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Industry Study

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Electronics Industry

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ELECTRONICS 2012

ABSTRACT: The semiconductor continues to claim the spot as the #1 US high-tech export and has grown to a $300 billion global market, fueling a $1.3 trillion consumer electronics industry. Historically, the US led semiconductor innovation, however, globalization allowed opportunities for South Korea and Taiwan to innovate as well. This innovation fueled Moore's Law of doubling computing capability on a microchip every 2 years. Since its invention in 1947 the transistor has been scaled down to microscopic size. Now smaller than a virus, over 1 billion transistors fit on a typical semiconductor (Figure 1). Miniaturization and its corresponding increase in computing capability have created a digital electronic environment that touches every facet of society, ranging from cloud computing, miniature medical devices, advanced video consoles, smart phones, advanced automotives, to high tech defense systems. The US has seen its market lead and influence in the semiconductor industry decline over last two decades primarily from globalization of supply chains and the off-shoring of key industry segments.

Global competitors developed in the Pacific Rim. South Korea and Taiwan dominate design and manufacturing, while China incentivizes companies to produce chips locally to meet demand and innovate indigenously. Foreign chip manufacturing threatens the global supply chain to commercial and defense programs. Supporting US innovation and research here in America is an imperative to counter that threat. The industry is at an inflection point and the US has an opportunity to enact policies to support domestic semiconductor firms and potentially re-shore segments of the industry and re-establish the United States as the undisputed leader in global semiconductors. This paper analyzes key areas of the industry and provides policy recommendations addressing the funding of basic research, export control, supply chain security and investment in human capital and innovation. The objective is to educate senior decision makers on the US semiconductor industry with respect to the economy and national security while presenting options to ensure continued vitality of the US industry.

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IBM Research - China, Beijing
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Semiconductor Manufacturing International Corporation (SMIC), Shanghai
US Consulate General, Shanghai
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INTRODUCTION

"Semiconductors...the crude oil of the twenty-first century."[1]

Michael Klaus

This paper documents a critical analysis of the US semiconductor sector by the Electronics Industry Study at the Industrial College of the Armed Forces (ICAF), Class of 2012. It is the culmination of a focused series of classroom seminar sessions and meetings with industry, government, and academic leaders through field studies in the metropolitan Washington, D.C. area, Silicon Valley (California), Taiwan, and China. This approach provides a wide range of perspectives from which to examine the selected industry's current condition, outlook, and challenges, and an opportunity for seminar fellows to develop and recommend policies that address key issues that significantly impact US national economic and security interests. The US ability to create innovative technologies has been the foundation of economic growth, relatively low unemployment for American workers, and ultimately, national security for our nation. The US electronics industry provides a successful model for prosperity and growth that can be achieved through American innovation and the practical application of scientific discovery to enhance productivity and advantage in everyday life— as well as critical capabilities for national defense. The electronics sector promotes economic welfare and serves national strategic needs.

At the heart of the electronics industry is the semiconductor, which drives the growth and technology enabling the entire electronics value chain. Because of its importance to electronics applications, and US weapon systems, the semiconductor industry is the focus of this report. The US semiconductor industry provides high-paying jobs for hundreds of thousands of skilled workers, as well as the enabling technology for thousands of products and services Americans use daily, such as personal computers, cell phones, digital music players, remote-controlled automobile door locks, the internet, on-line banking, digital cameras, and more.

Although the semiconductor industry began in the United States and many of its top innovations still come from this country, domestic firms face increasing challenges and competition due to market segregation and globalization. In particular, the Asian semiconductor industry is rapidly gaining ascendance in the global marketplace. Today, the shift of numerous semiconductor activities to Asia is diminishing the manufacturing base for trusted chips for US defense needs, increasing the likelihood of key US military technologies transferring to potential adversaries, and eroding the nation's competitive advantage in an industry vital to economic growth. To protect US national interests, policymakers need to understand where the semiconductor industry is headed, the implications current trends have on US security, and what policy measures are needed to safeguard security and maintain a competitive domestic industry.

INDUSTRY DEFINITION AND CURRENT CONDITION

THE SEMICONDUCTOR INDUSTRY

The advent of the semiconductor changed the world we live in forever. For our purposes, a semiconductor is a basic component used to make solid-state electronic circuits like diodes and transistors, which in turn are used to create integrated circuits (IC), most notably computer processors and memory chips.[2] The semiconductor is the heart and soul of all electronic devices, from a small transistor radio to the advanced computers in the Joint Strike Fighter, making them extremely important to our national defense, as technological superiority is a central tenet of US defense policy. Therefore, it is incumbent upon our nation to ensure the US defense industrial base maintains an edge in technology and innovation, ensuring our adversaries do not surprise us on the battlefield. The semiconductor industry is a compilation of companies that design and manufacture components like microprocessors, memory chips, integrated circuits, and transistors and the equipment necessary for their production. To accomplish this production, the industry has four main subdivisions: equipment/materials, design, fabrication, and packaging/testing.

The equipment and materials used to make semiconductors are highly specialized and expensive. The cost to build a fabrication plant can exceed $5 billion and the largest part of that expense is the equipment.[3] This equipment ranges from devices that solder electrical connections to sophisticated photolithography machines that etch the design image into a silicon wafer, ultimately leading to a finished computer chip. A single piece of equipment can easily exceed $15 million, and it takes hundreds of pieces of equipment to equip a plant.[4] To maintain the equipment, the user usually contracts with the original manufacturer for replacement parts and maintenance services. At nearly $18 billion in annual sales, US firms dominate the production of semiconductor manufacturing equipment, controlling 50 percent of the entire market and leaving only 50 percent for all other international companies combined.[5]

The design segment of the industry uses computer hardware and software known as Electronic Design Automation (EDA) to layout new semiconductors for production. As the amount of transistors on a die (chip) increased over time, it became impossible to design them without computer assistance. It is in this sector of the industry where the intellectual property (IP) rights for an IC reside. The individual semiconductor design is the IP. It must be protected to maintain a competitive advantage in the industry.

After the design is tested and proven functional, it is sent to a manufacturing facility, often called a foundry or fab, to produce the chips. Fabrication of a semiconductor is the actual manufacturing step. Because component sizes such as a transistor are measured in nanometers, it has extremely low tolerances for error and unusually strict requirements for purity. Manufacturing ICs may be one of the most complex and advanced manufacturing processes in the world.[6] The sophistication of today's fabrication plants means there is little human interaction unless the equipment malfunctions. A silicon wafer runs through the manufacturing process where the equipment etches in the planned design and cuts the wafer, yielding dozens or hundreds of pieces, each one known as a die. A single plant like the new Global Foundries plant can process 60,000 wafers a month.[7] Using a nominal one square-inch die, that is almost 5 million die every month from just one plant.[8]

Packaging and testing is the last major subdivision of the semiconductor industry. It entails mounting the die in protective packaging and making the necessary connections between the die and the pins, resulting in the final package, a computer chip.[9] Packaging and testing usually occur in the same location. Most packaging and testing takes place overseas in the fabrication plants. This allows the manufacturer to take advantage of their current facilities, reduces the transportation costs, places the final product closer to the point of sale and takes advantage of the cheaper labor rates.[10]

There are two main business structures employed in the semiconductor manufacturing industry. The first is to operate as a vertically integrated company. A vertically integrated company is one that designs and produces their own chips. This was the original concept employed by the earliest manufacturers because it allows the company to restrict the number of people who have access to the chip design. There are only a few vertically integrated companies left, but Intel, the largest chipmaker in the world, is one of them, showing it is still a viable option.

As the entire industry progressed at unprecedented speeds, making chips smaller and more complex, the industry went through some significant changes. In order to keep up with the rapid changes, firms began to spring up that were specialized in just one segment of the industry instead of using the vertically integrated model. This specialized business strategy allowed them to narrow their focus and accelerate change, giving them a competitive advantage. At first, many firms started to specialize.[11] Over time, market saturation led to consolidation. Some corporations even opted to continue to design chips, but wanted someone else to manufacture them because of the enormous costs to build a fabrication plant. These corporations became known as "fabless" corporations. This specialization had one other consequence. As each segment splintered, firms no longer needed to stay in Silicon Valley and outsourcing began. Firms began to look for competitive deals for their large capital expenditures like fabrication plants, and countries seeking a competitive advantage in the technology manufacturing process were willing to give lucrative incentives to lure them away. Corporations began building huge fabrication plants or foundries overseas at a fraction of the US cost. These foundries often do not design chips at all, but manufacture them for others. In the specialized business strategy, a fabless company will contract with a foundry to have their chips manufactured. One potential drawback: because a fabless company must send their designs to foundries, there is a potential for the theft of their IP. However, a foundry does have to worry about its reputation, and therefore they try hard to protect the designers' IP.

