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<u>The Dwight D. Eisenhower School for National Security and Resource Strategy</u>
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ELECTRONICS 2013

ABSTRACT: The Eisenhower School Electronics Industry Seminar analyzed the domestic and international industries that support the research, design, and manufacture of semiconductors for use in current and future electronic systems. Our findings include the continued dependency and declining influence of Department of Defense (DoD) over the consumer-driven, commercially-dominated microelectronics industry, obsolescence problems caused by incorporating microelectronic components with 18-24 month life cycles in DoD weapons systems designed to last for decades, the continued challenge of counterfeit parts, and the difficulties of accessing leading edge technologies in an era of declining resources. Recommendations to address these findings in priority order include: designate a lead office within DoD to champion informed life-cycle cost decision making for microelectronics; reduce counterfeit supply and demand by improving supply chain security; ensure access to leading edge and aging technologies by incentivizing use of the Trusted Foundry and trusted suppliers; preserve U.S. Government (USG) investment in research to maintain the U.S. technological edge and economic advantage; and invest in human capital to ensure a skilled workforce. USG and DoD leadership efforts to strengthen the semiconductor industry will drive continued innovation and advanced capabilities, economic prosperity and, ultimately, national security.

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Semiconductor Industry Association (SIA), Washington, DC
Defense MicroElectronics Activity (DMEA), Sacramento, CA
Electronic Design Automation Consortium (EDAC), Sunnyvale, CA
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Intel Corporation, Santa Clara, CA
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INTRODUCTION

"Innovation distinguishes between a leader and a follower." Steve Jobs (2006, as Apple's CEO)

This paper documents a critical analysis of the U.S. electronics industry with a focus on the semiconductor sector by the Electronics Industry Study at the Dwight D. Eisenhower School for National Security and Resource Strategy, Class of 2013. 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, New York, and Silicon Valley (California). The electronics industry is the foundation for a strong U.S. economy, and microelectronic innovation has sustained the U.S. as a global economic and military leader, advancing performance capabilities and strengthening our national security. This paper describes the electronics industry with a focus on semiconductors and circuit manufacturing, analyzes the current conditions and future outlook, and highlights five challenges: microelectronics life-cycle costs and sustainment, obsolescence, supply chain security, tax policy and a trained workforce. By critically examining the challenges, we offer policy recommendations for strengthening the U.S. electronics industry and, ultimately, our national security.

The electronics industry has been a reliable source of economic welfare and a leading American export for the last few decades. The industry's ability to create innovative technologies has been the foundation of economic growth, relatively low unemployment, and ultimately, a key enabler for national security. The U.S. electronics industry provides a model for U.S. industrial prosperity and growth through American innovation and the practical application of scientific discovery. National defense has benefitted from these technological innovations. Semiconductors are imbedded within every major weapon system. However, the Services and Department of Defense (DoD), working primarily with prime contractors, have limited influence over selection of subcontractors and the resulting semiconductor supply chain. These layers inject uncertainty and risk into DoD weapon systems and capabilities.

The industry overview and analysis that follow seek to provide an insight into the nature of the challenges for the electronics industry and recommendations to posture the U.S. and the DoD for success. This analysis makes use of Michael Porter's "Five Forces" framework to help understand the competitive forces shaping the industry and assess the strategic business strategies of leading U.S. firms for vitality now and over the next 15 years, as part of the defense industrial base.

THE SEMICONDUCTOR INDUSTRY DEFINED

The semiconductor is at the heart of the electronics industry, and the North American Industry Classification System (NAICS) has coded the industry as 33441, "Semiconductor and Circuit Manufacturing."[1] According to IBISWorld, a provider of industry-based research, the industry includes "firms engaged in manufacturing semiconductors and related devices and parts" in products such as integrated circuits, memory chips, microprocessors, diodes, transistors and other optoelectronic parts.[2] The primary innovation rule of thumb for the semiconductor industry is Moore's Law, originally a 1965 prediction by Gordon Moore. It predicts that the number of transistors can be placed on the same size chip doubles every 18-24 months, doubling processor performance at a cost equal to or lower than its predecessor.

As the United States' second largest manufactured export,[3] the semiconductor plays a critical role in the health of the U.S. economy, forming the foundation of America's $1.1 trillion dollar technology industry affecting a U.S. workforce of nearly 6 million.[4] Today's military weapons are high-tech systems with semiconductors at the heart of their design and performance. In the early years of the semiconductor industry, DoD was a driving force behind research and development (R&D). As the industry matured and consumer electronics became commonplace, the role of DoD in funding and guiding semiconductor R&D diminished. The semiconductor industry is considered mature, with very high revenue volatility, high capital intensity, medium regulation level, high barriers to entry, revenue growth at pace with the economy, a stabilized number of companies, established technology and processes, and market acceptance of products and brands.[5]

Semiconductor production can be subdivided into six phases: design, semiconductor equipment and materials, manufacturing (more commonly known as fabrication), assembly and test, customer support, and after-market supply. Each phase is critical to producing semiconductors and supporting DoD weapon systems. Some firms work in more than one phase. The process begins with the design of the integrated circuit and production masks utilizing intellectual property and computer aided design software. The equipment and materials include silicon, aluminum, lead and other raw materials to produce integrated circuits (IC), as well as the high-tech equipment to etch, place and layer the components on wafers. Manufacturing is the production of ICs on silicon wafers. Assembly and test consists of placing individual ICs into the customer's requested product and testing it against design specifications. Customer support includes the warranty and contractual servicing of the end product, which can be the actual hardware or a service solution. Finally, after-market suppliers are needed to sustain products through their life cycles.

Two major categories of ICs are used by DoD: Application-Specific Integrated Circuits (ASICs) and Field Programmable Gate Arrays (FPGAs). This analysis finds the global semiconductor industry to be healthy growing but not without risks. Additionally, the globalized nature of this industry poses some threats to the security of DoD weapon systems through counterfeiting, tampering and espionage.

