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Industry Study

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Electronics Industry

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ELECTRONICS 2011

ABSTRACT: Semiconductors have become ubiquitous across society and across the globe. They have ushered in an era of instant communication, constant information and knowledge sharing, and global awareness. In general, one would be hard-pressed to find any facet of people's lives that does not rely on semiconductor technology. The semiconductor industry sits as the foundation for the United States (U.S.) and global economies. The U.S. national and social infrastructure, along with military weapon systems, relies heavily on it. Our edge in semiconductor technology has enabled the U.S. to take a global leadership position in projecting diplomatic, information, economic, and military power. However, while the U.S. has remained at the apex of the market since its inception, that leadership is being challenged. Global currents, public policy, and intense global competition have led to a steady decline in the U.S. market share, lead in technological innovation, and attractiveness for the best and brightest workforce. These trends are undeniable and raise the question whether the U.S. wishes to remain at the forefront of the semiconductor industry with a vibrant and innovative workforce.

Recognizing the vital role of semiconductors in the U.S. economy and national security, 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 the U.S. domestic semiconductor industry remains a major contributor and catalyst for the entire U.S. national economy, yet is in steady decline relative to global markets. The U.S. government must recognize this decline and the serious economic and national security repercussions it will have. Only through a thorough understanding of the complexity of the industry can the government develop a comprehensive and informed strategy to address the causes and reverse the decline. This paper endeavors to further the discussion by defining and analyzing the global and domestic semiconductor industry, reviewing current trends and issues, and recommending a full set of government policy improvements to bolster the nation's economic strength and national security.

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Domestic

National Capital Region
BAE Systems Space Systems & Electronics, Manassas, VA
Committee on Armed Services, United States Senate
Finmeccanica North America, Washington, DC
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ICAF Seminar
- Defense Logistics Agency, Defense Supply Center Columbus
- Department of Commerce, Bureau of Industry and Security
- Department of Homeland Security (DHS), Office of Infrastructure Protection
- Electronic Design Automation Consortium (EDAC)
- F-35 Joint Program Office (JPO), Integrated Core Process Team
- Institute for Defense Analysis (IDA)
- IBM Research
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Office of the Deputy Undersecretary of Defense, Industrial Policy
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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
Semiconductor Industry Association (SIA), Washington, DC
Semiconductor Equipment and Materials International (SEMI), Washington, DC
Semiconductor Research Corporation (SRC), Washington, DC
Texas Instruments Inc., Washington, DC
Task Force on American Innovation (TFAI), Washington, DC
Virginia Semiconductor, Fredericksburg, VA

New York
IBM Watson Research Center, Yorktown Heights
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California
Applied Materials Inc., Sunnyvale
Defense MicroElectronics Activity (DMEA), Sacramento
Electronic Design Automation Consortium (EDAC), Sunnyvale
- (Cadence Design Systems; Mentor Graphics; Synopsys)

Gradient Design Automation, Santa Clara
Huawei Technologies, Santa Clara
Intel Corporation, Santa Clara
Magma Design Automation, San Jose
Pantronix Corp., Freemont

International
Taiwan
American Chamber of Commerce In Taipei, Taipei
American Institute in Taiwan (AIT), Taipei
ChipMOS Technologies, Inc., Hsinchu Science Park
Etron Technology, Inc., Taoyuan
Industrial Technology Research Institute (ITRI), Hsinchu Science Park
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Inotera Memories, Inc., Taoyuan
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Taiwan Semiconductor Industry Association (TSIA), Hsinchu Science Park
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Advanced Micro Devices (AMD) Research Center, Beijing
Cisco Systems, Inc., Beijing
IBM Research - China, Beijing
Semiconductor Industry Association (SIA), Beijing
Semiconductor Manufacturing International Corporation (SMIC), Shanghai
U.S. Consulate General, Shanghai
U.S. Information Technology Office (USITO), Beijing

INTRODUCTION

"With the dramatic new capabilities enabled by rapidly evolving technologies, DoD and intelligence agencies will need to be first adopters of the most advanced integrated circuits, and will be increasingly dependent on such chips for a defense and intelligence edge."[1]

Senator Joseph A. Lieberman

The semiconductor device has been the catalyst for global advances and the meteoric rise in standards of living, information processing, and the wireless age. One would be hard pressed to find a modern product or capability that does not rely on electronics and the semiconductor technology inside them. Advances in semiconductor technology have even altered society through their resultant applications, such as the personal computer, the Internet, and electronic banking. Semiconductors have also become the bedrock of the U.S. national security infrastructure enabling cutting-edge weapons, intelligence and communication capabilities, cyberwarfare, and advanced logistics. With such widespread diffusion into society and other industries, it follows that the semiconductor industry's success and growth within the U.S. has a direct impact on its overall economic and national security wellbeing.

The U.S. semiconductor industry remains a critical element of the nation's economy and defense and embodies the innovative underpinnings of the U.S. An increasingly global industry, it is a key driver for economic growth as both a multiplier and a technology enabler for the whole electronics value chain, in addition to many other industries.[2] Unfortunately, there appears to be widespread misunderstanding of the semiconductor industry's importance to U.S. economy and national security. This paucity of understanding leads to an underestimation of its worth, understatement of its value to the U.S. prosperity and leadership, and an under appreciation of the negative global trends within the industry.

The semiconductor industry has grown to a $300 billion industry feeding a $1.3 trillion electronics value chain.[3] Of interest to U.S. national policymakers is the considerable shift in roles within the industry since its inception. From its beginning in the 1950s, the industry relied heavily on U.S. government funding and leadership while consumer markets remained small. Over the last two decades, as consumer markets expanded, those roles have switched, with consumer markets dominating the industry while the U.S. military has less than a 1% share.[4] With such a small segment of the market, the U.S. military is a minor player and has little influence on the industry through the demand side. However, there are policy choices the nation can make to maximize the attractiveness and growth of the domestic semiconductor market.

While the U.S. remains the cutting-edge semiconductor industry leader, globalization and the maturing of the industry have led to the growth of foreign firms, particularly in the Asia-Pacific Rim, that are challenging U.S. dominance. Today six of the top ten semiconductor firms are headquartered outside the U.S.[5] While open market trends and growing foreign markets have spurred much of this migration, there are also public policy choices that have made the U.S. less attractive for business and workforce development within this high-end technology market.

Recognizing its importance, this analysis looks more closely at the semiconductor industry and presents a number of major trends that could negatively affect our national interests. In addition, three major challenges facing the U.S. are discussed with a focus on their root causes, national security implications, and potential remedies. The report concludes by exploring the outlook for the industry and providing a set of policy recommendations to address the challenges, to increase the opportunities for the U.S. semiconductor industry, and to improve the U.S. economic and national security posture.

INDUSTRY DEFINITION

The electronics industry is a complex market consisting of several segments along its value chain as described in Figure 1.[6] Unfortunately, it has no universally accepted definition. Therefore, it is imperative to establish a clear definition that bounds the scope before providing analysis. To focus this study, the seminar chose to concentrate on the semiconductor sub-industry, which includes all firms engaged in the design and manufacture of semiconductors and related devices. As the building block of all advanced electronics, and the U.S. #1 export from 2005-2009,[7] semiconductors represent the foundation of a trillion dollar global electronics industry and the enabler for all defense electronics capabilities.[8] Examples of products include integrated circuits (IC), memory chips, microprocessors, programmable logic devices, discrete components, and other optoelectronic devices.[9] For clarity, the terms semiconductors, IC, chip, microchip, component, and device are used interchangeably throughout this report. From a geographic perspective, the "U.S." industry is composed of firms whose headquarters reside in the U.S. and may include revenues from U.S. companies with overseas offices or manufacturing plants.

Taking one step below the electronics value chain in Figure 1, the value chain for a semiconductor device contains five major processes, as shown in Figure 2. Design involves the intellectual property to not only design the logical architecture a chip must have to provide a capability, it also involves decomposing this architecture down to the actual physical configuration needed for the chip to operate. Mask and fabrication are the key steps taking a silicon wafer and processing it such that the intended circuitry is generated on the wafer surface. This completed circuit chip is referred to as a die. Packaging involves placing the die into its final electrical configuration. Lastly, testing verifies the packaged chip performs its intended function correctly.

The semiconductor industry is broadly composed of three company types: integrated device manufacturers (IDMs), IC design firms, and manufacturing firms. IDMs, such as Intel and IBM, "vertically integrate" providing virtually all aspects of product development within the company, from concept design to product manufacturing. IC design firms, such as Advanced Micro Devices (AMD), are considered either "fabless" or "fab-lite" because they focus on design and rely on other companies to manufacture the components. Lastly, the manufacturing firms or "pure-play foundries," such as Taiwan Semiconductor Manufacturing Company (TSMC), specialize in high volume production of components based on designs provided by IC design firms.

While several areas drive demand within the semiconductor industry, Figure 3 illustrates how the Consumer, Computer and Communications segments make up about 85% of that demand.[10] As such, while companies strive to take advantage of growth opportunities outside those areas, as in the automotive industry, to date they have tended to specialize in one of those three major segments of the demand market.

DEFENSE ELECTRONICS INDUSTRIAL BASE (DEIB)

A segment of the semiconductor industry of critical importance to U.S. national security is the defense electronics industrial base. While it has become heavily reliant on the consumer market the nature of the environments within which the systems operate along with their long development and operational lifetimes leads to unique market conditions and a complexity of challenges.

As shown in Figure 3, the defense segment makes up less than 1% of the global seminconductor market. As such, with the exception of defense-specific technologies, the consumer market is driving the cutting edge of technology instead of the Department of Defense (DoD). Therefore, the DoD has become heavily dependent on the commercial market and its business cycles to fulfill much of its high performance requirements. With this dependence comes both advantages and risks. Recognizing the characteristics of this environment is critical to developing a comprehensive policy to address the challenges, risks, and opportunities.