The structure of the global semiconductor market is segment dependent. Vertically integrated companies (known as integrated device manufacturers (IDMs)), foundries, and equipment manufacturers are oligopolies within their respective segments, while design firms exhibit monopolistic competition, and the raw material market is perfect competition.[12] The following paragraph analyzes the structure of the market using Porter's Five Forces, from the perspective of the semiconductor manufacturers. The key buyers are makers of electronic products with the key suppliers being wafer production shops, semiconductor equipment manufacturers and raw material companies.

Competition: Competition is high within the US and international semiconductor markets. Variable and unstable growth rates in recent years have caused increased competition to maintain revenue streams; however, as the market recovered in 2010 this pressure has begun to ease.[13] **Buyer Power:** The semiconductor market exhibits moderate buyer power since there is a wide array of customers across many product lines, reducing buyer power. However, the rapid nature of innovation within this market allows firms to differentiate their products and build customer loyalty.[14] **Supplier Power:** Suppliers of raw materials and manufacturing equipment in this market also have moderate power due to highly specialized raw material compounds and equipment produced by only a few firms. Switching suppliers often incurs increased costs, including possible supply chain interruptions if raw materials of inadequate quality are purchased.[15] However, larger companies often produce some of these supplies in-house, tempering the power of suppliers.[16] **Barriers to Entry:** This market can be capital-intensive requiring highly sophisticated machinery/equipment and automated processes that require high rates of turnover to keep pace with emerging production practices.[17] Additionally, there are intellectual barriers in which existing firms own technologies and can spend considerable sums on research and development (R&D) contributing to the high barriers of entry.[18] **Threat of Substitutes:** In nearly every end-market, there are almost no substitutes to the semiconductor. Devices with semiconductors are typically excellent substitutes for older technologies, but not vice-versa.[19]

The global semiconductor industry generated sales of $299.5B in 2011 up 0.4% from 2010[20] when the industry recovered from recessionary effects of 2009 with a 30% increase.[21] American semiconductor companies continue to dominate the global market based on US corporate revenues accounting for $153B or 51% of global sales in 2011, up 3% from 2010. America's nearest competitor in the global market is Japan at approximately 20%.[22]

Industry forecasts US leadership in the global market to continue with 5% compound annual growth rate (CAGR) until 2015[23] with the emphasis on integrated circuits (vice discrete) which comprise 97% of US revenues.[24] Additionally, the semiconductor industry leads as the United States' number one high tech export and its second largest exporting industry overall[25] and is poised to continue this trend as the expansion of internet connectivity and demand for electronic devices grows. Of the $153B sold by US companies in 2011, $125B (82%) was to foreign companies leaving the domestic demand for US based firms at $28B (18%).[26]

US semiconductor firms also have one of the highest corporate reinvestment rates, averaging 28% of their revenues. In 2010, US semiconductor firms invested $20B and $13B to research and development and capital equipment respectively.[27] The global recession from 2007-2009 severely affected the US semiconductor market, however the explosion of the smartphone and tablet markets in 2010 helped the industry recover, driving an approximate 30% increase from previous year revenues. Estimates call for the high demand of mobile computing devices to continue in addition to digital TVs, set-top boxes and game consoles which are projected to grow at 10% or more from 2012-2017. The continued recovery of the US economy and subsequent return in industry production levels to pre-recession levels will likely help domestic semiconductor sales especially in the automotive industry, automated manufacturing equipment, and light emitting diode (LED) markets where it is forecasted to grow rapidly as the technology continues to mature and manufacturing costs decline.[28]

The US semiconductor industry also continues to lead nearly all aspects of semiconductor design and manufacturing. Intel, the world's largest IDM firm is responsible for 16.5%[29] of the global market share[30] and an industry leader in many facets of cutting-edge technology, both in circuit design[31] and fabrication. Intel is also at the forefront of development of the 450mm wafer manufacturing capability. Although across America every day firms, startups, research centers, government labs and universities are pushing the boundaries in semiconductor technology, the US semiconductor industry is not without its challenges. As more aspects of semiconductor manufacturing move offshore, the US will be challenged to maintain its technological and innovative edge in the semiconductor industry, threatening the preeminence of our weapons systems and national defense.

CHALLENGES

The analysis of the semiconductor market identified three overarching challenges that could further reduce US market share and domestic ability to innovate. The following three sections frame each of the challenges, while succeeding sections analyze the implications for the economy and national security. In addition, a series of three essays will provide data and analysis on these challenges.

MAJOR CHALLENGE #1 – TECHNOLOGY TRANSITION

One cannot have a conversation about the future of the semiconductor industry without Moore's Law. This widely-held planning estimate – projecting that the number of transistors in a given area of an integrated circuit (IC) chip will double every two years – has gone on to define an industry and set the expectation that electronic devices would continue to get faster, smaller and cheaper over time. However, two technological hurdles loom over the semiconductor industry: 1) approaching the minimum manageable transistor size to maintain Moore's Law performance scale and 2) the fabrication transition from 300mm wafers to 450mm wafers.

Chipmakers are approaching a Moore's Law scaling barrier with unmanageable power and heat dissipation associated with producing faster clock speeds in chips based on 22nm and smaller transistor technology. Industry's response to this impending barrier is additional research and development, both in changing the shape of the transistor as well as changing the semiconductor materials. Lack of success in this research could result in newer and/or smaller chipmakers narrowing the performance gap with industry giants like Intel. On the other hand, whichever firm is successful with breaking through the barrier, could very well create a gap between themselves and their competitors. Moore's Law performance scaling is related to the 450mm wafer issue due to some industry leaders claiming that future chips resulting from performance R&D will only be produced on 450mm wafers. The implication is that a competitive gap will increase between the large firms that make the 450mm transition and the smaller semiconductor manufacturers that do not make the transition.

Semiconductor manufacturers can produce up to 2.3 times more die on a 450mm wafer than a 300mm wafer, with an approximate $25% capital expenditure reduction for the cost of a new 450mm fab versus a new 300mm fab.[32] However, industry experts estimated investment in the research and tools for this transition will reach as much as $25-$40 billion. These costs are forcing firms to partner with each other and governments to make the transition. Intel, IBM, Samsung, Global Foundries and TSMC have formed the Global 450 Consortium (G450C) to pool research and development (R&D) resources. While the chipmakers see the direct benefit of producing more die per wafer, the tool manufacturers bear a large investment cost with less return on investment if only five companies make the transition. Some tool manufacturers through associations like the Semiconductor Industry Association (SEMI) have approached US lawmakers for potential funding to keep this production in the US.

MAJOR CHALLENGE #2 – GLOBALIZATION AND US DECLINE

While the US retains a 51% global market share of semiconductor exports, domestic manufacturing has declined precipitously over the past decade. Between 2005 and 2009, the total US percentage of global production capacity dropped from 25% to 14%. Of the 27 semiconductor fabs that closed worldwide in 2009, 15 of them were in the US.[33] It is unlikely that any combination of government policies will be able to reverse this outcome. As Apple's Steve Jobs informed President Obama in 2011, "those jobs aren't coming back."[34] In addition, from 1998 to 2008, 217,000 semiconductor jobs were eliminated in the US,[35] and 35 of 40 chip manufacturing plants under construction in 2007, were in Asia. While American and European economies have been sluggish, those of Asia, and China in particular, continue to grow in both demand for consumer electronics and in production of electronics.

The seminar's overseas visit to Taiwanese and Chinese firms confirmed the profound impact of China's growing demand on the semiconductor market. Semiconductors are China's #1 import. China pursued a two-pronged approach of enticing international chip and material firms to setup production in China through tax, land and infrastructure incentives, while supporting its own fledgling industry with protectionist measures and funding. According to one senior industry executive of a U.S. multinational corporation operating in Taiwan, the company was drawn to Taiwan due to their ability to get access to large loans at very low interest rates. This attractive cost of capital is extremely important to them as they consider the enormous cost of cutting edge fabrication facilities.