CURRENT CONDITIONS

The financial crisis of 2008-2009 caused the price of semiconductors to decrease by 3.2% as the market contracted with reduced sales.[6] However, the global demand for semiconductors will increase as consumers demand computing power in more and more products along with the economic recovery.[7] The demand for increasing performance of smaller, cheaper and reliable electronic devices drives the evolution of products within the semiconductor market. Demand for semiconductor devices will be further fueled by the proliferation of cloud computing and the development of computational systems that perform predictive analysis and data mining of voluminous, complex data sets, i.e. Big Data.

Within the industry, companies have chosen different structures and strategies to produce integrated circuits and memory chips. One structure type is a vertically integrated company, also called integrated design manufacturers (IDM), which owns most of the chip-making process from design to test. Examples of these companies include International Business Machines (IBM), Intel and Micron. A second type of structure is when a firm concentrates on the fabrication of ICs designed by other firms. These firms are called pure play foundries. In the U.S. pure play foundries include GLOBALFOUNDRIES [8] and IBM's Trusted Foundry. Additionally, aftermarket suppliers Rochester Electronics and Lansdale Semiconductors produce obsoleted ICs. The third type of company structure is a company that designs ICs for external manufacturing, i.e. "fabless" design companies. The preponderance of companies in the U.S. are in this category and include Altera, AMD, Broadcom, NVIDIA and Qualcomm. The two leading U.S. IDMs, IBM and Intel, were both profitable in 2012. For the last 5 years their average return on invested capital (ROIC: net income minus dividends divided by total capital) was 20.14 and 17.31, respectively.[9] The 5-year average ROIC is 24.60 for the semiconductor industry and 16.50 for the technology sector.[10] A ROIC above 10 is considered good and in indication the industry is creating value. The majority of U.S. semiconductor companies are "economically healthy" with a ROIC above 10, but there are other companies that are not creating value and operating with ROICs below 10.[11]

The diversity of business models within the semiconductor industry has brought a high level of innovation to the electronics industry. The IDM and Fabless companies such as IBM, Intel, and NVIDIA are investing large quantities of money to make chips smaller, more complex with more specialization while consuming less power in order to differentiate their products, and therefore gain some pricing power in a niche market. Without differentiation, companies are limited to merely selling commodities and accepting the price set by market forces which might not cover the average fixed and variable costs. Fixed costs are significant—the start-up costs to build a new manufacturing plant to produce 300 millimeter (mm) wafers with 22 nanometer (nm) geometry is estimated at $5 billion with an expected life cycle of 3-5 years.[12]

American companies in this industry rely heavily on patents, trade secrets, and licensing agreements to establish and protect proprietary technology and new product innovations.[13] For a company to develop new products, it typically must sustain high levels of R&D expenditures, which results in increasing operating costs. Semiconductor firms typically spend about 20% of revenue on R&D—a higher level than in almost any other industry in the US.[14]

IDMs, pure play foundries and equipment manufacturers are assessed to be oligopolies, which can exert some pricing power. Fabless design firms exhibit monopolistic competition with a large number of firms, differentiated products and low barriers to entry.

In an industry of $292 billion in global revenue, the U.S. captures about 50% of the total market revenue.[15] Looking at the semiconductor segments, IDMs earned $219 billion in revenue,[16] fabless design firms earned $73 billion in revenue, and pure play foundries earned $39.3 billion in revenue.[17] Looking at the supporting segments, semiconductor equipment and material firms earned $37.8 billion in revenue, and we estimate U.S. companies captured 40% of the global market;[18] assembly and test earned $24.5 billion in revenue, and we estimate U.S. companies captured 15% of the global market;[19] and electronic design automation earned $6.1 billion in revenue, and we estimate U.S. firms captured 80% of the global market.[20] The compound annual growth rate (CAGR) for the entire industry from 2007 to 2011 was 1.7%.[21] In comparison, the European market declined with a compound annual rate of change of -3.6%, and the Asia-Pacific market increased with a CAGR of 1.4%, over the same period. Marketline analysts forecast a CAGR of 7.3% through 2016 to grow the global semiconductors market to $524.6 billion—an increase of 42.3% since 2011.[22]

Over the past 5 years, the U.S. share of global semiconductor production capacity has been eroded by foreign producers investing in fabrication facilities (fabs). Overall, the U.S. semiconductor industry accounts for roughly 18% of the semiconductors produced in terms of volume for the global market. In fact, Asia produces 67% of the semiconductors on sale in the global market, Europe currently produces 11%, and the remaining 4% belongs to companies located in the Middle East and Africa.[23] In the past, U.S.-based companies outsourced manufacturing of lower-value semiconductors to countries like Korea, Singapore, Taiwan and China. A few of these manufacturers have expanded their capabilities and now act as full-fledged semiconductor designers, creating more opportunities and additional jobs, as well as attracting new capital.[24] In the 5 years to 2013, imports to the U.S. have increased in value at an annualized 9.8% to $45.5 billion, and China (accounting for 15.7% of industry imports), Costa Rica (15.6%), Malaysia (14.0%) and Taiwan (9.6%) are the largest sources of imported semiconductors.[25]

Not only are U.S. semiconductor imports rising, but U.S.-based fabrication facilities have faced falling exports due to competition from these Asian manufacturers. In 2013, U.S. exports are expected to account for an estimated 35.2% of revenue, down from 55.6% in 2008.[26] The movement of fabs from the U.S. to overseas locations should be a concern to policy makers, because semiconductor expertise, jobs and R&D investments are following the fabs.[27] Another potential downside to losing a U.S. fabrication capability is the potential loss of intellectual property when fabless designs are sent overseas. When questioned about this concern, industry representatives explained safeguards to limit IP transfer and their decisions to limit overseas production to older technologies. The increasing priority of safeguarding IP might also motivate Intel to incorporate a "pure play foundry" strategy as it manufactures chips for Altera and discusses production opportunities with Apple.[28]

Porter's Five Forces

To explore the structure of the semiconductor manufacturing market, we used Michael Porter's five forces model. Porter's five forces include rivalry among existing competitors, bargaining power of buyers and suppliers, threat of new entrants and threat of substitute products and services.[29] **Competition** within the industry varies based on the number and concentration of firms and their domestic and international locations. Starting with electronic design companies, three U.S. companies dominate the industry, yet each firm has differentiated its software and services to create market niches and command more than 50% of their market niche. For IC fabless design companies, there are many firms and competition for market share is fierce. Leading edge firms differentiate by delivery assurance and feature size to gain market share and create value; however, as the products become commoditized, the firms shift to price competition which diminishes returns. Foundries and IDMs possess some control over prices for leading edge products. Rivalry is high, and leading edge semiconductors enjoy a brief period of pre-eminence before they are outpaced by the next, better-performing product.