The DEIB is extremely broad and diverse. For simplicity, the seminar broke the market into three areas: consumer technology, cutting-edge defense technology, and sustaining technology. The consumer portion entails commercial parts such as microprocessors, programmable logic devices, and memory. The second area centers in the defense-unique areas that continue to push the cutting edge in performance, such as remote sensors and radiation-hardened electronics. The last category is driven by the extremely long lifetimes that defense systems are expected to have. As the commercial technological cutting edge presses forward, these weapons systems require increasingly obsolete technology to sustain mission effectiveness. The need for older and older parts raises a whole new set of challenges and risks that must be addressed.

CURRENT CONDITION

The global semiconductor industry generated $298.3B in revenues in 2010 and is forecast to grow to $397.2B by 2015.[11] The U.S. industry accounts for $59.3B in revenue and employs 185,000 workers[12] in approximately 1,300 firms.[13] A key enabler in the industry is a consistent re-investment of 25-30% of revenues in capital and research and development (R&D) expenditures[14]. The R&D expenditures serve as a multiplier to other industries and allow improvements in both products and productivity. As Figure 4 shows, IT-producing industries (including semiconductors) represent only 3% of gross domestic product (GDP) yet stimulate 25% of GDP growth.[15] At the same time, the industry has long provided the competitive lead for U.S. security and defense sectors. The U.S. military, considered the most technologically advanced in the world, has leveraged this advantage to both wage war and preserve the peace.

Of note is the migration of semiconductor fabrication outside the U.S., mostly to the Asia-Pacific region. "In the past, U.S.-based companies outsourced manufacturing of lower value-added semiconductors to [Asia-Pacific countries]…these manufacturers have grown out of that role and now act as full-fledged [IC] designers in their own right."[16] This migration has been partly fueled by the rapid growth of the Asian consumer electronics market, now accounting for over half of global demand.[17] With increased demand comes the need to establish local presence to gain market access. Further analysis of this "offshoring" phenomenon and its impacts is provided in the major challenge #1 section. Despite this exodus, the U.S. remains dominant in high-end segments, particularly microprocessors; global competitors, however, are working hard to close that gap.[18]

STRUCTURE OF THE INDUSTRY

The precise structure of the global semiconductor market is segment dependent. The IDMs and foundry markets are oligopolies while IC design firms exhibit monopolistic competition. The semiconductor industry is a mature market with industry revenue growing more slowly, large firms dominating the market, and stable, clearly segmented products and brands. The seminar used Porter's five forces model to analyze the structure of the industry, specifically focusing on the competition, buyer and supplier power, threat of new entrants and substitutes within the industry.[19]

Competition within this industry is intense across all segments. There is constant pressure to differentiate products based mainly on better, faster and cheaper performance. As such, firms must innovate as the move to the next technology node typically occurs within 12-18 months.[20] While there is intense competition across the industry, each segment generally contains only a few companies that represent the majority of market share. These segment "giants" tend to absorb smaller firms and entrants whose products best support their market strategy. It is also worth noting that the semiconductor industry heavily relies on intellectual property (IP) laws and rights, yet some international markets have not caught up to U.S. standards with regard to enforcement of those laws.[21] Without global enforcement, investments by U.S. companies may be compromised and their competitiveness weakened. As seen during the seminar's international visit, strong U.S. governance and enforcement standards remain a distinct competitive advantage and continue to encourage leading edge investment within the U.S. semiconductor market.

Buyer Power primarily applies to the makers of electronic products who procure the semiconductor components. These buyers enjoy a modest advantage in the commoditized chip arenas, such as discrete devices and memory. Conversely, buyers have far less influence in the specialized or differentiated chip market until competitors "catch up" to the latest technology.

Supplier Power also depends on market segment and varies from moderate to low. For IC design firms, the manufacturers (foundries) hold significant power. By contrast, the hundreds of suppliers that support an IDM have less influence. However, for both foundries and IDMs, the small number of equipment and raw materials providers increases the suppliers' influence.[22]

The Threat Of New Entrants is moderate in the semiconductor market.[23] The IC design firms require highly skilled workers and must compete in some areas with well-established dominant players.[24] For the foundries and IDMs, the upfront costs are substantial, with the cost of a leading-edge facility approaching $8-10 billion.[25]

Substitutes are very low for semiconductors based on their pervasiveness throughout society and the lack of a clear alternative. Semiconductors remain an integral part of the global economy, but this scenario is not guaranteed to remain forever.[26] In the future, development of new technologies could revolutionize the industry resulting in a transition away from traditional silicon-based technology and current manufacturing processes to something entirely different.

FIRM CONDUCT WITHIN THE INDUSTRY

As noted above, competition in the semiconductor industry is extremely high and drives the conduct of the industry's firms. As the industry has matured, business strategies have evolved. Some firms continue to be successful through market diversification. However, according to Standard & Poor's, more firms are achieving success through specialization rather than diversification.[27] Additionally, the timing of implementing business strategies is critical. Using the Strategic Game Board method of analyzing conduct within an industry, the seminar evaluated how, where, and when semiconductor firms choose to compete.[28]

The capital-intensive nature of the semiconductor industry drives the means by which firms compete. Companies are choosing to specialize in discrete segments of the semiconductor value chain: design, fabrication, packaging, or testing. This strategy allows firms to concentrate both their technological and human resources on specific markets within the semiconductor industry. However, even specialized firms have relied on outsourcing, a timely shift to a business plan based on contracting out some or all of the chip production,[29] to remain competitive.

Just as some firms are opting to compete in specialized segments of the semiconductor production process, others are concentrating on specific niche products within the semiconductor market. For example, Intel spun off its less profitable handheld and flash memory businesses to focus on its core competency, microprocessor development.[30] Similarly, companies like Xilinx and Altera have chosen to design only programmable logic components. Although product specialization is a current trend, the lines between the segments are blurring. With the popularity of mobile devices, such as tablet computers and smart phones, the component needs for the once discrete "communication," "consumer," and "computer" segments are beginning to merge. While all provide growth opportunities, this merging will also create conflict as the traditional segment leaders, such as Intel and Samsung, increasingly infringe on each other's market share.

Choosing when to compete may be the most critical decision firm leadership make. Due to the rate at which technology changes and the large number of product innovations, firms must make timely investments, whether in design or manufacturing capability, to be able to offer leading edge product performance. Failure to do so, or to underestimate the market demand signals for those technologies, may be disastrous due to the strong competition in all segments. Historically, the semiconductor market is cyclical. Introducing a product during market recession may result in a failure to capitalize on the massive investment required to roll out a new product. Exacerbating the problem, during the recessionary period competitors may be developing "the next big thing" that will render the company's product obsolete by the time the business cycle is expanding. "Timing is everything" may be a cliché, but it is certainly a truism in the semiconductor industry.

INDUSTRY PERFORMANCE

As shown in Figure 5, after two years of decline due to global recession, revenues for the global semiconductor market increased by 29.3% to $298.3 billion in 2010 and returned the market value to its pre-financial crisis trend.[31] The Asia-Pacific region accounts for 66.5% share of that global revenue while Europe and the Americas represent 12.8% and 20.7%, respectively.[32] The 2010-2015 global combined annual growth rate (CAGR) is forecast to be 5.9%.[33] However, analysts predict U.S. growth to be significantly lower at 1.9% during the same period.[34] By contrast, they predict the Asian-Pacific market will accelerate with a CAGR of 7.2% for 2010-2015, with China and South Korea CAGRs at 12.1% and 4.6%, respectively.[35]

Analysts also predict that U.S. semiconductor exports will continue to fall while import demand will increase. Of the $59.3B in revenues generated by the U.S. semiconductor industry in 2009, $46.7B was attributed to exports and $12.6B from domestic demand.[36] Despite being one of the largest exports of the U.S.,[37] semiconductor export revenues have actually decreased nearly 20% in the last five years[38] and account for the largest decrease in the electronic sector.[39] The value of U.S. exports is forecast to grow at a modest annual rate of 2.0% in the next 5 years reflecting the decreased competitiveness of U.S. semiconductors.[40] Additionally, the increase in global demand will outpace the growth of U.S. exports leading to a further decline in U.S. market share within the global semiconductor market. This fact is particularly troubling given President Obama's emphasis on increasing U.S. exports as a catalyst for overall economic growth.[41]

Similarly, the U.S. semiconductor industry is failing to keep pace with its own demand. In 2006, imports supplied 61% of U.S. domestic demand with most arriving from the Asia-Pacific region. This is expected to rise to over 69% by 2016.[42] The inability of the U.S. industry to grow with the increasing U.S. demand is due mainly to the offshoring of manufacturing facilities.

The Asia-Pacific region's strength will continue to increase at the expense of Europe and the Americas. Rising consumption spurred by China's demand growth will similarly increase the region's importance. Case-in-point: from 1999-2009, the Asia-Pacific's share of the global market rose from the mid-20% to over 50%; it is now nearly 70% and analysts see that trend continuing.[43]

In summary, the global semiconductor market is expected to achieve modest growth in the next five years with much of that growth in the Asia-Pacific region. The industry will continue to create value in terms of revenue, profit margins, and economic multipliers.[44] However, if no actions are taken it is likely the U.S. share in the global market will continue to diminish, decreasing domestic economic benefits and increasing U.S. reliance on foreign sources to fulfill its defense-related semiconductor needs which will have national security impacts.

DEFENSE ELECTRONICS INDUSTRY ANALYSIS

This section analyzes the current DEIB's ability to meet defense semiconductor needs. To perform this analysis, the seminar relied on the criteria DoD uses to perform its annual industrial capabilities review. Specifically, reliability, cost effectiveness, and sufficiency were used as the key evaluation criteria.[45] Table 1 contains the seminar's assessment. The seminar identified supply chain security as the largest challenge facing the DEIB. A short discussion of the three concerns (offshoring, counterfeit parts, and diminishing sources) listed in the table is provided later in this section, while supply chain security is discussed further in the major challenge #3 section.