The rise of Asia's semiconductor industry creates a potential US downward spiral of reduced manufacturing, less opportunities for innovation, and migration of human capital. Innovation often occurs where manufacturing happens and as manufacturing moves to China, so too will opportunities to innovate. Similarly, when businesses move overseas, high-paying job opportunities also follow. Top advanced academic graduates are no longer limited to making money in the US and are often following high salary offers of overseas jobs.

MAJOR CHALLENGE #3 – US REGULATORY ENVIRONMENT

As China, Taiwan, and other Asian countries create a business-friendly climate for high-tech firms like semiconductor manufacturing, the US is at a disadvantage with its corporate tax, export and immigration laws.

The US has one of highest corporate tax rates in the world.[36] The rates vary from 35% to 39% plus state taxes, while the world average in industrialized countries is 25%. Unlike most countries, the US government requires US based firms to pay taxes for revenues obtained in markets outside of America. "The vast majority of countries have adopted a territorial tax system to help their global companies better compete and to help repatriation of cash to invest in the home country."[37] Thus, US policy forces US firms to maintain revenues in other countries instead of repatriating and investing that capital. Additionally, the US R&D tax credit is one of the least competitive of developed economies.[38]

As semiconductors are the United States' number one export, a significant percentage of electronics firms' revenue comes from sales in overseas markets - IBM (64%), Intel (85%), and Texas Instruments (90%).[39] The US export control system is managed by four different government departments, implementing several laws by overseeing three distinct control lists and participating in over five international counter-proliferation regimes/arrangements. Many experts within the electronics industry point to this export control system as a construct geared to Cold War mentality that is out of touch with today's global economic realities. Furthermore, enforcement of these export controls is placing our US industries at a great disadvantage relative to their global competitors. For example, one semiconductor electronic design company lost deals where the project funding came from Europe, and the specification stated that technology subject to the International Traffic in Arms Regulations (ITAR) could not be used in the program. In one case, the requirement was for a custom IC for a fighter aircraft. While the IC did not technically add any "munitions capability" to the overall system, it became subject to the ITAR due to the "specially designed" nature of the chip. According to a company representative, "Your cell phone contains higher technology than was in this chip design."

Many of the brightest scientists emerging from US and foreign schools are foreign nationals. Does it make sense for the United States government to force this precious resource out of the country? Great minds with great ideas give the US a competitive advantage and the government should make it easy for high-tech companies to recruit advanced graduate students, whether they are foreign born or not. Losing these minds only weakens the US and makes other countries stronger.

OUTLOOK

Future Outlook: The US semiconductor industry is foundational to our defense industrial base. Maintaining secure and cost effective access to leading edge semiconductor technologies is critical to our national security. While the off-shoring of high-tech manufacturing jobs is an undesirable outcome, the real threat is how this trend, long term, could affect our most vital national security asset—our high-tech innovation culture. The sum total of our university and government research labs combined with high levels of both public and private R&D funding, give the US a unique and critical competitive advantage. In short, our military-industrial complex is a priceless asset that the US should protect at all costs. Each of the challenges outlined above, if left unchecked, creates conditions that threaten or undermine the US position as *the* global high-tech innovation leader. While policy options might not reverse the flow of manufacturing jobs, they could slow it significantly and create opportunities for new market segments to emerge through innovation and new product development. This section will consider some potential outcomes to the challenges outlined above, their potential impacts on off shoring and their implications for the global semiconductor industry and the Department of Defense through 2025.[40]

Transition to 450mm wafers: Based on our discussions with industry representatives, the consensus opinion is that, near term (2-3 years), the future of the semiconductor industry looks bright. Technology development (Moore's law) is likely to keep pace with the milestones outlined in the International Technology Roadmap for Semiconductors, and many firms are reasonably well positioned to maintain or perhaps expand their profitability due to increasing demand for end user products (smart phones, tablets, etc) globally, but especially in Asia. This outlook assumes, of course, no major shocks to the global economy from either Europe or the Middle East. However, the transition to 450 mm wafers will be a significant challenge for the industry. If it proceeds smoothly, with risks spread evenly across equipment and chip manufacturers, the industry will be well positioned for a new "golden age" by 2015, where profit margins expand and consumer prices decline. US firms will profit from this scenario. Conversely, if the G450C is unable to reach consensus on standards and managing financial risks, the transition to 450 mm wafers could be delayed perhaps as late as 2015, rather than 2012 as mapped by the ITRS. At a minimum, such a delay could slow Moore's Law significantly (cost per function), and, worst case, could result in further consolidation of firms within the industry. With 50% of the manufacturing equipment segment split between Applied Material (US) and ASML (Netherlands), further consolidation would reduce competition and could jeopardize US leadership in this area. The 450 mm transition does not represent an immediate threat for near-term Department of Defense (DoD) interests. However, over the longer term, the acquisition of US equipment firms by foreign companies could weaken the culture of innovation the US enjoys by limiting the access of chip designers and manufacturers to domestic manufacturing IP.

Moore's Law: Both the 2007 and 2011 ITRS reports highlight the fact that a feature-size-alone approach to continuing Moore's Law (more transistors per chip: "More Moore"), is unsustainable. The 2011 report outlines the need for "equivalent scaling" through chip design and functionality in order to continue Moore's Law (a.k.a.: "More-than-Moore"). To put this in perspective, the 2011 report suggests the scaling for high performance physical gates should decrease from 22nm to 18nm between 2012 and 2014. This would yield a maximum of a ~40% increase in total transistors. The remainder of the performance "doubling" will need to come from advances in things such as power control, 3-D gate design, chip stacking techniques, and/or integration of new materials such as non-CMOS elements like graphene.[41] Unfortunately, the cost of doing the basic R&D to overcome the physics challenges at these feature sizes is becoming increasingly expensive, making the "lower cost" portion of Moore's law difficult to sustain. Opinions within the industry vary on this issue given the significant technical challenges that lie ahead, but most believe the current strategy will allow Moore's Law to continue through the 2018-2020 timeframe. Beyond that point, the pace of Moore's Law will likely slow considerably absent a major breakthrough in materials or logic design.

Should Moore's Law slow significantly (Moore's Wall) the implications for the industry and DoD could be significant. With no new capabilities to differentiate new products, the most likely impact over time would be the "commodification" of microprocessors. Reduced chip demand would lead to an overcapacity in production, destructive competition, and reduced margins that would likely lead to a major consolidation of firms globally--similar to the current situation with commodity memory chip manufacturers. With declining margins and prospects for breakthrough advances, firms would face increased pressure to shift scarce R&D resources towards adapting existing technology to new applications vice basic research. Such reduced R&D spending by industry would remove a major source of funding for US universities, thereby weakening the culture of innovation upon which DoD depends. One additional outcome of a Moore's Wall scenario would be a narrowing of the US military's technology advantage. As leading edge chip technologies become ubiquitous, nations such as China would have a window of opportunity in which they would be able to "catch up" with the US by fielding more advanced microprocessors in front-line weapon systems.

Business Climate: One critical uncertainty facing the domestic industry is how the US government will address its current fiscal crisis. With the debt at $15.5 trillion, the deficit hovering around 9% of GDP, and gridlock the dominant force in Washington, time is running out for "easy" solutions. Should mandatory austerity measures be required to bring the debt and deficits under control, the impact on the business climate could permanently alter the nature of US industries. For example, as mentioned earlier, the US currently administers the highest corporate tax rate in the world. Should this rate go even higher to compensate for deficit spending, the pressure on businesses to move off-shore would increase substantially, especially given the financial incentives offered by our international competitors. While not directly related to our current fiscal crisis, other business climate affects such as export control laws and excessive environmental regulations could serve to accelerate the off-shoring of US semiconductor firms. As Mr. Jobs pointed out, once these firms leave, they do not come back.