Buyer power in the semiconductor market is moderate, depending on the age of the technology requested by customers. Initially, **buyers** have little pricing power over a new semiconductor technology. However, as time turns the product into a commodity, buyers gain power for the period until the manufacturer discontinues the product. Buyers, again, lose pricing power as a semiconductor technology ages and becomes rare. This is an issue for many DoD weapon systems as DoD often extends weapon's service timeline and original equipment manufacturers (OEM) no longer produce replacements. The cost of extending the service life of weapon systems based on commercial-off-the-shelf (COTS) equipment may be greater than many expect due to the non-availability of the OEM ICs and supporting semiconductors.

Suppliers of electronic design, raw materials and manufacturing equipment in this market also have moderate power due to highly specialized software, raw material compounds and equipment produced by only a few firms. The equipment sector operated profitably in 2012,[30] but these companies are dependent on regular OEMs purchases. Affirming this dependency, some IDMs have purchased stock in the equipment companies to strengthen their partnership.

The **threat of new entrants** is limited due to the investment required to construct a fabrication facility and begin production. More importantly, the skill sets required for designing integrated circuits are not readily available, creating fierce competition between semiconductor companies to recruit the best talent. Additionally, current patents and trade secrets disadvantage new entrants, as do the billions of research and development dollars invested annually. Finally, as the size of IC geometry approaches the atomic level, some in the industry have projected the end of scalable advances using silicon. Semiconductor fabs require tremendous power and water to operate, so location is a key factor in constructing a fab.

The industry is very concerned about the disruptive effect a silicon **substitute** would have. Companies are spending large sums of money and racing to be first to uncover the science and secure the intellectual property for the next game-changing product. However, there is no agreement on a clear, near-term replacement for silicon. A depiction of Porter's Five Forces can be found at Attachment 1.

OUTLOOK

The 2011 Budget Control Act established a "Super Committee" to find more than $1.2 trillion in savings over the period 2013 to 2021. In March 2013, after the Super Committee failed to act, sequestration was automatically invoked to implement automatic 10% reductions in all but exempted accounts. Sequestration adversely impacted DoD research, development, test and evaluation (RDT&E) accounts, as well as research funded by Defense Advanced Research Project Agency (DARPA), National Science Foundation (NSF) and National Institute of Standards and Technology (NIST). If sequestration continues, DoD will realize a 9.1% decline in DoD R&D and a 7.6% decrease in non-defense R&D annually (see Attachment 2).[31]

The President's fiscal year (FY) 2014 budget request, however, removes sequestration cuts to defense and non-defense R&D. It maintains defense R&D flat relative to 2013 funding levels and increases non-defense R&D by 8-20%.[32] The 2014 budget requests an overall 10.8% increase in NSF funding[33] and a 22.2% increase in NIST funding over 2013 levels (see Attachment 3).[34] Defense electronics R&D receives a big boost, a 9.8% increase in the 2014 budget request over 2013 funding (see Attachment 4).[35] The outlook for electronics RDT&E depends on the outcome of the current budget debate. If sequestration holds, electronics RDT&E will decline. But if a budget compromise is reached in line with the budget request priorities, it appears that electronics R&D will benefit from additional resources.

These USG funds are an important part of the "R&D Triangle" linking industry, academia and USG basic and applied long-term research. Based on discussions with industry and universities, USG research funding is the majority of basic research funding and can be considered the "Big R" of R&D. In 2008, the USG provided 57% of basic research funding, and the percentage has likely increased as the economy endured a financial crisis and uncertainty.[36] Meanwhile, the commercial sector is spending large amounts of its own resources to scale and adjust its current products to incorporate new feature sizes—applied research, design and development, which can be considered the "Big D" of R&D.

Industry Outlook: The Next 5 Years

During the next 5 years, leading-edge producers like Intel and Taiwan Semiconductor Manufacturing Company (TSMC) will likely transition from 300 mm to 450mm wafer production. Compared to the 300 mm wafer, the 450 mm sized wafer will reduce costs by 30% and allow for greater throughput.[37] The larger wafer size does not represent a major change to the underlying semiconductor technology. However, the larger wafer size will increase manufacturing productivity and reduce the cost-per function.

Current High Volume Manufacturing (HVM) in the industry uses 193 nm wavelength light during the photolithography process to produce 22 nm feature sizes. But, in 2015 IC design will require 10 nm feature sizes to reach Moore's Law objectives. As a result, industry R&D has been focused on developing Extreme Ultraviolet Lithography (EUVL) to further reduce feature sizes by reducing the light source wavelength in the lithography process to achieve 10 nm feature sizes. To become commercially viable, the process requires re-engineering of the entire optical path-source, collector and projection optics, reticles and photoresists.[38] In spite of these challenges, several manufacturers are establishing EUVL pilot lines and others have announced plans to pursue production tools in 2013.[39]

Industry Outlook: The Next 15 Years

The semiconductor industry is an exceptionally dynamic industry. During the next 15 years this is likely to remain true because of two major developments. First, many experts forecast that silicon will reach the limits of scaling within the next decade because further scaling will be limited by physics. However, other experts believe the industry will find ways to increase the number of transistors on a chip, such as adding more cores and producing three-dimensional chips. These efforts to combine advances in material science and design to improve performance have been dubbed "More than Moore," and they are most promising given the uncertainties of further scaling.