Table 1: Defense Electronics Industrial Base Assessment

	Reliable	Cost-effective	Sufficient	Challenge
Consumer	Yes	Yes	Yes	Supply Chain Security due to offshoring, counterfeit parts, and diminishing sources
Cutting-edge defense	Yes	Yes	Yes	
Sustaining	Yes	Yes	Yes	

Consumer technology. The consumer industry is extremely competitive and innovative, driving extensive investment in R&D and short technology refresh cycles. In some areas, such as memory, the intense competition has commoditized the product and driven the prices extremely low. Given the large number of producers, intense competition, and immense production capability, the consumer technology market is deemed very reliable, extremely cost-effective, and clearly sufficient to meet defense needs. But the strengths of this market lead to a number of concerns for the DoD. As the market spreads globally, DoD agencies are concerned with single-source overseas suppliers. In addition, the incredibly fast technology advances have increased the Diminishing Manufacturer Sources (DMS) problem as companies choose to retire old technology lines and propel technologies into sustainment. Lastly, the increasingly global market, the growing search for obsolete parts, and the tightening of defense budgets are generating a "perfect storm" where counterfeit parts may become a serious problem.

Cutting-edge defense technologies. By the nature of the intended operating environments, these technologies do not have viable commercial markets. Since most are considered vital to national security they fall within the International Trafficking in Arms Regulation and are fenced off from entering the global market. Therefore, they usually have only one or two manufacturers stateside. The result is a monopsonistic environment with minimal economies of scale and little incentive for innovation. To combat this, the government pays higher overhead costs and must provide the incentive by continually investing in R&D. Across this market, the current U.S. industrial base provides enough capability (reliability) and capacity (sufficiency) to meet DoD's needs.[46] However, due to the oligopolistic/monopolistic environments and extremely small order quantities, the DoD pays a premium to keep these firms in business. While this could raise doubt in its cost effectiveness, this technology has continually been classified as a critical technology to the DoD substantiating the benefit of continuing the funding.[47] Of particular concern is the diminishing number of U.S. manufacturers capable of providing the necessary capabilities. Today it is very common to have only one vendor for a specific technology.

Sustaining technology. As military systems are kept operational for longer periods, they require older and older technologies to maintain effectiveness. However, the electronics industry is continually propelling its technology base forward. As the old technology ages, it reaches a saturation point then begins to decline. Eventually the firm discontinues production. In other cases, the firms have long ago gone out of business or divested themselves of the production capability. This has far-reaching impacts to the Defense Department as its tries to maintain systems well beyond their component life cycles. With this obsolescence risk, the DoD has a number of options available to ensure the continued access to older electronics technology, including after-market firms specializing in discontinued parts and in-house government production capabilities. Given the availability of these options, the industry does provide the necessary reliability and sufficiency to meet defense department needs. For cost-effectiveness, like the cutting-edge defense technology area, the DoD will pay a premium for these obsolete, discontinued parts. When compared against the re-design costs or loss of mission effectiveness, the cost-effectiveness becomes acceptable. Unfortunately, many acquisition and logistics organizations are not aware of or choose not to utilize these options and instead procure the cheapest parts available. This raises concerns over managing diminishing sources and the rise in counterfeit parts.

Defense Electronics Concerns

As the DoD relies increasingly on the commercial semiconductor industry, while that industry becomes more globalized and semiconductor sources migrate overseas, it faces a growing challenge in securing its semiconductor supply chain. The three main drivers of this challenge center on the increase in offshoring of the semiconductor industry overseas, the growing number of counterfeit parts, and the diminishing number of suppliers for old or obsolete semiconductor components.

Offshoring. With the increasing migration of fabrication capabilities to overseas markets, the DoD faces a more challenging supply chain environment. In addition, as design capability has started to migrate as well, the DoD may encounter a future where the U.S. has lost the organic design capability, or intellectual property, to produce the cutting edge technology it relies on. In this situation, the DoD must be wary of single-source foreign suppliers that could greatly impact or influence U.S. national security, intentionally or not and must take steps to ensure the reliability of its supply chain. Unfortunately, there is no comprehensive policy guidance on foreign sourcing, although the DoD has begun taking steps to address these increasingly complex supply chain dynamics.[48] In addition, the slow communication and education flowdown are key obstacles to ensuring government offices have the latest guidance in today's dynamically-changing environment. Further discussion on offshoring is in the major challenge #1 section.

Counterfeit parts. With the increase in offshoring, there has also been an increase in counterfeit parts within the United States.[49] Incidents have spanned from obsolete technology to cutting-edge commercial parts. The DoD is not immune, having also experienced an increase in counterfeit incidents in its supply chain.[50] Definitions vary across the industry, but this paper will follow the Society of Automotive Engineers (SAE) International definition of a counterfeit part as one that "is a copy or substitute without legal right or authority to do so or one whose material, performance, or characteristics are knowingly misrepresented by a supplier in the supply chain."[51] This includes parts that may have been tampered with for malicious intent.

Both industry and government have become more aware of this problem and have begun taking corrective action. From 2010-2011, the Department of Commerce, the Government Accountability Office (GAO), and the Aerospace Industry Association (AIA) issued reports documenting the rise in counterfeit parts incidents and recommended a number of process improvements.[52] On the heels of the AIA report, this issue gained national interest after General (retired) James Clapper, Director of National Intelligence, included counterfeit parts as a worldwide threat in his testimony before the Senate Armed Services Committee.[53] In addition, the Committee "initiated an investigation into counterfeit electronic parts in the DoD's supply chain."[54] While the government lacks a comprehensive strategy, the recent spike in interest should increase awareness and catalyze the policy debate.

Diminishing Sources. A further area of concern for DoD stems from the interplay between short commercial technology innovation cycles and long defense system lives. As systems progress through decade-long development cycles and multi-decade operational lives, the availability of replacement parts is becoming a bigger problem. In many cases, by the time a new weapon system is fielded, it is relying on technology multiple generations old. In many cases, the original company no longer actively produces the components and, in some cases, is no longer in business. To make matters worse, the search for discontinued parts has led agencies to lower screening standards for the sake of mission effectiveness. This has opened the door for counterfeit parts to seep into the DoD supply chain. With longer development cycles and ever-faster technology refresh cycles, the DMS issue is becoming more and more problematic. While disjointed guidance exists, a bigger problem entails a lack of understanding and appreciation of the problem at the senior levels of government. This is discussed further in the major challenge #3 section on supply chain security.

Through this research on the DEIB, common themes arose which should be addressed to improve the security of the DoD supply chains and ensure national security needs can be met.

1. There is no single DoD entity responsible for defense microelectronics. This results in multiple guidance sources with no one having accountability or ownership for success.
2. There is no comprehensive set of policy guidance for electronics. This is especially important with the increased use of commercial parts and increased offshoring.
3. The communication and education processes for new policies are not adequately pushing information and assistance to the acquisition and sustainment offices in a timely fashion.

As mentioned above, the biggest challenge for DoD is to maintain a secure supply chain. Whether its cutting-edge microprocessors for servers and laptops, cutting-edge infrared sensors for space applications, or 20-year old application specific integrated circuits (ASICs) for F-15s, the DoD relies on these electronic components to maintain mission effectiveness. Securing the supply chain is discussed further in the major challenge #3 section.

INDUSTRY TRENDS

After analyzing the global and domestic semiconductor industries, the seminar identified four interrelated trends that, if left unchecked, may negatively affect the U.S. national security and economic wellbeing. These trends fall within the following categories: Globalization, Innovation, Human Capital, and Emerging Technologies. Because of the potential impacts, it is important for U.S. senior policymakers to understand them and ensure a comprehensive and reasoned strategy is developed. The following section explores each trend in more detail, analyzes the implications to U.S. national security, and begins the dialogue on possible policy actions that might change the trends in the U.S.'s favor.

GLOBALIZATION

The forces of globalization have significantly influenced the U.S. semiconductor industry in both positive and negative ways. These forces must be understood to fully comprehend the global dynamics shaping the industry before developing any policy recommendations. First off a definition: globalization involves the interdependence of countries through cross border interactions dealing with capital, goods, services and technology.[55]

Ironically, the semiconductor industry, which propelled the U.S. to economic and technological greatness, has catalyzed the very competitive global market that is threatening U.S. preeminence today. Globalization has enabled the fast migration of large parts of the semiconductor industry outside the U.S., as discussed above. It has also led to an increase in foreign innovation and an intense global competition for talented human resources, which is discussed in the following sections. The current trends, spawned on by globalization, are not in the U.S.'s favor; however, a purposeful, crosscutting strategy could stem the tide and strengthen the U.S. economic and security posture.

On the positive side, globalization is opening new markets to the semiconductor industry. The spread of microelectronics and mobile devices around the globe has increased the demand for semiconductor devices. This provides an opportunity for the U.S. semiconductor industry to expand its revenues and possibly market share, if the environment is optimized for the new globalized marketplace. Unfortunately, the recent U.S. track record has not been strong.

Globalization changed the dynamics of semiconductor competition with rapid shifts of market shares among national economies. This shift led to the fast migration of semiconductor firms to the Asia-Pacific region discussed in the earlier section. What was once a predominantly U.S. market is now spread throughout the world. While this originally included just the lower technology portions of the value chain, such as manufacturing, test, and assembly, today it also includes the high technology segments, such as R&D and design.

Ideally, this shift in market segments is encouraged and expected to lead to greater value for the U.S., if all parties adhere to free market principles. However, the advantages of having modern semiconductor facilities in one's nation, with high paying jobs, increased tax base, and spin off technology businesses has led foreign governments to aggressively compete for semiconductor business with increasing financial, tax, infrastructure, and workforce incentives.[56] If left unmatched, these incentives will most likely continue the migration away from the U.S.

Economically, the migration overseas has affected the U.S. market share, decreased U.S. trade balance through reduced semiconductor exports, and slowed the U.S. economic growth. From a national security perspective, this migration has propelled every weapon system and procurement program into an extremely complex global supply chain environment. No longer can the government acquire all the components it needs from domestic sources. With this increased foreign supplier base comes an increased risk to the security of that supply chain and hence U.S. national security. Further details regarding further offshoring and the global supply chain are provided in the major challenge #1 and #3 sections, later in the report.