One consistent theme echoed in our discussions with industry experts was the connection between R&D funding and the culture of innovation that enables US industry leadership. According to a leading US university researcher, 80% of their funding comes from US government sources. Thus far, cuts to discretionary spending, including the defense budget, have left R&D funding largely intact. However, should austerity measures force deep cuts to R&D funding, the basic research necessary to advance innovations would inevitably slow or even stop at some universities and government labs. This outcome would have a profoundly negative impact on the US industry. Without the "anchor" of a strong and innovative R&D culture to retain it, the remaining US semiconductor design and manufacturing firms would have little incentive to remain in the U.S.

ESSAYS ON MAJOR ISSUES

ESSAY 1: WORKFORCE AND HUMAN CAPITAL (EDUCATION AND TRAINING)

Introduction: The US needs to develop and retain the highly educated and technically skilled workforce necessary to maintain our technology and innovation leadership. Production has been shifting to Asia, threatening the global leadership role of the US. The Semiconductor Industry Association states their industry has a shortage of educated and skilled labor due to the US decreasing competitiveness in Science, Technology, Engineering, and Math (STEM) degrees and policies, which prohibit foreign nationals from obtaining work visas.[42] The National Security Strategy requires strengthening education to maintain competitiveness of the US workforce in a global economy.[43] Loss of global leadership in technology innovation will weaken our national security. A RAND study concluded, "Technological capability is more widely diffused to potential competitors and may provide adversaries with capability to pursue nontraditional strategies and tactics on the battlefield or through insurgency and terrorism." [44]

STEM Shortage? There is much debate about whether there is currently a shortage of human capital resources with STEM degrees to meet education and skill requirements. Some argue current shortages are driving production and innovation overseas, while others argue US salary levels have not risen significantly to drive increased demand for technical workers (see Figure 2 –

US STEM Salaries).[45] All agree that if we do not reverse the trend of decreasing STEM competitiveness, Asia will become the global leaders, which will threaten our military superiority.[46]

Based on Office of Science and Technology concerns of an aging federal workforce and a shortage of qualified replacements, a RAND study reported they "found no consistent and convincing evidence that the federal government faces current or impending shortages of STEM workers."[47] This lack of a shortage conflicts with reports received from industry representatives. The President's Council of Advisors on Science and Technology reported in February 2012 that "economic forecasts point to a need for producing, over the next decade, approximately 1 million more college graduates in STEM fields..."[48] RAND's report on US competitiveness in S&T identified underperformance of US K–12 students in STEM, and limited attractiveness of STEM careers. The report concluded the US still leads the world in S&T, but China, India, and South Korea show rapid growth.[49] As we learned during our Field Study in China and Taiwan, Asian pursuit of "Indigenous Innovation" is limited by an education model and culture which create fear of failure and risk of losing face, focus on the test, and constrain collaboration and creativity.

<u>Government and Industry STEM Education Programs:</u> In a report from the US Government Accountability Office (GAO) released in January 2012, GAO examined the effectiveness of STEM education programs administered by federal agencies. GAO found 13 agencies spent $3 billion on 200 separate STEM programs. Over 80% of the programs overlapped with other STEM programs, and agencies were unable to evaluate program effectiveness due to lack of performance measures.[50] GAO recognized current efforts by the National Science and Technology Council to develop a five-year strategic plan and inventory federal STEM education activities. GAO recommends that "as the Office of Science and Technology Policy leads the government-wide STEM education strategic planning effort, it should work with agencies to better align their activities with a government-wide strategy, develop a plan for sustained coordination, identify programs for potential consolidation or elimination, and assist agencies in determining how to better evaluate their programs."[51]

The US needs to improve our future number of students with STEM degrees. Industry is working many diverse programs aimed at improving STEM education efforts. Federal and state governments have also been actively promoting STEM efforts across the nation. In February 2012, the President's Council of Advisors on Science and Technology recommended to adopt empirically validated teaching practices, replace standard laboratory courses with discovery-based research courses, launch a national experiment in post-secondary mathematics education, encourage partnerships among stakeholders to diversify pathways to STEM careers, and create a Presidential Council on STEM Education with leadership from the academic and business communities.[52] In 2011, the National Science Foundation recommended policy makers improve K-12 STEM education by elevating science to the same level of importance as reading and mathematics and develop effective assessment systems, and improve support systems for STEM teachers to improve their effectiveness and encourage peer-to-peer collaboration, professional learning communities, and outreach with universities and other organizations.[53]

<u>Foreign Nationals' Visas and Green Cards:</u> Based on unilateral STEM education improvement efforts, there is recognition of necessity for action, but it will take sustained effort to reverse declining trends. Our foreign competitors send their most talented students to US universities for the best STEM education. Based on a US shortage of skilled employees, we need to attract the smartest students and retain them in our workforce.[54] US companies have requested reform of the process for obtaining H-1B visas and employment-based green cards. Every year only 120,000 employment-based green cards are available, although over 1,000,000 highly skilled and educated professionals apply. Within the electronics semiconductor industry, over 3,700 holders of H-1B visas are currently waiting for approval to become permanent residents, and over 500 applicants have been waiting more than four years. Some professionals have been waiting in

the EB green card system for ten years due to massive backlogs.[55] The Semiconductor Industry Association calls on congressional reform to "exempt graduates with advanced STEM degrees from US universities from the EB green card cap to allow US employers to retain foreign-born employees already working in America; and streamline the path from student to permanent resident to allow US companies to access key talent, particularly individuals educated at US universities."[56]

Conclusion: In a comparison of ICAF Electronics Industry Study reports over the past five years, there were reoccurring recommendations for reform in visas and STEM education. Visa reform has been tied-up with overall immigration reform and Congress is reluctant to open-up jobs for foreigners with current high US unemployment rates. Based on a review of the issues affecting human capital resources in the electronics industry workforce, there is government and industry consensus for reform. To protect our vital national security interest to maintain a leading edge on innovation for the future, the President and Congress need to provide national guidance and oversight for STEM education reform focused on teaching degree requirements and pay incentives, curriculum standards, progressive goals, and measurable outcomes. Although this not a current crisis, to maintain innovation in the US we need to curb the growing trend of fewer students pursuing STEM education opportunities and turning away foreigners educated in the US who can fill our technical workforce shortages. – Terrence McKenrick

ESSAY 2: SUPPLY CHAIN SECURITY FOR DOD ELECTRONICS

The breadth and scope of the US military's acquisition system, the large number of diverse military capabilities it produces, and the enormity of the supply chain required to procure, operate, and sustain these platforms pose many challenges for the DoD and its contractors. The US military's strategy and its entire range of war-fighting capabilities all rely directly or indirectly on a wide variety of systems and sub-systems comprised, in part, or entirely of electronic components. These weapons and information systems are fundamental to the way America provides for its defense.[57] Consequently, ensuring that all of these electronic components perform as intended is of vital importance to maximize mission success and minimize loss of life.

The large number of recent government reports and news accounts of counterfeit electronic parts and the risks associated with electronic component tampering suggests widespread awareness of DoD supply chain security concerns and issues. No part of the DoD supply chain has escaped the negative impact from counterfeits,[58] In fact the problem is widespread and growing. In 2011 the DoD had "1,363 separate verified counterfeit-part incidents worldwide, a fourfold increase from 324 in 2009."[59] An incident may involve a single part or larger quantities. Congressional investigations suggest the number is closer to 1800.[60] This essay discusses security issues and risk mitigation efforts associated with counterfeit electronic parts and product tampering in the DoD supply chain. It does not address risks posed by changing business economics, natural disasters, raw material limitations, theft, and similar physical security threats.

New laws, DoD-specific acquisition policies and procedures, as well as a collection of acquisition and inventory management best practices all aim to counter the counterfeit electronic parts problem, but there is no *silver bullet* to fix this issue. The most viable option is to implement these policies and procedures to form a robust, multi-facetted, defense-in-depth approach that will significantly improve DoD supply chain security in spite of the global growth of counterfeit electronics.

Military Requirements, Commercial Solutions − An Inherent Conflict: Several underlying reasons have given rise to the supply chain security issues now facing the DoD. These include:

- The introduction of the commercial-off-the-shelf (COTS) concept in the 1990s for DoD designs and procurements meant migrating away from the strict and expensive quality control efforts governed by military standards and specifications.[61]
- The globalization of the electronics industry, with its center of gravity now situated in Asia, makes it "increasingly difficult to track the trade in, and determine the pedigree of, electronic components in the complex global electronics supply chain."[62]
- The pace of technology innovation and its corresponding adaptation, along with the accompanying strong market forces, drive this globalized commercial electronics supply chain to relatively short product cycles of just a few years.
- The design and acquisition cycles of major DoD weapons systems typically last upwards of ten years, and service life cycles typically span 20 to 30 years after delivery.
- The DoD's minimal buying power in the semiconductor market provides no viable business case for manufacturers to continue producing comparatively small numbers of antiquated electronic parts.