There is intense research ongoing to find a follow-on technology to silicon. The stakes are high. A scalable, mass-producible follow-on technology to silicon will be a game changer in the electronics industry. The company and nation that discovers and implements this technology is bound to become a world leader in semiconductors and can cause a period of "creative destruction" in the current electronics industry. In addition to limited corporate research, much of this basic research is taking place at universities and government research labs.

In the far term, researchers will pursue nanotechnology and photonics as a path to further miniaturization. Two nanotechnologies being investigated are 2 nm carbon nanotube Field Effect Transistors (FETs) and Graphene. Transistors made from nanotubes are faster and more energy efficient than their silicon peers. However, there are significant technical challenges to making nanotube transistor based circuits a reality. A manufacturing process must be created that can place each nanotube in a specified orientation and have high adhesion to the gate dielectric and low contact resistance.[40] Similarly, graphene is another nanomaterial that is touted to deliver devices that work at ultrahigh speeds and low power. Graphene is a one-atom thick sheet of pure carbon atoms that is strong, transparent and bendable. With graphene, it is theoretically possible to manufacture flexible electronics and integrate devices into arbitrary substrates such as plastics, silicon or glass. However, technical challenges surrounding materials and manufacturing process remain and must be overcome.

Considerable research is also being conducted to build photonic ICs with silicon. In photonics, light particles produced by lasers or diodes are used to perform logic at much higher speeds and bandwidth than traditional ICs. The silicon wafer is an ideal media for creating planar waveguide circuits. The high index contrast between silicon and the silicon dioxide insulator make it possible to scale down photonic devices to the nanometer level.[41] As a result, silicon photonics has great potential for high volume manufacturing of optical integrated circuitry and integration with Complementary Metal-Oxide Semiconductor (CMOS) circuits within a single package. As a result, major manufacturers (e.g. IBM, Intel, and Samsung) have active programs in silicon photonics and the top three defense companies (Lockheed-Martin, BAE Systems, and Boeing) also have research programs in this area.[42]

GOVERNMENT GOALS AND ROLE

The goals of the USG for the electronics industry should be to ensure access for defense programs and U.S. companies to technology and microelectronics in a fast-paced and global market. Creating or inappropriately applying restrictive policies and regulations can have unintended second and third order effects. U.S. policymakers should consider staying on the path to "do no harm," and understand the implications of incentives that other countries are offering to firms to attract the industry and retain skilled workers.

Because DoD is a small consumer of semiconductors, relative to the commercial market, the nation has the capacity to produce enough semiconductors and integrated circuits to meet surge and mobilization requirements. The U.S. currently has 785 firms that contribute to microelectronics manufacturing,[43] and Defense Logistics Agency (DLA) can rapidly contract ICs from OEMs or from distributors with assistance.

A significant production capability for the DoD is provided through the Trusted Foundry Program. This program was established in 2003 in response to Deputy Secretary of Defense Paul Wolfowitz's "Defense Trusted Integrated Circuit Strategy" memorandum. In the memo, Wolfowitz charged the DoD to identify IC facilities that could qualify as trusted sources for ASICs based on facility clearances or certification.[44] Administered by the National Security Agency's (NSA) Trusted Access Program Office (TAPO), with firm certification by the Defense Microelectronics Agency (DMEA), the DoD has invested over $700M in the program over the past 10 years. It has provides government agencies access to secure microelectronic services and manufacturing capability.[45]

As the name implies, the Trusted Foundry program provides security for government programs by protecting against technology corruption, product tampering, and counterfeiting.[46] While these facets are beneficial, equally important is the access that this program provides to leading edge technology. Included in the trusted foundry relationship, the government has "gold customer" access to all of IBM's processes, R&D and proprietary libraries.[47] Additionally, all this advanced capability is provided to the government at commercial rates, despite the low volumes typically associated with military requirements.[48] In essence, the Trusted Foundry program has returned a modicum of priority, buying power and control to the DoD within the semiconductor market.

The DoD has other in-house sources of production beyond the Trusted Foundry. DLA oversees a contract through SRI International to offer microcircuit and microprocessor emulation services.[49] This provides a DoD-controlled source of chip emulation to restock the shelves of critical integrated circuits if these parts are not otherwise available from commercial venders. Additionally, the Defense Microelectronics Activity (DMEA) operates an Advanced Reconfigurable Manufacturing for Semiconductors (ARMS) facility in McClellan, CA to produce form, fit, and functionally equivalent ICs across multiple manufacturing processes.[50] While IBM's

Trusted Foundry is the gatekeeper to leading edge technology, DMEA systematically acquires design and IP and staffs the ARMS foundry to serve as the shepherd of trailing edge electronics. In this role, DMEA can reverse engineer, redesign, and re-manufacture parts at the IC, Printed Circuit Board or system component level to meet program needs.[51] DMEA has also accredited 55 firms and added them to the list of trusted suppliers.[52]

The current acquisition strategy to procure COTS equipment and then upgrade systems using spiral development lends itself to the rapid acquisition of commercially advanced electronic systems. However, the quantity of components and the expected lifespan of the system will determine the impact that obsolescence will have on the system. These industry trends and the resultant lessons learned have garnered significant attention in recent years, and the USG has implemented numerous changes to shape its interaction with the industry.