In such an open global marketplace, a nation must focus on its comparative advantage and counter aggressive incentives to maximize its attractiveness to business development and foreign investment. In the case of the U.S., its comparative advantages center on its integrated R&D system with government, academia, and industry, its world-leading universities, its entrepreneurial business climate, its IP rights and protection, and its highly-skilled workforce. [57] Any policy recommendations should not reduce any of the existing advantages the U.S. holds.

In addition, the U.S. government should counter the aggressive foreign incentives to create favorable conditions for corporate investment. Trusting in free trade principles is laudable, however, it is dangerous when other countries exploit their domestic labor, employ trade barriers and ignore environmental standards. The U.S. government must engage in this environment and take steps to ensure worldwide competitive conditions exist domestically. Further discussion of policy options is provided in the major challenge #1 section.

INNOVATION

Since WWII, the United States has been a leader in developing cutting-edge technology and high-value manufacturing. During this time, the U.S. has sent a man to the moon and developed the integrated circuit and microprocessors, which resulted in a culture-changing way of life around IC-based electronic devices that includes products like the PC, the Internet, Google, Amazon.com, blogs, twitter pages, and revolutionary products like Apple iPod, iPad, iPhone, satellite communications, and numerous GPS-based devices.

However, while the U.S. remains a world semiconductor leader in the areas of design, high-end manufacturing, and manufacturing equipment development, its lead is under severe pressure from foreign competition. As discussed earlier, globalization has broken down information barriers as the very technology the U.S. invented has made global competition a reality and is now being used to compete directly against the U.S. To survive economically in the semiconductor industry, the U.S. must maintain the lead in innovation and technology.[58] If the U.S. fails to maintain the lead in innovation it will lose the ability to influence the development and deployment of future technology causing the U.S. to lose its innovation leadership position in the world economy.

Finally, our national security and ability to project power abroad relies on innovative technologies and the ability to develop and deploy the most advanced weapons systems on the planet. Failure to maintain that technological edge could significantly compromise our global military leadership as other countries continue to innovate and increase their capabilities.

The backbone of the American economy and future innovation is the private sector. To remain competitive in an ever-expanding global market, U.S. corporations must move faster and remain more agile than their foreign competition. However, because of the complexity and increased cost of new R&D, private firms are finding the need to collaborate to share resources and costs amongst each other. By necessity, innovation is becoming more collaborative and extends across the supply chain to include suppliers, clients, governments and universities.[59] As capital requirements and R&D complexity increase in the semiconductor industry, the government has an increasingly important role to play in supporting the conditions that foster domestic innovation. To facilitate the needed collaboration across the private sector, universities, and government, any government strategies developed to foster innovation should be aimed at three main areas: maintaining balanced government regulations, fostering a positive business environment, and encouraging education and development of human capital in technology.

HUMAN CAPITAL

From an organizational perspective, human capital refers to the collective value of the organization's intellectual capital, which includes various competencies, knowledge, and skills.[60] One can see from this definition that few things are more important to a nation's sustained success than its capacity to utilize and replenish human capital reserves. This is especially true in the high-technology semiconductor industry. Current trends for U.S. human capital reveal an environment in which many foreign competitors directly challenge the U.S. firms that have historically led the field with regard to technology and scientific innovation. This has spawned a growing debate concerning the sufficiency of the U.S. workforce to meet technology and innovation demands for future economic success. If one considers that technological innovation will be the lifeblood that champions tomorrow's economic successes, and that scientific expertise is now considered a worthy metric for a nation's future competitive potential, then the U.S. outlook is, indeed, worrisome. As human capital resources become more important to America's economic well-being, it seems the nation has lost its edge in seeding its future workforce with excellent science, technology, engineering, and mathematics (STEM) skill sets. While this does not currently represent an economic emergency, the future seems bleak without major improvements.

A recent RAND report succinctly defines the problem: "The basic argument that the United States might be losing its competitive edge can be summarized as follows…Globalization and the rise of other geographic areas (e.g., India, China, and Europe) will lead to a relative decline in U.S. economic power, U.S. innovation, and [research and development] enterprise."[61] Complicating the STEM issue further, the U.S. has "for several decades invested too little in sustaining its [science and technology] leadership and flow of [science and technology] workers; for example there are too few teachers in science and mathematics in K-12 and they are not sufficiently well prepared."[62] This, inevitably, leads to further reductions in the numbers of students pursuing STEM subjects, and increases subsequent systemic disadvantages once the cycle begins anew. This presents profoundly negative national security implications, which are discussed in the major challenge #2 section.

EMERGING TECHNOLOGIES

The semiconductor industry has been the catalyst for major advances in the global standard of living and it holds tremendous potential for the future. Through its meteoric rise in capability, the industry has inspired voracious consumer and commercial appetites for more and more performance. This growth has come on the back of semiconductors, specifically the Complementary Metal-Oxide-Semiconductor (CMOS) technology at the heart of the current market. To meet the need, future capabilities will require lower power, more functionality, and higher speed in smaller areas. While CMOS has been able to meet the demand to date, there are impending physical boundaries, which will someday limit its advance.[63] Given these challenges, the semiconductor industry is working on both evolutionary and revolutionary technologies to drive capabilities forward. The evolutionary efforts are exploring innovative techniques and processes to further push CMOS technology, while the revolutionary efforts are looking to entirely new mechanisms and techniques to one day replace CMOS as the core of the industry.

The semiconductor industry is investing in several evolutionary technologies including new processes, materials, and architectures. The industry continues to research better, cheaper ways to manufacture chips, as well as continuing its focus on reducing the size and power of CMOS components. In addition, the industry remains interested in novel combinations of materials and their electrical properties to maximize performance and minimize size and power. 3D is an example of a new architectural chip packaging solution that has significant promise. It is a method to increase functionality, increase density, and reduce power consumption by stacking and interconnecting semiconductor components instead of laying them out side-by-side on a circuit board.[64] There are currently ongoing efforts to define 3D standards, inspection techniques, bonding technology, interface standards, and reliability standards to help the industry make this evolutionary technique a reality within the next few years.[65] This and other evolutionary techniques have the promise of extending CMOS technologies for at least two more decades.[66]

Looking beyond CMOS, government and industry are researching numerous revolutionary technologies such as nanotechnologies, quantum computing, and biotechnologies. Current investments in these technologies have resulted in many promising accomplishments, but it will most likely require another decade or two of R&D before any of these will be ready for the consumer, commercial, and government markets.[67]

The keys to achieving the full potential of both evolutionary and revolutionary technologies are a highly talented, innovative workforce combined with a steady and deliberate basic and applied research investment. As innovation and the workforce were discussed previously, this section focuses on the importance of research investment to the semiconductor industry's future. Basic research involves the scientific investigation of new techniques, mechanisms, and properties and is often the drive for revolutionary changes. Applied research then looks at how to take this knowledge and apply it towards a product.

Unfortunately, U.S. government R&D funding has shown a negative trend relative to GDP. As Figure 5 shows, the federal government accounts for about 26 percent of overall national R&D funding.[68] Any negative trends in government spending, therefore, could have a significant impact on the innovation and health of the semiconductor industry. This is especially true in the realm of basic research, where profit-driven companies cannot invest heavily in efforts with payoffs a decade or more into the future or possibly with no payoff at all. The stockholders' focus on short-term quarterly profits will not support it. This is the key area where the strategic focus of the government and its ability to plan and fund long-term projects makes the most sense. Most industry experts agree that what is needed to break through to the "next big thing" is a large investment in basic research.

Unlike basic research, ample funding for applied research exists within the semiconductor industry. In fact, the industry has one of the highest R&D investment rates in the world, spending about 17 percent of its annual sales on R&D, mostly on applied research.[69] This rate is twice the average investment of the S&P 500 and is a key driver in U.S. economic growth as it benefits other industries which are increasingly dependent on semiconductors.[70] While most of the industry's investment falls within the United States, Figure 6 illustrates how U.S. firms' share of investment outside the country has increased over the past decade.[71] Further, this trend is likely to continue given current government policies and economics.

CHALLENGES

Following our analysis of the semiconductor market, its current trends, and the unique aspects of the defense sector, the seminar identified three overarching challenges facing the industry that have the potential to significantly impact the U.S. economy and U.S. national security. The following three sections delve deeper into each of these issues, exploring the root causes and national security implications. They conclude with a discussion on the potential actions that might mitigate the challenges.

MAJOR CHALLENGE #1 – OFFSHORING

Government policies and market forces significantly impact business decision making, to include decisions regarding location. While success or failure is ultimately up to the company, firms locate where government policies create a favorable business environment and generate a competitive advantage. Factors affecting the decisions of where to locate facilities include proximity to markets, availability and cost of skilled labor, construction, transportation, trade policy, export controls, intellectual property rights, and taxation.[72] The economic growth and military superiority of the U.S. has been due in large part to U.S. leadership and innovation in electronics and semiconductor technology, often viewed as a significant source of U.S. competitive advantage. However, the recent migration of semiconductor firms outside of the U.S. raises doubt whether the U.S. marketplace maintains its global attractiveness. This section explores the causes behind the offshoring, including a comparison of U.S. and foreign policies, discusses the national security implications, and begins the dialogue on potential actions to improve the situation.

ISSUE ANALYSIS

In looking at the offshoring phenomenon, the seminar identified a growing drive by foreign countries to increase their domestic semiconductor markets through most any means at their disposal. As the migration began with lower technology assembly and testing capabilities, foreign countries are now interested in improving their higher-end technology capabilities. [73] Foreign countries have identified the positive economic effects of high-technology workforces, technological innovation, and related electronics industries and they are aggressively pursuing strategies to improve in all areas. As globalization continues to change the marketplace and large emerging markets arise, senior policymakers must develop a balanced strategy that maintains U.S. competitiveness on the global stage while not hampering U.S. firms' ability to access the expanding global market. While the technological leadership initiatives are addressed in the next section, the remainder of this section explores a key area where U.S. has lost the competitive edge, tax policy.