These facts illustrate why there is strong demand within the DoD for what quickly becomes out-of-production semiconductors to support sustainment of US military systems and why the commercial market cannot be relied upon to provide legitimate replacement parts over the life span of a weapons system.

Supply and Demand Yield Easy Profits: Asia, Russia, and India export some counterfeit semiconductors, but the large majority of counterfeits come from China.[63] While China does have laws against counterfeiting, enforcement of these laws is lax.[64]

There are approximately 5,500 businesses in Guiyu, China that "[dismantle] 1.5 million pounds of junked computers, cell phones and other devices a year."[65] This massive e-waste recycling effort provides a ready source of inexpensive, used semiconductor chips and other electronic parts that form the foundation for many of the counterfeit products that plague the DoD supply chain and the global commercial market.[66] Large profit margins, as high as 2000 percent in some instances,[67] drive the counterfeit electronic parts business and provide ample motivation for counterfeiters to skirt laws and to devise ways to continually bypass existing or new anti-counterfeiting measures.

Given that this illegal enterprise makes up large portions of the economy in some sectors of China,[68] it is easy to understand the Chinese government's reluctance to shut down the source of employment for such large groups of people, regardless of its illegitimacy. Interviews conducted by the ICAF Electronics Industry Study seminar during their studies in China indicate the Chinese government is increasing its attention in this area, but results to date have been minimal and any significant progress will likely take years. Coordinated efforts to fight the flow of counterfeit semiconductors have had some success at catching some higher-profile profiteers, but have had little if any effect on reducing the problem. This illustrates that law enforcement efforts aimed at stopping the production of counterfeits at its source, intercepting these parts before they enter the US, or arresting distributors of counterfeit chips after these chips have made their way into the DoD supply chain are not sufficient to ensure the integrity and pedigree of semiconductors in the DoD supply chain. Therefore, a robust defensive posture is the only way to positively assure DoD supply chain security in the near-term.

Regulations, Guidelines, and Best Practices: There are a number of DoD procurement regulations, guidelines, strategy documents, and best practices, all aimed at addressing the problem of counterfeit electronic parts in the DoD supply chain. The most recent of these is an amendment to Section 818 of the National Defense Authorization Act for Fiscal Year 2012 that aims to comprehensively resolve many of the long-time impediments to addressing the challenge of counterfeit electronics in the DoD supply chain. [69] The 2011 DoD Program Protection Plan Outline and Guidance provides a process for managing risks associated with, among other things, "supply chain exploit/insertion"[70] and is now mandated by DoD acquisition policies. Beyond these requirements, an all-inclusive 2010 US Department of Commerce report on counterfeit electronics in the DoD[71] offers specific practices and procedures to counter the many ways by which counterfeit parts find their way into the DoD supply chain. Yet despite the magnitude of the problem and the seemingly widespread publicity it receives, few people within the affected DoD organizations seem to be aware of the associated legal requirements and liabilities, and most of these organizations do not have established policies to prevent the infiltration of counterfeits into the supply chain.[72] For these established policies to be effective, thorough coordination and communication throughout the DoD and across its relationship with industry is vitally important to ensure comprehensive implementation and to achieve the required level of supply chain security.

Trusted Sources and Other Efforts: Although there have been no publicized incidences of verified tampering with DoD electronics occurring in the supply chain, surreptitious alteration of semiconductor chips to purposely cause failure, degraded performance, or to enable espionage against the US is considered a serious threat. The microscopic circuitry and layered construction of a typical chip makes it essentially impossible to determine the chip's integrity after production. To address this problem, the DoD supply chain risk management policy requires the fabrication of specialized DoD application-specific integrated circuits (ASICs) be provided by accredited suppliers.[73] There are two options, previously established under the DoD's Trusted Foundry Program, that enable DoD acquisition and sustainment programs to help meet these requirements. The Trusted Access Program Office (TAPO), managed by the National Security Agency, acts as a design consultant, a testing facility, and a packaging provider that employs a contract with IBM to design (if necessary) and manufacture critical and highly sensitive ASICs and other semiconductors with a "certified chain-of-custody."[74] The Defense Microelectronics Activity (DMEA) manages a collection of agreements with, and access to, a group of 51 accredited, trusted semiconductor fabrication facilities. They can search existing inventories of parts, identify a suitable substitute part,[75] or produce limited quantities of original semiconductors for designs that are no longer procurable.[76]

There are several policy, procedure, training, and standards initiatives underway to improve supply chain security, as well as R&D efforts that are exploring technology-based methods to foil semiconductor counterfeiters and provide the means to verify chips' authenticity, easily and repeatedly, throughout its travels in the supply chain.[77]

Conclusions: The scourge of counterfeit electronic parts and products across the globe is widespread and pervasive and its impact on the DoD supply chain is costly. The risks for mission failure, equipment failure, and the risks to human life caused by counterfeit electronics parts are significant and the threat posed by product tampering in the DoD supply chain is equally so. ICAF Electronics Industry Study papers from the past five years have all embraced similar strategies aimed at enhancing supply chain security – developing revised acquisition requirement and creating comprehensive supply chain risk management being primary among these recommendations. Our research indicates these efforts have generally been accomplished but widespread adaptation remains as the key for likely success. While none of the DoD policies, practices, and capabilities can individually mitigate all of the risks, collectively they offer a robust solution to a complex and persistent problem and the best hope for successfully securing the DoD supply chain against counterfeit and adulterated electronic parts. The key element for achieving this critically important goal is underscoring the need for thorough implementation of, and strict adherence to, all of these policies and best practices throughout the entire DoD acquisition and sustainment enterprise.

– Mark Lewis

ESSAY 3: US INNOVATION AND TECHNOLOGY LEADERSHIP

Innovation is "the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method in business practices, workplace organization or external relations."[78] A review of the applicable literature provided insight into key factors that support innovation in industry, and in government. In "Sustaining US Economic Growth," the authors looked at growth in the US economy in general, and in the IT industry specifically, and attributed it to three commonly accepted economic factors. These three factors were human capital, physical capital, and ideas.[79] Of the three, they suggest that ideas (also termed technology leadership) were most responsible for contributing to growth, but at the same time were also least likely to be positively influenced by government policy.[80]

A review of trends in US innovation and technology leadership provides very consistent findings. While the US is still a key player in global innovation, the effects of globalization and increased competition have meant a significant loss in US innovation and technological leadership, and ultimately market share over the last twenty years. This is important, because innovation and technology leadership have historically been the foundation of US economic growth, job creation, and national security.[81] Government and university R&D has been critical to the US as a technology leader and pacesetter. It pushes the performance envelope, and provides the innovations for tomorrow.