Recent Policy Changes

There have been changes in the role of government in the past year. Responding to the challenges of counterfeit parts, the USG has taken action in the last year to secure the supply chain. In October 2012, the Assistant Secretary of Defense for Research and Engineering signed out the Defense Microelectronics Strategy to Congress and highlighted efforts to "infuse trust across the full supply chain via program protection planning and trusted suppliers" and "broadly improve commercial-off-the-shelf and DoD-specific procurement."[53] Congress has since requested an update with added emphasis on photonic integrated circuits which will support advanced telecommunications and electronic warfare.[54]

Both the FY12 and FY13 National Defense Authorization Act (NDAA) included legislation to secure the supply chain by imposing liability for counterfeit parts onto the prime contractor. Section 818 of the FY12 NDAA recommended use of trusted supplier and levied civil liability for counterfeit parts.[55] Section 833 of the FY13 NDAA amended Section 818 to outline contractor responsibilities and limited liability for counterfeit electronic parts if the contractor tested chips as part of a counterfeit detection and avoidance plan.[56] The DoD has also improved supply chain security with OSD/AT&L Overarching DoD Counterfeit Prevention Guidance Memorandum which emphasized PPP, testing and reporting.[57]

Another recent policy, DoD Instruction (DODI) 5200.44, *Protection of Mission Critical Functions to Achieve Trusted Systems and Networks (TSN)*, implements DoD's trusted systems and networks strategy of robust systems engineering, supply chain risk management, security, counterintelligence, intelligence, information assurance, hardware and software assurance and information system security engineering. This overarching instruction directs program managers to ensure that critical DoD systems and networks contain trusted electronics, including the mandate that, mission critical functions and components be provided with assurance consistent with their criticality and that of the system. DODI 5200.44 also attempts to assess and minimize risk to DoD systems from untrusted and potentially compromised system components by assigning roles and responsibilities and directing various actions.

DLA has also issued guidance by standardizing the definition of counterfeit, publishing a Qualified Suppliers List of Distributors, posting alleged counterfeit practices in the Government Industry Data Exchange Program (GIDEP), and preventing reoccurrence by updating Defense Contractors Review List.[58] Earlier this year, DLA mandated DNA markings be placed on Federal Supply Class 5962 Electronic Microcircuits to improve traceability and accountability of chips sold directly to DLA.[59] Additionally, the Office of the Secretary of Defense for Manufacturing and Industrial Base Policy has endorsed industry standards AS 6174, Counterfeit Materials, which reduce supply chain risk by establishing clear expectations and promoting the use of best practices.[60] These policies are useful to the Department of Homeland Security's (DHS) Customs and Border Patrol and Immigration and Customs Enforcement divisions as they identify and seize imported counterfeit semiconductors and electronics.

CHALLENGES, ASSESSMENT AND POLICY RECOMMENDATIONS

1. Recent government policy and strategy documents such as the 2012 DoD Microelectronics Strategy and DODI 5200.44 identified key concerns surrounding the industry; however, they fall short in assigning an authority to coordinate and implement their intended solutions. OSD should appoint a DoD lead for microelectronics life-cycle costs and sustainment to ensure their integrity and availability. The appointed lead should be the designated focal point responsible for life-cycle cost decision making, policy development and enforcement of the initiatives outlined in the strategy.

The 2012 DoD Microelectronics Strategy was a solid first step in herding the various elements of the electronics industry towards DoD goals and needs. However, lacking in this strategy was a shepherd responsible for the effort across the entire lifecycle. To be successful, many of the initiatives require a champion to oversee and synchronize diverse activities while enforcing gains with policy and regulation. Designating a specific office or offices as the coordinator of DoD microelectronics policy and granting them the responsibility and authority to enforce change will ensure the strategy a better chance of success.

2. Obsolescence lies at the root of many of the DoD's challenges within the electronics industry. To address this significant issue OSD should provide further clarification and action in the following areas: 1) sponsor an updated cost/benefit analysis of COTS vs. government-unique electronics as well as Application Specific Integrated Circuits (ASIC) vs. Field Programmable Gate Arrays (FPGA) for DoD needs that considers costs across the entire lifecycle through development, acquisition, sustainment, and disposal, and 2) incorporate study findings into milestone decisions while requiring program managers to incorporate full lifecycle costs in program choices.

One crucial area that this newly ordained office must consider is the potential overreach of using COTS devices in DoD electronics applications. Since the 1994 directive to use COTS for military procurement was implemented, there has not been an end-to-end study that has validated the value of using COTS as the preferred method of acquisition. An updated analysis quantifying the tradeoffs for the entire lifecycle is needed to ensure the IC decisions made at the beginning of a program make sense during each phase of the program and cumulatively across the lifecycle.

Underlying this reconsideration of COTS and the overarching issue of obsolescence management is a full understanding that lower lifecycle costs may entail larger up-front expenditures. Program managers and milestone decision authorities must be appropriately incentivized to look beyond the FYDP at full lifecycle costs when making IC choices for their respective programs. For additional information on this topic, see Essay #1, *Planning for Obsolescence*.

3. As described in the section on Recent Policy Changes, supply chain security has moved to the forefront of electronics policy initiatives over the past year. Further action is required to sustain and increase momentum in this area including steps to 1) strengthen and focus the

intent of NDAA and DODI 5200.44, 2) enhance Trusted Foundry and Trusted Supplier programs and 3) incorporate simple best-practice anti-counterfeit efforts.

Guidance in the FY2012 and FY2013 NDAA, as well as language in DODI 5200.44 *Protection of Mission Critical Functions to Achieve Trusted Systems and Networks (TSN)* are worthwhile and necessary first steps in securing the DoD's electronic supply chain. However, rather than leaving guidance language as a "should" in outside regulations, these policies must be included as "musts" in the overarching program instructions such as DODI 5000.02, *Operation of the Defense Acquisition System,* and incorporated into PPP directives. Additionally, the DoD should continue to strengthen the Trusted Foundry Program and incentivize the use of trusted suppliers. To remain effective, these programs must provide a worthwhile return on investment for the industry partners that are participants. Supply Chain Security policy that incorporates and mandates use of the Trusted Foundries and Suppliers can be the primary revenue generator to sustain these programs. In the quest for eliminating counterfeits in the DoD supply chain, simple process changes—such as only buying from OEMs or authorized distributors (to include Trusted Suppliers)—provide the Occam's razor solution.[61] As a baseline, this simple solution must be incorporated into existing acquisition and sustainment policies and practices. For more on this issue, see Essay #2, *Secure Supply Chain.*

4. To level the playing field for domestic semiconductor manufacturing companies, lawmakers should modify America's corporate tax policy by lowering U.S. corporate tax rates and increasing R&D tax credits.