Corporate Tax Rate. The U.S. corporate tax rate is the second highest tax rate in the industrialized world.[74] It stands around 39%; 35% from the federal rate plus 4% from the average state rate.[75] The global average in industrialized countries sits at 25%.[76] The large difference between the U.S. rate and other countries' imposes a number of additional costs on the semiconductor industry and sets the U.S. marketplace at a distinct disadvantage. In fact, with today's low interest rates, it is cheaper to borrow cash than repatriate profits.[77] When combined with the large emerging market and the extremely aggressive tax relief and tax holiday incentives provided by foreign countries, it becomes clear why the semiconductor industry has migrated to the Asia-Pacific region so quickly.

Repatriation of Profits. Compounding the corporate tax rate issue is the U.S. tax policy that requires U.S. based firms to pay the tax difference, up to the U.S. corporate tax rate, on all revenues generated in overseas markets. [78] For example, if a U.S. firm conducts business in either Taiwan or Singapore they are required to pay a 17% corporate income tax within that country.[79] On top of that, the firm will need to pay an additional 18% rate when repatriating those revenues back within the U.S. The U.S. is the only country that requires this and it clearly puts the U.S. marketplace at a global disadvantage.[80] Unfortunately, this policy has driven U.S. firms operating in international markets to keep their revenues offshore and not repatriate them. Analysts estimate around $1 trillion in U.S. corporate profits are being held overseas due to the double taxation of corporate profits if they were brought back.[81] This trend is particularly negative in that the U.S. is missing the investment and multiplier benefits those revenues would have domestically and the longer the revenues are held overseas, the greater the possibility they will be invested overseas further improving foreign economic growth and global competitiveness.

NATIONAL SECURITY IMPLICATIONS

As the 2010 National Security Strategy indicates, the economic vitality of the U.S. directly affects its national security.[82] With that in mind, continued offshoring of the semiconductor industry poses direct risks to the nation's economy and national security. In addition, the defense industrial base has long relied on the cutting-edge semiconductor industry and its innovation leadership to maintain the military's technological dominance. As the industry and its intellectual capital transition overseas, it will significantly affect the U.S. military's ability to secure the national interests. Retaining a robust semiconductor industrial base in the U.S. is essential for national security.

MITIGATION ALTERNATIVES

The key is to develop a set of policies that create an environment favorable to long-term investment in the U.S. semiconductor industry. It must establish incentives to foster innovation and maintain U.S. advantage thereby bolstering the U.S. economy. The long-term payoff is a thriving semiconductor industry that delivers high paying jobs creating a perpetuating springboard for further innovation, development and security.

Per the previous discussion, a key area in improving the U.S. business environment is modifying tax policy to make the U.S. more competitive on the global stage. An obvious possibility is to reduce the corporate tax rate to a level competitive with the world. In addition to improving the attractiveness of the U.S. semiconductor industry, this change would affect all industries. If deemed inappropriate for all industries, there could be options where targeted tax incentives or holidays are provided to industries deemed strategically important, such as semiconductors.

While reducing the corporate tax rate may alleviate the repatriation problem, removing or significantly modifying the repatriation tax law may also encourage U.S. firms operating abroad to bring those revenues back into the country. The investment and multiplier effects within the national, state and local economies would quickly offset the small loss of revenue from tax income.

As the semiconductor industry is a significant source of U.S. competitive advantage and there is a desire to grow the U.S. economy out of this recession, a more competitive tax policy is worth considering in order to make the U.S. more dramatically and globally attractive to the expanding semiconductor industry.

MAJOR CHALLENGE #2 –TECHNOLOGICAL LEADERSHIP

As with all technology-based industries, products in the semiconductor industry are quickly commoditized and require continual innovation to stay ahead of the competition. In the past 50 years the U.S. has dominated the cutting-edge of semiconductor technology because of the U.S. capacity and ability to innovate and lead the industry.

While U.S. companies still maintain a leading role in semiconductor design, electronic design tools, and fabrication equipment, their lead as the premier innovators in technology development is under severe pressure from foreign competition. The very technology that U.S. companies developed have ignited globalization, made global competition a reality, and is now being used to compete directly against the U.S. Much like industry leaders from the recent past, such as Kodak, Xerox, Bell Labs and AC Delco, it is very possible that U.S. companies will no longer be as competitive in the future without the ability to stay globally competitive by leading technological innovation. This section explores the threats to U.S. technological leadership, specifically in the areas of R&D and STEM, discusses the national security implications, and explores how to alleviate the challenge.

ISSUE ANALYSIS

As foreign competition has greatly reduced the amount of semiconductors manufactured and packaged domestically, U.S. semiconductor firms have mainly focused on world-class innovation in R&D, semiconductor development and design, and microchip fabrication equipment development to maintain their competitive advantage. Their future success in maintaining technological leadership relies greatly on aligning U.S. public policies with the global environment. The U.S. can bolster the domestic marketplace by integrating R&D of new products and processes and improving the quality and competitiveness of the STEM workforce and education system.

Research and Development

Government and private sector cooperation is required to optimize the investment in basic and applied R&D. But as mentioned earlier, the combined U.S. R&D investment is declining relative to GDP. In fact in 2008, U.S. R&D per GDP investment ranked eighth in the world, falling nearly 23% below world leader, South Korea. [83] However, the complexity involved in today's research as well as the capital requirements needed to conduct basic research has greatly increased over the last two decades. In addition, U.S. firms face increased pressure to maximize short-term profits which greatly reduces their ability to focus on long-term investments. As a result, private investment in basic research is declining and has required increasing support from the government in order to maintain the current investment level. The pressure on short-term profits has forced the private sector to move its R&D funding away from basic research towards applied research. The reality of these trends indicates that increased U.S. government involvement is required to keep basic R&D viable in the U.S. Additionally, these trends indicate the increasing importance of cooperative R&D conducted at universities and colleges and funded through combined contributions from the government and private corporations.

There are two challenges to improving R&D investment in the semiconductor industry: (1) R&D tax structure and other incentives to invest in the U.S.; (2) federal support for basic research in science and engineering.[84]

First, in the area of taxes and incentives, market forces and foreign industrial policies are creating powerful incentives to shift new production and R&D investment offshore. Per a survey of semiconductor companies, industry R&D investment inside the U.S. is expected to continue its migration overseas, dropping over nine percentage points from 2009-2013.[85] As discussed in the offshoring section, key factors behind this trend are the high U.S. corporate tax rate, the tax burden on repatriated funds, but also an inconsistent R&D tax credit policy.[86] While the U.S. policies hinder R&D investment in the country, other governments see the benefit of a domestic seminconductor industry and are rapidly expanding their incentives to prospective investors.

The second challenge to R&D is the waning U.S. government investment in basic research. A recent RAND report indicates that federal funding for basic research has significantly lagged historic levels. [87] Cuts in research funding can have a dramatic chilling effect on scientific and technological innovation, because private industry is often unable to make up the difference in funding levels. It is unlikely that large-scale investment redistribution in this area, because private industry simply cannot undertake R&D endeavors that do not offer the prospect of financial gain. The result is a predictable loss of national productivity and competitiveness. While government basic research funding has decreased, so too has industry's. The business sector spends more than four times as much on applied research as on basic research[88] – not surprising since companies need to make a profit in the short term. However, basic research tends to have the highest impact per cost for "leap-ahead" discoveries, such as the current GPS and the Internet.[89] Government policy should address the importance of basic research to U.S. innovation dominance, economic growth, and national security.

Science Technology Engineering and Math (STEM)

The United States has "for several decades invested too little in sustaining its [science and technology] leadership and flow of [science and technology] workers; for example there are too few teachers in science and mathematics in K-12 and they are not sufficiently well prepared."[90] This, inevitably, leads to further reductions in the numbers of students pursuing STEM subjects, and increases subsequent systemic disadvantages once the cycle begins anew.

Currently, "seventy percent of engineers with PhD's who graduate from U.S. universities are foreign-born."[91] Even this statement fails to deliver the full magnitude of America's human resource problem, however, because many of those foreign-born PhD recipients must leave the United States soon after graduation. The U.S. actually prevents them from entering its intellectual capital pool. Through this action, America is squandering a very valuable and expensive resource. The U.S. draws these quality foreign-born students by means of its renowned reputation for collegiate-level educational excellence. These students are the beneficiaries of America's cutting-edge university system, but then the U.S. government denies H-1B immigration visas that would provide a return on its investment. The foreign students, through no fault of their own, find themselves with little option other than to return to their homelands. These sought-after professionals then integrate into the high-quality workforces used by America's economic rivals to unseat the U.S. from its preeminent economic position.

Compounding the matter further, the governments of other countries in Asia and Europe have aggressively pursued efforts to improve their human capital resources, often much more vigorously than U.S. efforts.[92] The National Academy of Science offers this assessment: "We sense that in the face of so many other daunting near-term challenges, U.S. government and industry are letting the crucial strategic issues of U.S. competitiveness slip below the surface."[93] If this trend continues, it is likely that the next generation of Americans will be the first to have a lower quality of life than that enjoyed by their parents. Additionally, when one considers that America continues to underutilize the foreign talent trained in elite U.S. universities, there is a real chance that U.S firms, including semiconductor firms, will lack the required human capital to remain competitive.

NATIONAL SECURITY IMPLICATIONS

The challenges to righting the trends of offshoring R&D investment by U.S. semiconductor companies and maintaining U.S. technical leadership in innovation have direct national security implications. As the industry leader, U.S. semiconductor companies are able to shape and possess deep knowledge of the standards for design and manufacturing of microchips. This translates directly to the Defense Industrial Base as new weapons and command and control systems are designed that rely on leading edge technology. Transition of this leadership offshore would deteriorate U.S. influence and understanding of how microchips are designed and thus allow other militaries to have a technological advantage over the U.S. military. Additionally, the negative impact to the U.S. economy and world trade balance associated with moving R&D and design of microchips offshore would have significant impact to both employment and government revenues.