The US funds nearly fifty government laboratories, clearly showing an understanding of the significance of investment in R&D. Understanding the importance of being the engine of innovation and technology leadership, the US established DARPA in 1958. DARPA's mission is to prevent strategic surprise from negatively impacting US national security and create strategic surprise for US adversaries by maintaining the technological superiority and revolutionary change for the US military.[82] In fact, DARPA invented the Internet, which today makes up 4.7 percent or $684 billion of the US economy and provides a $4.2 trillion global opportunity per CNN Money.[83]

In addition to the US government, there are many examples of American firms like Apple, Intel, Google, Microsoft, Facebook, Twitter, Texas Instruments, and IBM that have shown world class technology leadership. The US technology leadership in both the government and commercial sectors is without equal. Examples including the personal computer, social media, the semiconductor, and the smart phone all illustrate America's track record of technology leadership in the world.[84]

However, in 2009, the Information Technology and Innovation Foundation (ITIF) published a report measuring the "global innovative-based competitiveness" of forty developed nations.[85] In the ITIF report, the US ranked sixth of the countries surveyed for "global innovative-based competitiveness, having fallen precipitously from a solid first place in 2000."[86] If this ranking was not disconcerting enough, they also found that the US ranked last of the forty nations for improvement in "international competitiveness and innovative capacity" over the previous decade.[87] The ITIF follow-up report in 2011 confirmed the 2009 findings and added several additional measures of innovation and supporting factors to the ranking. The US now ranked fourth of the forty-four developed nations investigated for innovation, a finding that would have been consistent in 2009 had that study used the additional measures. [88] More critically, the US placed second to last for rate of change in innovation from 2000-2011, and twenty-seventh for rate of change from 2009-2011.[89] The report highlighted several U.S strengths among the factors, including business investment in R&D (5th), eGovernment (2nd), business climate (4th), GDP per working adult (1st), and labor productivity (3rd); and several US weaknesses including effective corporate tax rates (35th), trade balance (37th), and foreign direct investment (34th).[90]

An annual study called "The Global Innovation Index (GII)" used a composite index of more than twenty factors to rank countries according to their innovative capabilities and support for innovation.[91] In the 2011 report, the US ranked seventh of 125 countries measured, moving up from eleventh in the 2010 report.[92] However, this ranking was largely due to high placement on output measures. On the five combined measures of enablers of innovation (inputs), the US placed thirteenth or lower on four out of five measures (institutions, 15th; human capital and research, 13th; infrastructure, 14th; market sophistication, 4th; and business sophistication, 15th). The GII methodology also called for averaging the average of these five factors with an average of the two output factors (scientific outputs and creative outputs), camouflaging the fact that without the weighting, the US would have finished much lower (below the top ten) on a measure of only the innovation enablers.[93]

In addition, looking further at the GII measure of human capital and research is particularly instructive. This measure is comprised of three sub factors: elementary and secondary education, tertiary education, and research and development. Leaving aside the measure of research and development to focus on the education measures, the US ranked thirty-sixth on the measure of elementary and secondary education, and forty-sixth on tertiary education.[94] This is consistent with the concerns expressed in several other studies about the continued malaise in US education. In fact, a recent study by McKinsey & Company concluded, "educational achievement gaps impose on the United States the economic equivalent of a permanent national recession. The recurring annual economic cost of the international achievement gap is substantially larger than the deep recession the United States is currently experiencing."[95] They go on to point out the US is lagging significantly behind its first world competitors on most measures of educational success, particularly those in the STEM disciplines. This includes ranking 25th of 30 nations in math and 24th of 30 in science.[96] In addition, over the last forty years the US has dropped from leading the developed nations in high school graduation rates to ranking 18th out of 24 countries measured today.[97] A similar, but more precipitous drop has occurred in US college graduation rates, dropping from ranking first in 1995 to fourteenth in 2008.[98] Although the performance trend indicates significant challenges with US STEM development, the US university system is widely considered as the best in the world and the location of choice for advanced education and university research.

Another serious trend noted in the studies is the decline in US R&D investment. As the NSF noted in its 2012 report on global R&D investment trends, "R&D expenditures can be viewed as long-term investments in innovation."[99] While the US has long led the world in investment in R&D, over the last decade that lead has declined significantly. Since the 1960s, US investment in R&D as a percentage of discretionary spending has fallen from a high of 17 percent to just over 9 percent in 2008.[100] In addition, the US lead in R&D investment is rapidly closing as China and other emerging economies rapidly increase their public funding. China, in particular, is increasing investment in R&D by twelve percent annually, more than seven times the rate of growth in the U.S.[101]

The mix of US R&D investment is also an important factor. While US investment in R&D has remained relatively constant as a percentage of GDP since the 1960s, the composition of that investment has changed significantly. In 1960, government funding was more than 65% of US R&D spending, while industry contributed less than 35%. Since then the government share has steadily decreased, and been replaced by an increase in industry share. Today the exact opposite is true; by 2008, the government share had shrunk to less than 30% of total R&D expenditures while industry was responsible for nearly 70% of funding.[102] While serious on its face, this statistic also hides another critical issue. Industry targets its 70% of US investment on development and commercialization of incremental product improvements designed to give them commercial advantage, and not at the innovative, high-growth, job-creating technologies of the future that have been the drivers of US national success. In fact, fully 80% of industry funded R&D is focused on development, with only 20% going to basic and applied research. This statistic is reversed in self-funded R&D performed by universities and colleges, with more than 80% of funding going toward basic research. US government R&D funding is a mix with approximately 40% going towards basic research, 20% to applied, and the remaining 40% to development, predominantly of Defense programs.[103] This is an important fact because basic research generally delivers the breakthroughs in technology innovation that have traditionally fueled US economic growth.[104] Government investment is clearly a critical addition to investment by universities and colleges to fund the basic and applied research that industry is unwilling or unable to.

As the ITIF report noted, the US is also suffering from reduction in its ability to compete because of increased business costs. This has the result of hurting the US balance of trade, and reducing direct foreign investment. "The US has aggregate structural costs that are 17.6 percent higher than those of its nine largest trading partners, putting US companies at a significant disadvantage."[105] A Manufacturing Institute study conducted in 2006 and updated in 2008 identifies the single factor that is responsible for the US structural cost disadvantage, a corporate tax rate higher than that of the nine largest US trading partners by nearly 8%.[106]

Historical data clearly shows US is still a leader in innovation and technology leadership. However, unless the US makes changes in the supporting factors it is doomed to continue the downward spiral of the last twenty years. By taking decisive action now, the US can maintain its leadership role in technological innovation and restore this important underpinning of our national economy and national defense. – Anthony Davis and Jessie Showers

ESSAY 4: THE FUTURE OF SEMICONDUCTOR TECHNOLOGY

The world, and the US in particular, has benefited immeasurably from the continuous improvements in computing performance enabled by silicon-based ICs. This technology has strengthened the US economy, and enabled the country to develop the unrivaled capabilities required to deter persistent threats and secure national interests. However, despite a concerted industry effort, the technology that has under-pinned this enhanced performance since the mid 1980s is rapidly approaching its physical and practical limits. Promising new technologies exist, but none are likely to mature to the extent necessary to replace silicon-based, microprocessor chips for at least another ten years. In the interim, chip designers will pursue innovative techniques to enhance the computational performance of existing ICs, while development teams vie to perfect a successor technology. The nation that succeeds in this endeavor may well hold a near-term comparative advantage economically and potentially even militarily. Therefore, the remainder of this section will explore the relevant trends in semiconductor technology, and present recommendations for sustaining an environment that promotes cutting-edge R&D.

Issue – Maintaining a Domestic Industrial Base for Integrated Circuits: Over time, much of the advanced manufacturing capability for ICs has moved overseas in response to both foreign incentives and a shift in the consumer electronics market towards Southeast Asia. This trend in foreign manufacturing of state-of-the-art electronics poses economic and national security concerns for the US. Unfortunately, the only thing that can counteract the market forces driving the current commoditized product towards the Asia Pacific is a disruptive technology that negates the advantages of current silicon-based ICs. That fact has not been lost on the world's emerging economic powers. Already, research teams around the globe are competing to be the first to develop the leap-ahead technology that could propel a nation to world prominence.

Challenge – End of the Road for Current Technology, Uncertain Path Ahead: The transformative effect of information technology (IT) would not have been possible without the sustained improvement in computing performance brought on by Moore's Law. As a result, computers and computer networks have now permeated virtually every sector of our society. Today's pervasive IT infrastructure enables innovative ideas to flourish and enhances productivity, which generates revenue and fuels the demand for more capable systems. This cycle has spawned a global semiconductor industry that generates over $400 billion annually, and supports the broader trillion dollar consumer electronics industry. Sustaining this huge economic engine requires continued improvement in computing performance.[107]

The Moore's Law projection of increasing chip density, in combination with the prevailing trend in faster clock speeds, enabled single-processor performance to grow at a phenomenal rate. From the late 1980s onward, microprocessor performance grew at a rate of more than fifty percent per year.[108] However, by the beginning of the 21st century, it had become apparent that processor performance was facing major design constraints. Faster clock speeds and more complex circuitry were combining to dissipate several hundred watts of power per system. For the first time since it was widely adopted, complementary metal oxide semiconductor (CMOS) technology was resulting in the generation of more power than could practicably be dissipated in mass market computing devices. As a result, the growth of single-processor performance essentially leveled off.