The absolute decline in American manufacturing employees and the relative decline in American manufacturing has been well documented. The semiconductor industry, despite the long-standing cachet and appeal of Silicon Valley, has not been spared. A recurring theme during discussions with industry and government representatives alike is the fact that the U.S. currently has the highest corporate tax rate of any industrialized nation in the world. American semiconductor firms, however, remain burdened with a real tax rate greatly in excess of any Organization for Economic Cooperation and Development (OECD) nation. Examination of the tax rate is especially dramatic when compared to the emerging semiconductor meccas in Asia. In a highly globalized market and until this anti-competitive tax rate is addressed, U.S. firms will continue to speak with their feet. Beyond the corporate tax rate, the U.S. has become a veritable also-ran in fostering and rewarding research and development, the true lifeblood of an industry that obsoletes itself on a bi-annual basis. Taiwan, Singapore, China, Russia and multiple European nations provide more generous R&D tax credits than the U.S. Squeezed economically on all fronts, American firms have increasingly deemphasized basic research in favor of product development, an ominous trend for the continuance of Moore's law. More on this subject can be found in Essay #3, *Government Policy to Improve Research and Development.*

5. Science, technology, engineering and mathematics (STEM) education is an enduring issue across multiple industries; however, the effects of STEM imbalances are exceptionally pronounced with respect to semiconductor design and manufacturing. To meet the future needs of the industry, USG leadership should 1) provide greater outreach of government and DoD facilities (i.e. research labs and service schools) in STEM-related initiatives to encourage and energize student participation at all levels of K-12, 2) explore ways to provide better financial support to students pursuing STEM degrees, 3) consider more opportunities for Master/PhD graduates to encourage U.S. born students to pursue advanced degrees, 5)

continue support of immigration bills with regard to H-1B visa support for STEM industries, and 6) facilitate academia and industry partnerships to address sub-baccalaureate needs to build the "middle-skill" workforce.

The warnings have been heard repeatedly since the National Academy of Sciences 2007 release of *Rising above the Gathering Storm, Energizing and Employing America for a Brighter Future*.[62] The document reiterated that the U.S. education system is failing and that the nation is falling dreadfully behind other advanced nations. Throughout this study, the prognosticators contend the U.S. is deficient in STEM education, does not produce sufficient numbers of graduates to meet industry demands, and fails to allow the best and brightest foreign students to remain in the U.S. upon graduation. Additionally, this industry study noticed a significant increase in concern over "middle-skill" STEM workers requiring less than a bachelor degree, who form the backbone of the U.S. manufacturing capability.[63] In order to solve these problems, academia, industry, and government must come together to work toward actionable solutions to solve STEM education deficiencies.[64] For more information on this topic, please refer to Essay #4, *Innovation Equals Global Leadership and Power*.

ESSAYS

Janus was the Roman god of beginnings and endings. He possessed two faces, one that looked back at the year that had passed and one that looked forward at the year to come.[65] In many respects, the realities of the electronics industry demand that the DoD possesses similar characteristics. Like a modern-day Janus, the DoD must look forward and enable access to the most advanced technology that the commercial semiconductor industry produces to maintain its competitive advantage in providing national security. At the same time, it must look back and maintain its hardware with the old technology that the overall industry has long since left behind.

The following essays capture the dichotomous interests of the DoD in the electronics realm and provide the background detail from which the group's recommendations were derived. With eyes on the past, Essays 1 and 2 outline DoD's efforts in battling obsolescence and securing its supply chain from tampering and counterfeit electronics. Looking to the future, Essays 3 and 4 address Government's role in supporting cutting edge R&D and building the workforce that will lead the semiconductor industry of tomorrow. The DoD stands perched on the doorway of technology transition—from leading edge to obsolescence. Ensuring access to this technology threshold predominately shapes the areas for potential for policy adjustment.

ESSAY #1 – Planning for Obsolescence--Potential Acquisition Solutions for Commercial-Off-the-Shelf (COTS) and Intellectual Property (IP)

Though most DoD weapon system components are bound to face obsolescence issues at some time in their lifecycle, the collision of the DoD's lengthy acquisition processes with the rapid pace of technological advance make this a significant problem for ICs and electronic components. Average production runs for electronic components are 1-2 years with availability from authorized suppliers for another 5-10 years.[66] Large DoD weapon systems are often in design and development for a decade and in operation for several decades. While programs are required to develop life cycle cost estimates for milestone reviews, electronic obsolescence has not been adequately planned for in these estimates. Therefore, programs often have not budgeted appropriately for electronic obsolescence.

The DoD has been forced to make balloon payments in the operations and maintenance phase (and some programs even prior to production start) to redesign, rebuild, retest and retrofit systems due to electronics obsolescence. This issue becomes more difficult and costly as microchips get more and more complex and more software is embedded in the electronics. DMEA estimates that a single case of electronic component obsolescence can cost up to $2.4M and 64 weeks to resolve.[67] In one particularly egregious case, the phase out of a $30 component on a $750 board left the product integrator of an in-flight navigation system facing an unbudgeted $3.3M system redesign effort.[68]

Staying the course with the current acquisition model of using COTS electronics without a detailed and deliberate obsolescence management plan is unacceptable. To utilize COTS electronics effectively requires the program to plan for modularity and use of open systems while also considering obsolescence and supply chain security. The current acquisition model is costing the government huge sums of money to keep electronics-intensive systems operating decades after the chips are out of production. Even with policies and regulations in place to force acquisition programs to require open systems, modularity, diminishing manufacturing sources plans, supply chain protection, etc., DoD programs are running into obsolescence for which there is no plan and no budget.