In addition to the risks from reduced R&D, the declining trends in U.S. STEM skills contain profound national security implications, as they imply an eventual loss of America's ability to maintain its high-end semiconductor leadership as well as its leadership in the follow-on electronics and defense sectors. RAND contends that, "The [U.S.] is increasingly reliant on foreign [science and technology] talent, and [science and technology] careers have become increasingly unattractive [to the U.S. workforce]."[94] The National Academy of Science poses an even more sobering assessment: "America's competitive position in the world now faces even greater challenges, exacerbated by the economic turmoil of the last few years and by the rapid and persistent worldwide advance of education, knowledge, innovation, investment, and industrial infrastructure."[95]

MITIGATION ALTERNATIVES

In this globally competitive environment, U.S. companies require government cooperation. As mentioned previously, foreign countries are starting initiatives to foster innovation and growth and gain on America's ability to generate, and thus control, future innovation. America's quality of life, high paying-jobs, and growing incomes all depend on whether or not the U.S. economy can outperform competitors. In today's global economy, a more focused national strategy is required to motivate, and integrate public and private investment.

The U.S. could maintain a balanced R&D investment portfolio to complement the market demands that drive the industry to invest. The U.S. government would focus its scarce resources on basic research that would cultivate the next big thing as the industry reaches the physical limitations of silicon. The one exception is in the defense-unique market, where government applied research is appropriate due to the lack of a viable commercial business case.

In addition, the U.S. could take action to improve STEM skills. This could be a twofold effort looking at improving the domestic U.S. abilities as well as improving the integration of foreign born talent into the U.S. intellectual pool.

The first effort requires encouraging STEM education among America's youth to increase the talent pool in the U.S. for semiconductor R&D. This should include efforts to improve the U.S. K-12 education system to make it more competitive to global standards and to create incentives for students to pursue higher degrees in the technical fields.

The second requires possible immigration policy reforms to optimize the utilization of foreign students into key industrial areas, such as semiconductor R&D. "U.S. immigration policies should encourage highly skilled workers to stay and work in the [U.S.], and thereby create jobs and economic growth in this country and provide a return on investment for their U.S. education."[96]

MAJOR CHALLENGE #3 – SUPPLY CHAIN SECURITY

Managing the efficiency and effectiveness of semiconductor supply chains has increased in complexity by orders of magnitude over the past few decades due to globalization. As discussed earlier, the semiconductor industry has migrated considerably overseas leading to increased U.S. reliance on overseas sources. With this ever-expanding global supply chain, the U.S. government faces increased challenges from counterfeiting and diminishing manufacturing sources.[97] This has raised U.S. focus on the importance of maintaining a trusted, or secure supply chain. President Obama emphasized this very focus in "The Comprehensive National Cybersecurity Initiative (CNCI)" where he set the national goal "to defend against the full spectrum of threats by….increasing the security of the supply chain for key information technologies."[98] This section explores the threats to U.S. semiconductor supply chains (counterfeit parts and diminishing sources), discusses the national security implications, and presents potential corrective actions.

ISSUE ANALYSIS

Semiconductors are the brains behind today's electronic equipment and are essential to DoD's systems and weaponry. As a result, semiconductors pose an opportunity for counterfeiting and tampering, particularly as semiconductor manufacturing moves offshore. In his paper entitled *Demystifying Shashoujian: China's "Assassin's Mace" Concept*, Jason Bruzdzinski stated, "PLA analysts are carefully studying the vulnerabilities of U.S. weapons, platforms and military systems...to develop operational methods to counter technologically superior adversaries in a future war."[99] Compounding the nefarious supply chain concerns is the increase in the Diminishing Manufacturing Sources (DMS) that result from technology advances and thus the retirement of old technology lines.

The DoD has begun taking steps to address these increasingly complex supply chain dynamics. While supply chain management has been a long-standing discipline within the Program Manager's functional area, the growing use of commercial products and foreign suppliers have spawned new challenges. In the most recent response, the Deputy Secretary of Defense (DEPSECDEF) issued guidance in 2009, later revised in 2010, calling for strengthened supply chain risk management (SCRM) to improve the integrity of components used in DoD systems.[100] Beyond this top-level guidance, there is a lack of detailed and integrated lower-level guidance to assist acquisition and sustainment offices in conducting this effort.

Counterfeit Semiconductors

Reiterating the earlier definition, a counterfeit part is one that "is a copy or substitute without legal right or authority to do so or one whose material, performance, or characteristics are knowingly misrepresented by a supplier in the supply chain."[101] U.S. Department of Commerce reported a 142% rise in reported electronics counterfeit incidents in the DoD supply chain between 2005 and 2008.[102] This issue is exacerbated by DoD systems' long life cycles (decades) beyond original equipment manufacturer sustainability.

A subset of the counterfeit problem involves tampering. While counterfeiting is done for economic gain, tampering is done for espionage or sabotage.[103] A semiconductor becomes tampered when it is knowingly inserted with malicious circuitry resulting in actions that are unintended by its users. Detecting such tampering can be very difficult, if not impossible, to identify. This makes semiconductors very appealing to those wishing to infiltrate or do harm.[104]

To combat this growing risk and improve confidence in the supply chain, Deputy Secretary of Defense (DEPSECDEF) issued the Defense Trusted Integrated Circuit Strategy guidance in 2003.[105] Following that guidance, the DoD and the National Security Agency (NSA) established the Trusted Foundry program and put in place a 10-year contract with IBM to provide trusted foundry manufacturing. In addition, a Trusted Supplier Accreditation program was established to certify semiconductor manufacturers. There are currently 47 suppliers that have received this certification and, by guidance, all DoD procurements must utilized either of these trusted sources.[106] Unfortunately, this framework only ensures the trustworthiness of application specific integrated circuits (ASICs) and does not encompass the many other semiconductor product types such as processors and programmable logic devices.

To combat the tampering risk, the Defense Advanced Research Projects Agency (DARPA) announced in December 2007 its Trust in Integrated Circuits program. The program's intent is to develop ways to test whether electronics built for military equipment have been compromised in any way.[107] The challenge the program faces is creating tests that identify potentially tampered devices without destroying them. Additionally, the tests need to be conducted efficiently to conserve time and dollar resources.[108]

Diminishing Manufacturing Sources (DMS)

DMS is another issue facing the DoD in its reliance on semiconductors. Semiconductors in DoD systems are quickly eclipsed by advances in commercial technology. When DoD replacement semiconductors are required, there may be just a few or no manufacturers who can produce the part. Once made aware, the DoD program manager (PM) has an extensive capability to address diminishing sources and obsolescence. DMS has been a longstanding concern in the acquisition policy community. PMs are required to address DMS throughout a program life cycle and include it in their Systems Engineering Plans.[109]

Further guidance is provided in three major handbooks produced within the DoD.[110,111] Beyond the guidance, there exist multiple design and fabrication capabilities within the DoD and industry. Through the before-mentioned Trusted Foundry program, PMs can access a large inventory of old technology capabilities at the IBM facility. In addition, the DoD operates the Defense MicroElectronics Activity (DMEA). Through the DMEA, PMs have access to government design and fabrication facilities to answer their obsolescence issues.[112] Lastly, industry has also responded on its own. For example, Rochester Electronics started in 1981 with the sole objective of providing aftermarket semiconductor production solutions.[113]

NATIONAL SECURITY IMPLICATIONS

As the market continues to globalize and the DoD increases its use of commercial devices, defense agencies have increased their reliance on foreign companies for national security capabilities. For example, until recently, all high performance field programmable gate arrays (FPGAs) were manufactured overseas.[114] In this situation, the DoD must be wary of single-source foreign suppliers that could greatly impact or influence U.S. national security, intentionally or not. In 2003, there was an investigation into the reliability of FPGAs manufactured by two overseas foundries. The investigation found one foundry's product unreliable, while the other was acceptable.[115] If there had not been the additional supplier, the nation could have experienced a crippling setback.[116] Without proper mitigation of supply chain risks, the U.S. may face significant degradation, cost increases, and schedule impacts.

As a counterfeit part example, both the U.S. Air Force and the Missile Defense Agency (MDA) encountered counterfeits resulting from the procurement of discontinued processors from dealers. U.S. Air Force F-15 technicians recognized strange markings on procured flight control panel processors.[117] Similarly, MDA technicians noticed what appeared to be resurfacing and remarking. Luckily, none of the processors was ever installed into operational systems.[118]

While there are no confirmed accounts of tampering as an offensive measure, there is significant speculation that such tactics are being employed. For example, it is suspected that Israel embedded tampered chips into Syrian air defense radars, which allowed Israel to bomb Syria undetected in 2007.[119]

The DMS problem typically becomes a national security issue for older platforms, when replacement parts cannot be fielded. This leads to the potential of critical systems being unusable. In addition, the DMS problem can even be an issue for new platforms. The F-35 Joint Program Office already sees DMS as a critical issue for the program.[120]

MITIGATION ALTERNATIVES

The DoD has taken numerous steps (Trusted Foundry, DMEA, DARPA) to reduce the risks presented by the use of microelectronics in a globalized world. However, as mentioned in the

DEIB section, these efforts are disjointed and not integrated into a cogent DoD strategic plan. First off, the DoD would benefit from identifying one office responsible for the defense microelectronics sector and for developing a comprehensive policy guidance that addresses the supply chains concerns voiced above. Second, that entity should engage with industry, international standards organizations, and academia to develop that comprehensive strategy that address all facets of microelectronics including Supply Chain Risk Management, all microelectronic product types (not just ASICs), and the use of offshore parts from foreign suppliers (parts not made or available in the U.S.).

OUTLOOK

For the foreseeable future semiconductors will become increasingly prevalent in society. As people become more connected through smartphones, tablets, and the internet, the semiconductor industry will advance and grow to meet their needs. This steadily increasing demand bodes well for the future of the global semiconductor market. In this section, the seminar presents our short-term and long-term outlook on where the global, as well as the U.S., semiconductor industry is going.