As power constraints began to impede the pace and effectiveness of CMOS based scaling, the electronics industry responded by developing new techniques for maximizing the full potential of each new chip design and thus, continuing the trend of increasing computing performance though at a lower rate. Today, getting the most out of state-of-the-art IC designs requires incorporating new system functionality in the package, or on the chip, and linking multiple chips together in parallel chip-multiprocessors. This "More-than-Moore" (MtM) approach will become an increasingly important component of the industry's strategy to enhance performance and spur market growth at least until a successor to CMOS is developed. However, it can't sustain the industry in the long run.[109]

Consequently, the quest is underway to develop the technology that will restore the rate of improvement in computing performance witnessed in the second half of the 20th century. A considerable amount of R&D has been focused on exotic materials such as germanium, gallium nitride and graphene based structures. While these advanced materials have the potential to greatly increase chip performance, they all use the same CMOS technology as current silicon based semiconductors. As a result, exotic materials may help sustain the industry in the near term, but are not likely to significantly alter the competitive game going forward.

Quantum tunneling transistors are a game changing approach that has recently gained some attention. However, slower predicted processing times will likely limit the wide-spread applicability of quantum technology.[110] Another approach, and area of considerable research, involves the use of electron-spin-based devices (spintronics) rather than charged based devices (electronics). Nevertheless, like other promising technologies, large fundamental and practical problems remain to be solved before spintronics systems can be considered as a replacement for CMOS. Even then, given the complexity of today's chips, it may take decades to introduce any new logic device into volume production.[111]

Implications – National Security Concerns of Foreign-made ICs: As technology matured, ICs became commoditized and manufacturing capability began to consolidate into a small number of highly specialized firms, many of which are located overseas. The off-shoring of advanced IC manufacturing capability presents a significant threat to US national security from both a quality assurance and technology leadership perspective. Although defense contractors rely on advanced microprocessors to control the complex electronics in today's cutting-edge military hardware, those chips are increasingly produced overseas where it is difficult to guarantee the integrity of product. Foreign providers have been known to ship counterfeit products, and could potentially build harmful or even deadly features into a circuit package. Increased reliance on foreign manufacturing also threatens to undermine the US's technological advantage. Experience has shown that there is a synergistic relationship between manufacturing and technology innovation. As more and more production moves overseas, the US runs the risk of losing the research and development capabilities that generally support manufacturing efforts.

Opportunities – Strengthening the US Position on the Strategic Game Board: As previously discussed, there is no clear-cut winner in the race to identify the technology that will eventually replace CMOS in IC chips. Several technologies are currently being researched, each with its particular strengths and weaknesses. What is needed most in this environment is a sustained commitment to basic research. Appropriate government incentives, such as a permanent R&D tax credit, would help to sustain industry's substantial commitment to R&D.

Effective research and development requires subject matter expertise. Unfortunately, much of that expertise is currently coming from foreign-born students in American universities. The US essentially opens its doors to the best and brightest from across the globe, but then rapidly closes the door shortly after foreign nationals complete their degree requirements. Rather than have talent return home where their expertise benefits a foreign country, graduates should be granted H1-B visas to remain in the United States, where their expertise is highly desired.

The US must also realize that it is embroiled in a fierce competition for industrial technology and manufacturing expertise. The world's emerging economic powers have made it a matter of national priority to attract high-tech industries, and the semi-conductor sector in particular. Foreign governments are offering substantial incentives to lure companies to re-locate facilities overseas. The US should consider measures, such as a more globally competitive corporate tax rate, to ensure domestic manufacturers are not disadvantaged by US-based operations.

Conclusions: Over the past five years, ICAF Electronics Industry Study groups have reached very similar conclusions - in order to secure its future economic and national security interests, the US must cultivate an environment that promotes cutting edge R&D and nurtures business development. In pursuit of these goals, the US should adopt a permanent R&D tax credit, offer more H1-B visas to foreign-born US graduates, and reduce the corporate tax rate to a more globally competitive level. Adopting these measures will promote US interests by helping to guarantee that the next Silicon Valley is not located in a global competitor's technology development park. – Vince Malone

GOVERNMENT GOALS AND ROLE

Goals: The government goal with respect to the electronics industry is to create a level playing field that better enables US companies to compete in the global market place. The global marketplace is a reality and is here to stay. Countries will interact with each other, and produce goods and services in the marketplace in accordance with their comparative advantages. We should attempt to maintain those comparative advantages that are vital to our national security—whether they are specifically related to our defense, or related more broadly to the health of our economy. For the electronics industry the US comparative advantage is in innovation and semiconductor design. To maintain this comparative advantage several policy recommendations must be implemented.

Policy Recommendation #1 – R&D Tax Credit and R&D Funding: The primary driver for innovation is a strong program for R&D. It has two components: basic research and applied research. Basic research is typically focused on next generation technology that normally does not have payoff in the near term. It is typically funded by the government and it is conducted in government laboratories and universities. Applied research is typically focused on advancements of current technology to the next level and is funded by industry to make improvements on products currently in the market. In order to spark continued R&D in both areas, the government should increase funding for basic R&D and provide a permanent tax credit for applied R&D. To further incentivize corporations to conduct R&D in the US, the corporate tax rates should be lowered to a globally accepted rate that will keep corporations within the U.S. and draw others back. This recommendation is similar to past ICAF class recommendations for both permanent R&D tax credit and tax incentives to keep this industry from moving off-shore. While the Obama administration has not declared a tax incentive specifically for the electronics industry, it did announce, in February 2012 a proposal to reduce the corporate tax rate from 35 percent to 28 percent. This rate would put the US in line with other advanced countries, help encourage greater investment in the US, and reduce the tax-related economic distortions. At the same time, however, this proposal promises to reduce the number of tax loopholes that companies were using to lower their effective tax rate. The final result is unclear. Additionally, the government has funded two new initiatives: the Nanoelectronics Research Initiative (NRI) and the Focus Center Research Program (FCFP) to utilize government, industry and universities to come up with innovative research solutions for the electronics industry.

Policy Recommendation #2 – Export Control: For many years, numerous reports and studies (to include previous ICAF industry studies) have highlighted the need for smarter export control policies that (1) bring our export controls in line with the realities of today's global economy, and (2) promote cooperation among our allies. The Department of Defense, specifically the Under Secretary of Defense for Acquisition, Technology, and Logistics' Deputy Assistant Secretary of Defense for Manufacturing and Industrial Base Policy , should fully engage and stay engaged with the Department of Commerce as it implements President Obama's Export Control Reform plan. The Administration should approach Congress with a unified voice, especially as it gets closer to making recommendations that require Congress to enact changes to current law. The key area of focus right now is to work with Department of Commerce and industry to move certain overly-restricted items from the U.S. Munitions List to the less-restrictive Commerce Control List. Several categories of equipment have already been reviewed, along with Category XI, Military Electronics, is due to be reviewed in the near future. We should keep in mind that semiconductors impact multiple categories of equipment (for example, VII: Tanks and Military Vehicles, VIII: Aircraft, and XV: Spacecraft). Furthermore, DASD/MIBP should investigate the Department of Commerce's two new export reform control fusion cells in order to determine their applicability to DoD. These cells, which were created in March 2012, are the Export Enforcement Coordination Center (E2C2) and the Information Triage Unit (ITU).

Policy Recommendation #3 – Supply Chain Security: While supply chain security is an issue for the entire electronics industry, the DoD is more vulnerable to counterfeit chips due to the incorporation of older technology that is sometimes hard to acquire. The DoD must be involved with the effort to attack the problem. USD(AT&L) should work to ensure 100 percent compliance with all DoD regulations and that GAO best practices are applied across the acquisition and sustainment communities to ensure procurement policy requirements and established best practices to mitigate the risks associated with counterfeit parts. The DoD should continue funding for the Trusted Foundry Program. Additionally DMEA and TAPO leadership must undertake a communication campaign to better educate the DoD acquisition community regarding their unique capabilities to counter both the counterfeit threat and the threat of product tampering, sabotage, and espionage. While the 2012 NDAA provides language that puts more responsibility on our contractors to mitigate the risk of counterfeit parts, a holistic government/industry look at the US e-waste problem will provide comprehensive help to reduce the counterfeit problem. This would require creation of a business model to recycle or dispose of e-waste within the US thereby reducing the source of raw materials for counterfeit parts. Furthermore, the Administration should continue to use strategic and economic dialogue to pressure the Chinese government to take meaningful steps to eradicate their illegal counterfeit semiconductor "industry."