Many of the obsolescence issues are exacerbated by the program offices' quests to reap near-term savings and avoid overruns. Early in program design and development, program managers and prime contractors are incentivized to cut the budget required for R&D and procurement. This pressure will only increase as budgets are cut in the tight fiscal environments of today. Life cycle cost is considered at major milestone reviews, but budgets for operations and maintenance generally fall well beyond the five-year budget horizon. This places a premium on reducing up front development and procurement costs often at the expense of future operations and maintenance bills. Programs often make decisions to use COTS electronics such as FPGAs to reduce development and procurement costs but underestimate the effects of obsolescence. This creates large unplanned budget shortfalls for the operations and maintenance phase of the program where the majority of the life cycle costs occur for major weapon systems.

To counter this trend, more detailed study should be accomplished for weapon systems to determine the best strategies for electronics obsolescence based on life cycle cost prior to approving initial system designs. This must be done prior to initial design so the cost and benefit trades can include electronic part selection and design. The analysis should include trade off decisions for COTS electronics such as FPGAs versus government unique electronics such as ASICs as well as a plan for electronics upgrades or life-time buys of electronic components.

Along with life cycle cost analysis, the initial acquisition strategy should consider alternate acquisition models that have the potential for addressing electronics obsolescence in novel ways. As a starting point, we offer four possible models: Special Forces Model, Government-Purpose Design Model, Hybrid Model, and Licensing Arrangement Model. None of the models will work in every case, but each could be applied effectively in appropriate cases to mitigate electronics obsolescence.

One way to tackle obsolescence is to shorten the weapon system's life cycle; the Special Forces model accomplishes this often by using COTs or modified COTS in systems that are built for a short term need and thrown away when the mission is complete. The Special Forces acquisition community works very closely with industry communicating their needs and often does not maintain their systems for long durations. The COTs or modified COTS equipment is used for missions as needed, and then replaced as new equipment becomes available on the market.

This model allows the Special Forces to keep up with the commercial market, use the latest electronic equipment and deal with very little obsolescence. This model is sustainable because of the small scale and relatively large budget of Special Forces. Expanding this model on a DoD-wide scale may likely be too costly in today's budget environment. However, life cycle cost analysis should consider this model for each weapon system. Equipment that is relatively low cost and highly electronics intensive such as communications equipment may be a good target for this model.

Assuming that weapon system life cycles cannot reasonably be shortened, the DoD could go back to the original strategy for microelectronics using a Government-Purpose Design model and move away from COTS. The first microelectronic chips were designed and used for government applications in the mid-20th century. During that time, the government owned the designs and had significant influence in the market. Long life cycle government electronics were produced for many years because the government was the main customer. If the DoD needed more chips to replace failed electronics, then the DoD would pay for more to be built. This model stopped working when the government became a minority customer and the consumer market became the driving force in the electronics industry.

To go back to this model, the government would need to pay a significant premium to have industry design, test and build custom government-purpose microelectronic components such as ASIC processors. This would require significant up front cost, on the order of \$1 to \$3 million, versus the cost of procuring commercial FPGA processors.[69] However, because the government would own the designs, the government would be able to have the ASICs produced at any time by taking the design to a trusted foundry. This could save large amounts of money in the operations and maintenance phase of weapon systems by eliminating costly redesigns due to obsolescence. The long-term savings could far surpass the initial investment for custom microelectronics during the acquisition phase. Further, the DoD would have more long-term flexibility by allowing trades between legacy electronics and redesign for more capability. However, as referenced earlier in this essay, further study is needed to quantify the life cycle costs comparison of COTS versus government unique ICs.

A Hybrid Model that starts with COTS electronics but allows for government-purpose rights after COTS electronics production runs are over is also possible. This hybrid model could get the government the best of the options above. If the government could use the COTS microelectronics strategy for acquisition and have rights to the design upon obsolescence, then savings could be achieved during acquisition and O&M. This could be achieved through acquisition contract clauses allowing the owner of the microelectronic designs to transfer government purpose rights to the government when the original owner no longer wishes to produce the component. The contract clauses would have to flow all the way down to lowest supply tier for electronic components. A good track record for this approach for some components has been successfully used by DMEA in California.

This Hybrid Model also offers a means to potentially tie in the benefits of the existing Trusted Foundry and Trusted Supplier infrastructure. The government could use trusted foundries to produce microelectronics designs that are no longer available on the commercial market to keep aging weapons systems in operation at a relatively low cost. This could avoid costly life-time buys, reverse engineering and redesign, rebuild and retest cycles due to obsolescence. The microelectronic companies may agree to this because the designs would be very old as measured by the commercial market, and the companies would be given the first right of refusal for producing the obsolete components. This hybrid model would allow for savings using COTS designs while avoiding the need to go to untrusted sources and/or costly redesign that often is required when the COTS components go obsolete.

Rather than obtaining obsolete IP, one final way to battle obsolescence is to contract with the prime to secure access to the COTS IP immediately at development and production through a Licensing Arrangement Model. As an example, BAE began licensing leading edge, commercially developed Power Architecture Core technology from Freescale in 2012 to increase the satellite processing power of their space-ruggedized chips by 10 times the current rate.[70] Merging leading edge commercial companies such as Freescale with defense industry stalwarts such as BAE through licensing and partnering arrangements can provide a win-win-win for the DoD, the military contractor, and the commercial company. For the government, it provides access to leading edge technology from a wider array of sources that may otherwise be available. Additionally, it places the source of the product into a trusted supply chain that is geared towards a longer-term (perhaps even the entire lifecycle of the weapon system) relationship with the government. For the licensees, it allows them to specialize in their own area of expertise (such as radiation hardening) while still improving the performance of the products they offer. Finally, for the licensors, it expands their sales without hindering their ability to modify and enhance their product for the fast-paced commercial market. Like the Hybrid Model, this arrangement also ties neatly into the existing Trusted Foundry and Trusted Supplier infrastructure; the DoD has a ready and secure manufacturing capability to harvest the applicable IP of an increasing base of U.S. fabless design companies. Once again, it is a win-win-win relationship.

