electronics, spin-based devices, ferromagnetic logic, atomic switches, and nano-electromechanical-system (NEMS) switches.[101] These emerging initiatives have the potential to increase computational speed while using less electrical power and generating less heat.

The DoD's future capabilities with respect to electronic and advanced weapon systems are heavily dependent upon the results of research and development achievements within the commercial semiconductor industry. As the semiconductor industry continues to grow and expand globally, DoD's market share and influence will continue to decline, along with its ability to influence the industry via market forces. Because of this reduced influence, DoD will continue to use COTS products in major weapon systems as a cost saving measure.

## GOVERNMENT GOALS AND ROLE

### "Stay Out of the Way!"

When the Electronics Industry Study seminar asked electronics industry leaders what the desired role of the government in supporting their industry, most said, "Stay out of the way!" This approach, however, will not address the national security concerns outlined above. The seminar's approach has been to formulate recommendations that take the counsel of the industry leaders into account. Because the U.S. government cannot roll back the forces of globalization, the DoD will continue to use electronic parts manufactured overseas and must foster methodologies to ensure a supply of trusted ICs. Our recommendations support this effort.

### Government Policy Recommendations

Although there is no single policy that will maintain or increase semiconductor research, design, and manufacturing in the U.S., a combination of several policies may improve U.S. competitiveness in a global environment. The continued success of the U.S. semiconductor industry and the health of national security will require the following government policy changes.

1) **Develop a comprehensive national innovation strategy.** Many nations possess and develop policies based on an aggressive innovation strategy. The U.S. has typically let market forces drive the nation's innovation. Without sacrificing free market idealisms, the time is right for the U.S. government to lead the nation and show the

world the U.S. is committed to leading the world's innovation. Some of the potential pieces of this strategy are outlined below.

a) **Adopt favorable tax policies to improve U.S. semiconductor companies' competitiveness while maintaining domestic manufacturing.** The U.S. government should increase tax incentives by reducing the corporate tax rates and establishing favorable capital depreciation rules to entice domestic semiconductor firms to continue manufacturing in the U.S. Tax incentives could also improve U.S. competitiveness by improving domestic manufacturing ability to compete on the world market.[102]

b) **Reform export control policies to promote cooperation with U.S. friends and allies and help ensure U.S. competitiveness.** Export control restrictions must be reformed to reduce complexity and redundancy, and in protect dual-use technology for military and commercial applications, while encouraging trade. Many firms prefer to operate in the U.S. due to its strong intellectual property laws. Changes in export policies when coupled with a supportive tax structure should promote the backshoring of semiconductor manufacturing to the U.S.

c) **Fund long-term R&D to generate the next transformational technology.** The nation must increase government support for long-term research in break-thru technologies. In a decade, China will be more R&D intensive than the U.S. and it will spend more dollars on R&D.[103] The U.S. must aggressively develop the next transformation switching technology to maintain its leadership in the semiconductor industry. This will only be possible with consistent and substantive investments in private and government sponsored R&D.[104]

d) **Improve supply of STEM graduates and retention of foreign-born scientists and engineers.** To eliminate access to human capital as a reason for semiconductor firms to locate operations overseas, the U.S. government and local state governments must work in concert to improve the education sector to generate more STEM graduates.[105] It is also critical to improve immigration policies to attract and retain foreign-born scientists and engineers.[106] This recommendation has benefits that reach far beyond just the electronics industry.

e) **Work with industry to expand its commitment to STEM K-12 education.** In general, the industry leaders the seminar encountered related their company's commitment to give back educational services to the communities their factories and laboratories are located in. The best educational ideas the seminar received from an industry leader was to ask children how they wanted to change the world, and then show them how to use science and technology to do just that. High-tech companies, like semiconductor firms, are well positioned to show children examples of how their products are changing the world, and incite interest in STEM disciplines. Government should provide incentives to encourage industry to provide these demonstrations to their local communities and reach out beyond their communities to the max extent feasible.

2) **Continue to develop the Trusted IC program and develop policies to enforce the use of the program.** Trusted foundries provide a solid base for the manufacture of critical defense ICs. However, the majority of defense bound ICs or non-critical ICs, originate outside the trusted foundry model. DARPA's Trusted IC program is set to address the need for a capability to assess trust for all ICs, especially for those not manufactured at a trusted foundry. This project aims to test the integrity of ASICs and FPGAs to guard against the potential for malicious manipulation of ICs. The additional trust this program will provide is fundamental to the security of our nation and the DoD should focus all necessary resources on developing and applying this technology.

3) **Reform acquisition program ma nagement to account for DMS.** Program managers must plan to manage DMS by incorporating continuous modernization into every phase of the acquisition cycle. This will minimize the upgrade intervals and maximize capability to the war fighter by providing him with the most modern semiconductors available. Program managers must also expand the use of FPGAs to solve or mitigate many current or future DMS shortfalls in semiconductors. The reprogrammable nature of FPGAs makes it easier to make a newer, faster FPGA and accomplish the same exact function performed by the antiquated FPGA. Some acquisition programs use this approach today, but program managers must expand FPGA use.

4) **Expand the use of modified COTS.** The use of COTS products can provide the shortest development-to-fielding cycle available, but these products must be conducive to military use and longevity. A potential solution is to work with industry to produce a "modified COTS" product that meets military specifications, but does not place an undue burden on industry (or undue cost on DoD) to develop a military-unique microprocessor, integrated circuit or complete system.[107] The value of modified COTS products to DoD is to significantly reduce R&D costs, reduce time-to-market, increase ability to upgrade, and increase availability of the product since industry will be producing the baseline product concurrently with the modified COTS product.

## CONCLUSION

The seminar's research and field studies identified four challenges that require U.S government attention, and recommends nine policy changes to address these challenges. By acting on these recommendations, the U.S. government can assure the domestic semiconductor industry's competitiveness in a global environment. The U.S. must establish the conditions necessary to continue as a leading innovator in the industry, especially as current technology reaches its theoretical limits and new switching technologies are developed. The DoD must also take the necessary steps to ensure a supply of reliable, high-quality semiconductor devices that perform their design function, free from tampering and corruption.

The global semiconductor industry remains healthy, and is poised to continue its positive impact on globalization, productivity and the worldwide standard of living. For the time being, the U.S. semiconductor industry also seems healthy, although forces at work on the industry may cause problems in the future. Because of its importance to the national economy and national security, the U.S. government should take steps to combat the externalities that might entice U.S. manufacturers to offshore the innovation capacity from the design segment of the semiconductor industry. Doing so will ensure these skills and value creation activities remain at home to benefit the U.S.

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