Policy Recommendation #4 – Human Capital: We lose too many highly-desired foreign graduate students after they earn their degree. This not only deprives the US electronics industry of a source of new ideas, but also encourages these graduates to take their new-found knowledge home in order to start putting it to use with companies (competitors) back home. The US government should establish a policy to exempt US University graduates with advanced STEM degrees from employment-based green card cap. Furthermore, in order to encourage the individual to stay in the US, the government should streamline the path from student to permanent resident. These policies should be periodically reviewed in order to reassess the availability of US citizen STEM graduates and the market for employment opportunities. At the same time, we should not solely rely upon foreign STEM graduates to maintain our innovation capabilities. The Administration and Congress must provide national guidance, oversight, and resourcing for STEM education n reform. These efforts should focus on teaching degree requirements and pay incentives, curriculum standards, progressive goals, and measurable outcomes.

CONCLUSION

The global semiconductor industry is at a self-determined "inflection point" where the progress of cutting edge development will face physical scaling challenges down to the atomic level. Predictions in accordance with Moore's Law are coming to a head and industry experts predict that they will be able to operate along the two year doubling trend for about the next six to eight years. With current transistor size and composition at 22 nanometers, the next few cycles of scaling if achieved could reach the size of just a few atoms. The semiconductor is the number one grossing US export and the US led the industry for the last 50 years, but has steadily declined about 10 percent of the global market in the last two decades. However, coupled with the current global economic downturn, these leading edge challenges in turn will have significant impacts on industry structure, both domestic and global, and may further erode US dominance. The seminar examined key areas of the global semiconductor industry through research and group engagement with several sectors represented in the defense industrial base, domestic semiconductor industry, global semiconductor industry and the DoD.

During this semester long research effort, the several issues documented over the past five reports were reassessed and current state and emerging issues were researched. With research and development pushing the bounds of atomic structures, current progress may define the final decade of US dominance in this vital industry, which is a cornerstone of US national security. This "inflection point" provides a key decision window in which the US government can take measures to strengthen the viability and future competitiveness of the US semiconductor industry. The current report addressed opportunities and threats in the semiconductor supply chain, emerging technologies and innovation, workforce and human capital, technology leadership, government roles and responsibilities and current challenges and future outlooks. The spectacular headlines of counterfeit parts, cyber threat and decline in American STEM levels are becoming all too common. The US remains the leader in the semiconductor industry, is recognized as the premier educational system, is the recognized leader in innovation and R&D and maintains the most sophisticated military in the world. Despite these great successes, the semiconductor industry continues to migrate off-shore and the remaining domestic capabilities continue to experience significant stress. US policy efforts should address those factors affecting the US industry decline, supporting R&D and eliminating threats to DoD supply chains. The US has the innovative edge and vast resources to sustain its lead in the semiconductor industry against any competition. The current fiscal challenges will further compound efforts to find a simple solution. The old approach of just "throwing more money at it" will not make these challenges go away. Focused efforts across government agencies and departments can provide the semiconductor the policy and fiscal support it needs to define the direction of the global industry beyond the current inflection point.

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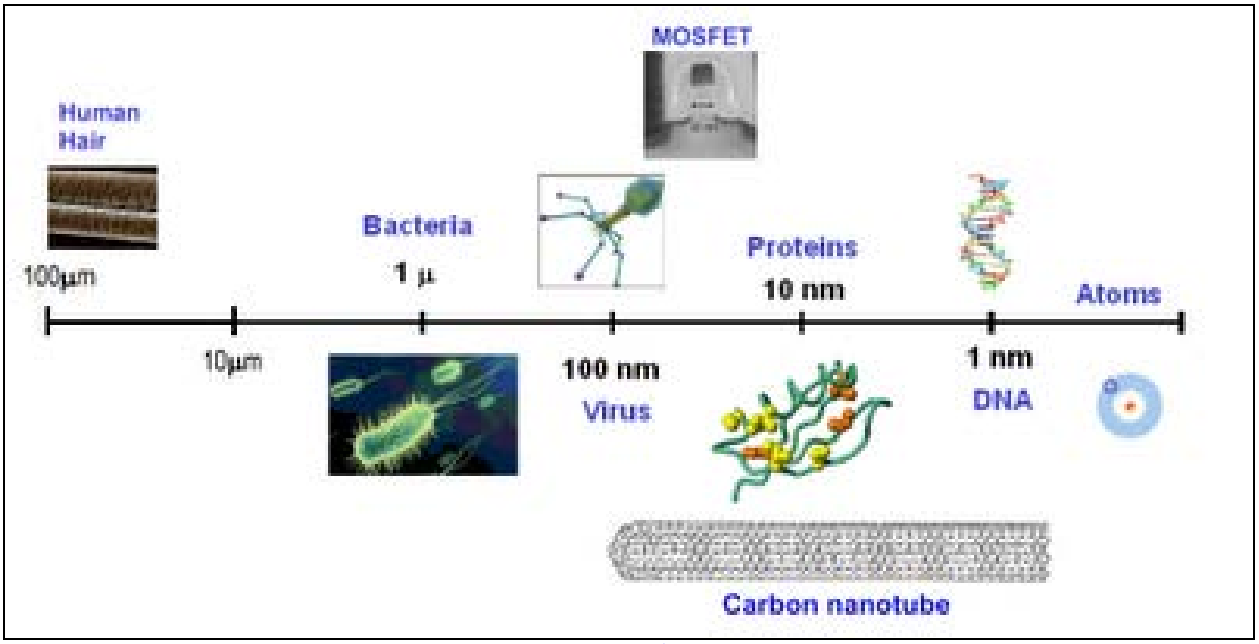
FIGURES



Source: www.fastsignals.blogspot.com

Figure 1. Transistor Size Comparison

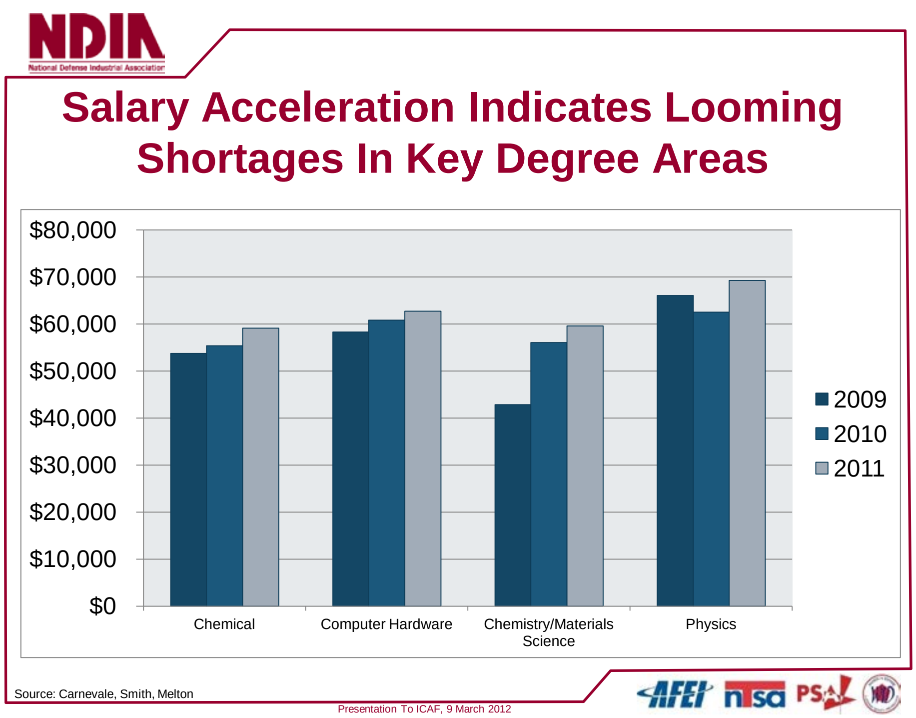


Figure 2. US STEM Salaries

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
US	United States
WWII	World War II

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