SHORT-TERM (NEXT 5 YEARS)

The global semiconductor industry will continue to grow steadily over the next five years increasing revenues more than $100B over the 2010 levels. However, with the existing business environment and U.S. policies, the U.S. will likely only receive about $6B of that increase. Without any changes in the U.S. marketplace, the ongoing trend of migration overseas will continue along with a decline in U.S. semiconductor exports. Bottomline, the U.S. decline in global semiconductor market share is expected to continue.

In the short-term, the U.S. will remain as the world leader in the high-tech portions of the semiconductor value chain. However, the growing trend of offshoring R&D, innovation, and human capital will also continue and pose increasingly more pressure on U.S. dominance at the cutting-edge of technology.

The industry will continue to focus on evolutionary efforts to maximize the performance of CMOS-based designs. Through continued miniaturization, 3D techniques, and materials engineering, the industry will further advance levels of performance, while reducing the size, weight, and power, to meet consumer market demands.

The DoD will come to rely more on commercial components and overseas sources to satisfy its requirements. With the increasingly globalized industry, maintaining stable and secure supply chains will become more of a problem and require more resources in time, people, and funding to manage them. Counterfeit and tampered parts along with diminishing sources will become major efforts for DoD acquisition and sustainment offices.

LONG-TERM (15 YEARS OUT)

The global semiconductor industry will continue to grow and prosper as technology reaches farther into everyday life and becomes available to more of the global population. As globalization continues to influence markets, the industry will continue to migrate to the most advantageous locations. This will likely include an increase in the Asia-Pacific region, but may increasingly involve other emerging markets such as Brazil, India, or Africa. If current conditions persist, the U.S. market share decline will continue. Its role will likely be limited to the high-end market, but even that share will have diminished as other countries improve their human capital and innovation.

Inside the industry, the structure will continue to drive intense competition. As capitalization and investment costs increase, large firms will continue to dominate the landscape and direction of the industry.

CMOS will undoubtedly still be the foundation of the industry; however, it will likely reach practical limits to its expansion as investment costs rise prohibitively. If R&D has been successfully integrated, planned, and executed, revolutionary methods will be approaching the point where viable consumer products may be possible.

Supply chain security will remain at the forefront of DoD semiconductor use. With the diffusion of the market, the technology, and the innovation, new and complex methods of counterfeiting and tampering will arise.

As this outlook shows, there is an opportunity for effective government public policy now. If U.S. public policy is adapted to the current environment and is tailored to support the high-tech semiconductor industry, then this outlook can been changed considerably into the U.S.'s favor.

GOVERNMENT'S ROLE

A common theme in past semiconductor industry reports and analyses was the recommendation for the U.S. government to stay out of the way and let the natural market trends dominate. While some of this attitude remained this year, there was an increasing sense that the U.S. government could and should support the conditions that could improve the health of the industry and hence the nation. From the industry side, the theme centered on improving public policy to account for the present, globally competitive environment. The current policies often put the U.S. industry at a disadvantage against much more aggressive competitors. As one visiting lecturer quoted, "The U.S. is playing tennis; while the rest of the world is playing football…we're getting killed." The second theme resounded from the government and policy side and focused on the national security implications of the market and the need to secure our supply chains. As such, the 2011 electronics seminar's approach to policy focused on updating public policy to improve how the government supports the industry with the goal of improving global competitiveness, economic growth, and national security.

POLICY RECOMMENDATIONS

Building on the government's role, the seminar recommends the following five actions to both create a positive corporate environment and to secure the DoD's semiconductor supply chain:

(1) **Reform tax policy** for corporations, including permanent R&D tax relief as proposed in the President's 2011 budget, reduction of corporate tax rates and deferral of taxes on overseas income.[121] This would allow U.S. corporations to plan accurately, maximize R&D spending in the U.S., put America on more equal competitive footing with other countries seeking to entice semiconductor investment, and encourage repatriation of overseas funds. This could include lesser tax rates for repatriated revenues given corporations invest those revenues in U.S.-based R&D or STEM-related programs and a tax credit for U.S. companies that donate equipment to universities. These reforms would mitigate the industry challenges in *offshoring* and *STEM* described above.

(2) **Balance R&D spending** to complement the market demands driving the industry to invest. The U.S. government should focus its R&D funding on basic research initiatives to cultivate an innovative and creative industry. In addition, the government should maintain its applied research funding for those semiconductor technologies that are defense-unique and have no commercial market. At the national level, R&D must be managed as a portfolio of projects and government and industry collaboration with all stakeholders to develop research platforms. This investment in research is critical to both the *STEM* challenges in the U.S., the need to maintain *technological leadership* in this industry, and could quell some *offshoring* causes.

(3) **Encourage STEM education** amongst America's youth to increase the talent pool in the U.S. for semiconductor R&D. This includes efforts to improve our K-12 education system to make it more competitive to global standards and creating incentives for students to pursue higher degrees in technical fields. Addressing STEM will address the challenges discussed above in *offshoring, STEM*, and *technological leadership*.

(4) **Reform immigration policies for foreign students**. "U.S. immigration policies should encourage these highly skilled workers to stay and work in the United States, and thereby create jobs and economic growth in this country and provide a return on investment for their U.S. education."[122] Immigration policy needs adaptation to tie education received to follow on work and preferential visa decisions to promote high-skill immigration beneficial to national needs.[123] These reforms would directly address the *offshoring, STEM*, and *technological leadership* challenges.

(5) The DoD should **align existing agencies, processes, and resources** to ensure department-wide unity of effort, eliminate redundancies, and refine command and control relationships to maximize the effectiveness and efficiency of the defense semiconductor sector. This entails establishing one accountable entity within DoD to establish comprehensive guidance, especially detailed guidance on implementing Supply Chain Risk Management, that aligns authorities, increases collaboration and mutual support across the department, and increases the overall security posture of defense supply chains. Lastly, this entity would engage as the policy center between associations, academia, companies, and standards organizations and the acquisition and sustainment offices most needing of the latest guidance and education. This alignment effort would address the *DEIB challenges* of assured and trusted supply for DoD while also contributing directly to the industry in the areas of *offshoring* and *technological leadership.*

CONCLUSION

The seminar's research revealed how important the semiconductor industry is to the vitality and health of the global and, especially, the U.S. economy. It sits as a foundation of our way of life as well as our national security. The analysis also highlighted a number of trends within the industry that threaten U.S. leadership and give rise to three major challenges affecting the nation's well being, prosperity, and national security. Fortunately, all areas, while potentially detrimental, also offer incredible opportunities if properly handled. Bottomline, the U.S. must take steps to update its public policy to take into account the extremely dynamic strategic environment the industry faces. While the U.S. industry does not need to be subsidized or bailed out, it must be allowed to play on a fair and even global playing field. With supportive, rather than restrictive, policies the incredibly diverse and innovative U.S. semiconductor market will no doubt do well on the world stage, as it has in the past.

In addition, the government, particularly the DoD, must work to ensure the reliability of their global supply chains. They must have comprehensive policies that allow for well-informed economic decisions, while also ensuring their sources are trusted and assured. The military's effectiveness and technological leadership rely on it.

Lastly, the global semiconductor market is an extremely strong market and the foundation of the United States' economic, technological, and military brilliance over the past fifty years. The global marketplace and rapid globalization offers incredible opportunities for U.S. industry. However, the U.S. market share has been in steady decline and is constantly under assault by foreign competitors desiring a piece of the pie. Unless U.S. public policy recognizes the fierce competition and fights to level the playing field, the historic U.S. semiconductor dominance will become a thing of the past. The United States has the right tools and talent to stem the tide; it simply needs to remove the regulatory burden and allow the industry to compete more freely.

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FIGURES

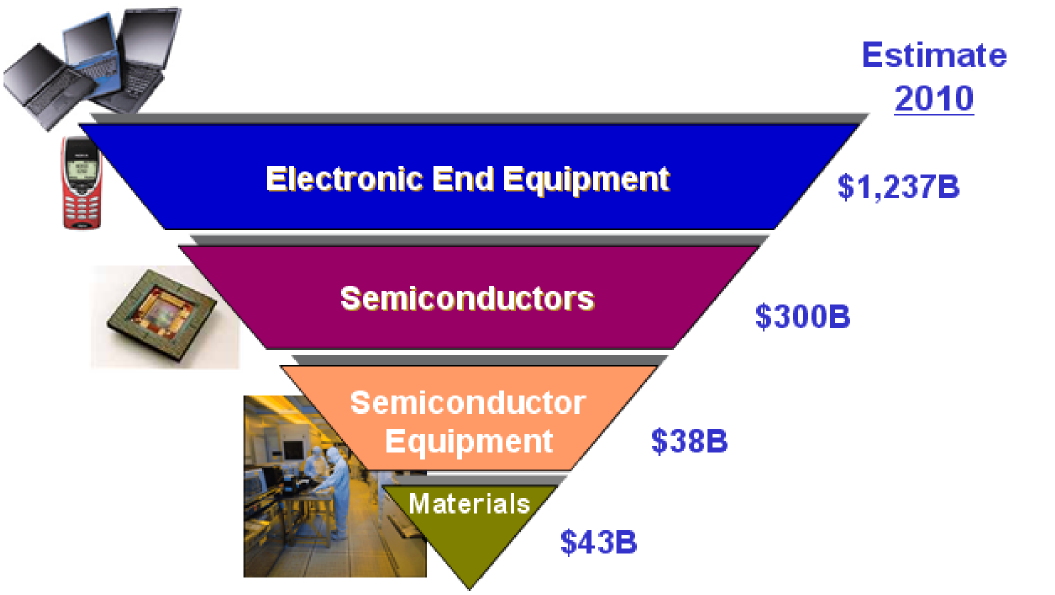

Figure 1. Electronics Industry Value Chain

Figure 2. Semiconductor Value Chain

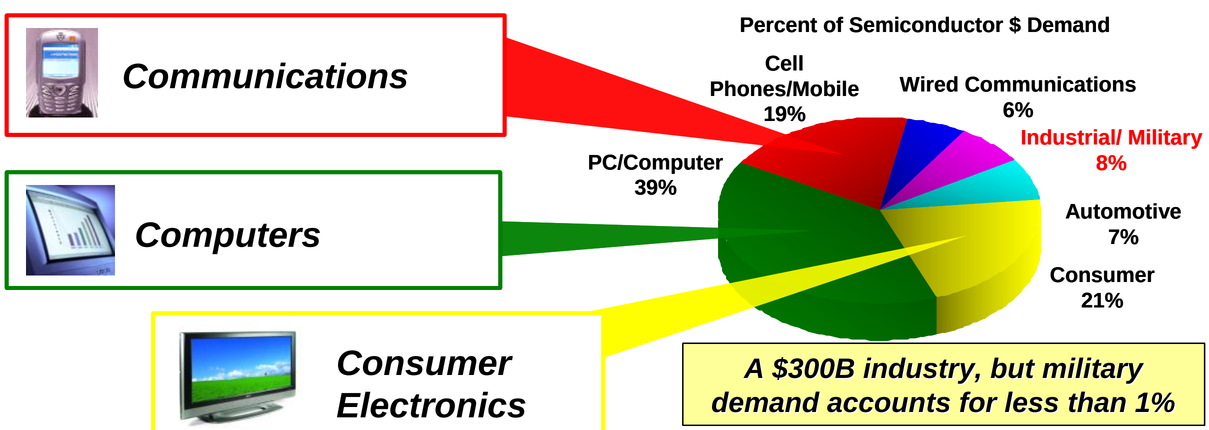

Figure 3. Semiconductor Demand Drivers, 2010

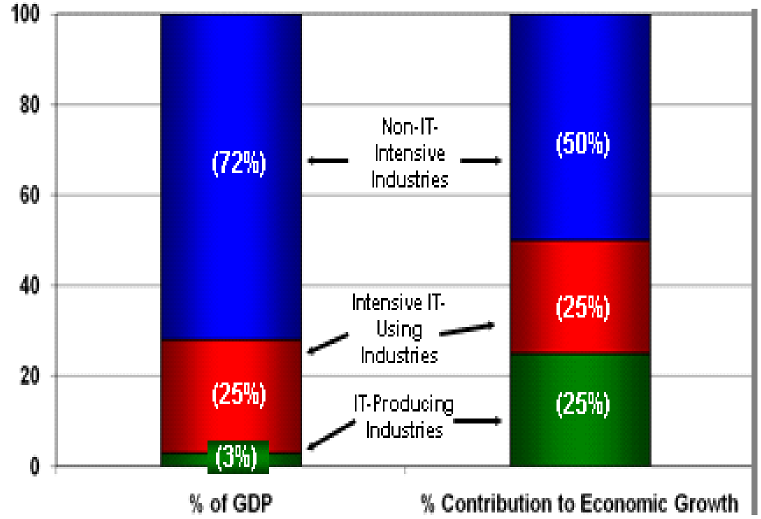

Figure 4. IT Producing Industries Spur Growth

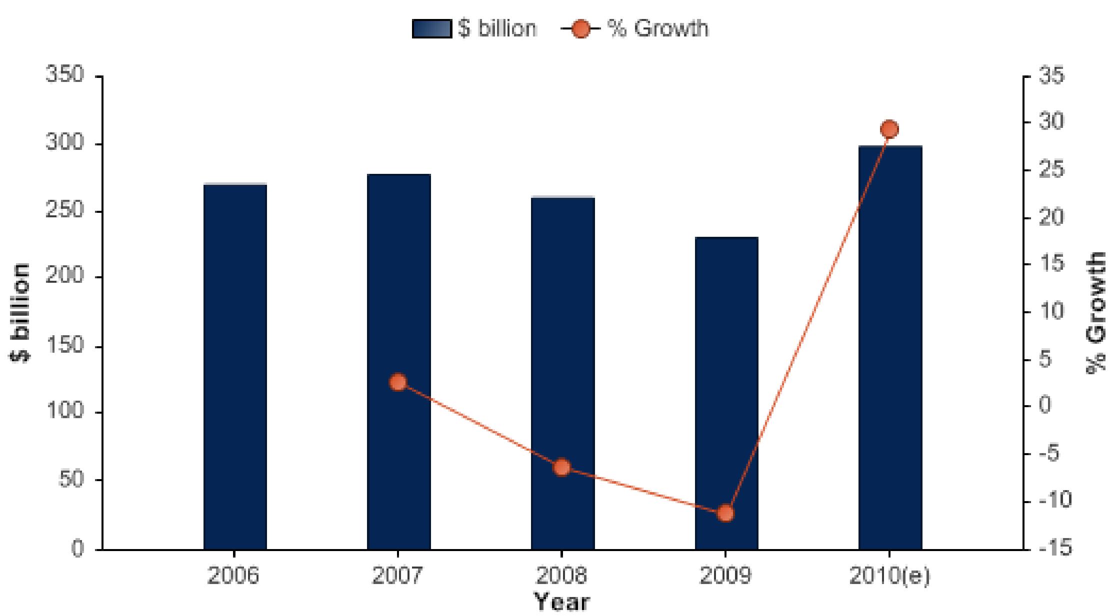

Figure 5. Global semiconductor market value

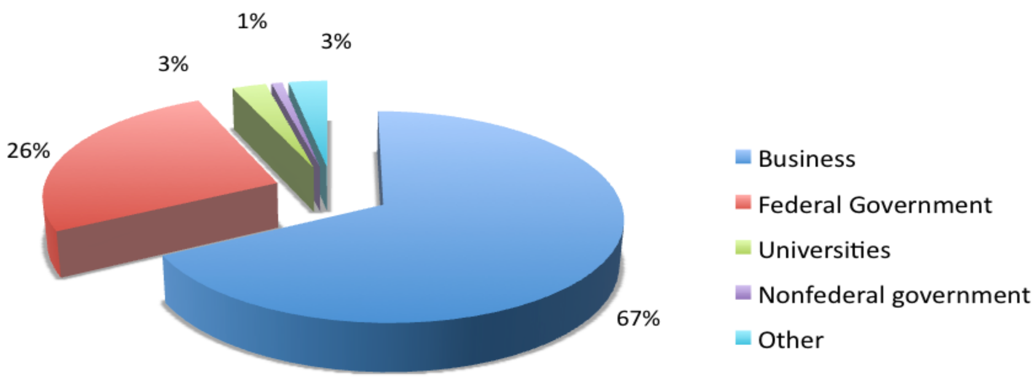

Figure 6. U.S. R&D Funding Sources (2008)

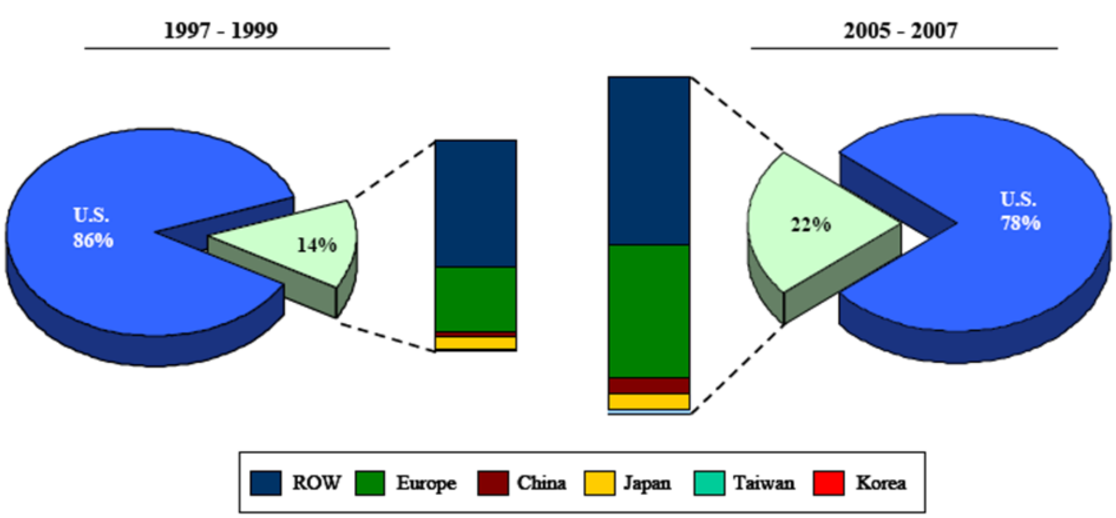

Figure 7. U.S. Semiconductor Firm Global Investment

ACRONYMS

3D	Three Dimensional
AIA	Aerospace Industry Association
AMD	Advanced Micro Devices
ASIC	Application-Specific Integrated Circuit
CAGR	Compound Annual Growth Rate
CMOS	Complementary Metal-Oxide-Semiconductor
CNCI	Comprehensive National Cybersecurity Initiative
DARPA	Defense Advanced Research Projects Agency
DEIB	Defense Electronics Industry Base
DEPSECDEF	Deputy Secretary of Defense
DMEA	Defense MicroElectronics Activity
DMS	Diminishing Manufacturer Sources
DoD	Department of Defense
FPGA	Field Programmable Gate Array
GAO	Government Accountability Office
GDP	Gross Domestic Product
GPS	Global Positioning System
IBM	International Business Machines
IC	Integrated Circuit
ICAF	Industrial College of the Armed Forces
IDM	Integrated Device Manufacturer
IP	Intellectual Property
MDA	Missile Defense Agency
NSA	National Security Agency
PC	Personal Computer
PhD	Philosophiae Doctor
PM	Program Manager
R&D	Research and Development
SAE	Society of Automotive Engineers
S&P	Standard and Poor’s
SCRM	Supply Chain Risk Management
SIA	Semiconductor Industry Association
STEM	Science, Technology, Engineering, and Mathematics
TSMC	Taiwan Semiconductor Manufacturing Company
UMC	United Microelectronics Corporation
U.S.	United States
WWII	World War II

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