While there are many models that could be utilized for electronics-based weapon systems, it is critical for programs to use life cycle cost analysis prior to initial designs with special consideration for electronic components to support acquisition strategy and design decisions. Up front analysis and, in some cases, upfront investment could save significant life cycle for weapon systems. Lt Col Mark Davis, U.S. Air Force, and Colonel Mark MacDonald, U.S. Air Force

Essay #2 – Secure Supply Chain

As General Patrick O'Reilly, the former Director of the Missile Defense Agency aptly stated: "We do not want a $12 million missile defense interceptor's reliability compromised by a $2 counterfeit part."[71] As trade becomes increasingly global and opaque, concerns about what goes on within the global supply chain emerge. Are the items ordered the items received? Will the items be received in a timely manner? What is the true source of the items? Have the items been tampered with? If they have been, who did the tampering and what were their motivations?

These concerns are real, and they can have devastating effects ranging from higher costs to loss of life. But what characterizes a secure supply chain? In general, a secure supply chain means the ability to fulfill orders in accordance with the quantity and quality of parts specified, while securing against tampering such as remarked or intentionally mismarked parts, and absent any malicious embedded design features or intentional latent defects. One major obstacle the defense industry faces in providing a secure supply chain is the increasing prevalence of counterfeit electronic parts being introduced into the system.

Counterfeiting is defined as "the process of fraudulently manufacturing, altering, or distributing a product that is of lesser value than the genuine product, and also applies to reproductions of packaging when the intent is to defraud or to violate protections under trademark, copyright, or patent laws."[72] Current estimates suggest that global semiconductor counterfeiting is on the order of $15B per year. Projecting current trends, this market could reach $27.9B to

$33.2B by 2015.[73] The U.S. share of this counterfeit semiconductor market is approximately $2.4B per year, or roughly 16 percent of the total world value of counterfeit semiconductor products.[74] Counterfeits are especially problematic for the DoD because of the premium charged for high-reliability, military-grade semiconductors and the grey-market demand for these mostly obsolete parts. This class of semiconductors represents less than one percent of the total semiconductor market, meaning that there is essentially no industrial base for high-reliability products.[75]

Protecting the global supply chain requires detailed knowledge of each link in the chain. Any breach or "breakage" of any one link results in a failure. Due to the low volume of chips required for typical military applications, most Original Chip Manufacturers (OCMs) are unwilling to fulfill orders in a timely manner, sometimes taking as long as 24 months.[76] Unwilling or unable to wait for OCMs to fulfill these orders, government purchasers are forced to look elsewhere to meet their needs, mainly in the form of brokers. Brokers do not produce products, they simply purchase and store products on the open market and provide them for resale. The products they sell are not easily verifiable. "In a recent survey of worldwide OEM and government purchasing, it was found that today they buy from brokers 26 percent of the time."[77] This percentage may be even higher for spare semiconductor products managed by the Defense Logistics Agency (DLA); reviews of contracts awarded by DLA have shown that up to 50 percent have gone to the broker market.[78] While the vast majority of these brokers are honest, most do not have the systems in place to catch counterfeits before they enter the supply chain. Some independent distributors have estimated that as much as 35 percent of their incoming inventory is counterfeit.[79] Cost is the limiting factor in verification, as the equipment needed for physical inspection and test counterfeits runs into the hundreds of thousands of dollars.[80]

Understanding the risks and consequences of potential failures can help focus efforts to protect, secure, monitor and shield from unwanted tampering. To secure the supply chain for microelectronics, the DoD must consider cost instead of pricing. While the DoD is still very cost conscious, "even if [the DoD is] getting a bargain on a component purchase, the cost of manufacturing down-time or failure of the end-product if the product is faulty or counterfeit far out-weighs front-end savings."[81] Cost can be measured in time as well, meaning that the time cost required to obtain a chip from an OCM may be worth the reduction in risk from sourcing the part from the broker market.

One method available to the DoD to stem the tide of counterfeit semiconductors in the supply chain is to increase the usage of existing programs such as The Trusted Foundry Program and accredited suppliers. This network of providers assures the highest standard of quality as well as controlled access to limit potential tampering or overruns. Additionally, availability of the DMEA-authorized after-market vendors, such as Rochester Electronics and Landsdale Semiconductor, and other authorized remanufacturers add to the security and reliability of the supply chain.

Leaders within the defense industry recommend a simple solution for countering many of the supply chain security challenges: buy from reputable vendors and buy COTS where it will meet your needs.[82] Buying from reputable vendors is a fairly obvious solution, but the DoD often balks at buying commercial parts as evidenced with the trusted supplier program as COTS may be more susceptible to tampering without the protective processes employed in a secure supply chain. But as was discussed by major electronics industry leaders, buying customized product under close inspection and scrutiny may lead to additional attention by our enemies, which are motivated to tamper with these items. Keeping the supply in the commercial sector provides some protection simply because it is now harder to target components destined to DoD customers, i.e. security through obscurity.

The DoD should incentivize procurement from authorized vendors or distributors. The 2013 NDAA contains language to encourage vendors to establish a robust supply chain management program, but this language needs to be codified into law as quickly as possible. Most vendors agree that this simple act will dramatically reduce the probability of counterfeit parts in the DoD electronics supply chain. Another opportunity for the DoD is to establish cost thresholds, below which cost is not a factor for awarding a contract for electronic parts across all parts procurement agencies. This will allow elimination of low bidders who are likely sourcing the parts from less than reputable sources. The funds saved on these low cost parts are insignificant when weighed against the cost of a lost aircraft or warfighter's life.[83]

Microcircuits should be marked by the original manufacturer in such a way as to reduce the likelihood of counterfeit parts, tampering, or mishandling; however, marking technology is not mature enough to mandate a particular technique. DNA marking is the current method mandated by DLA, but it may drive some manufacturers out of the defense business and may not achieve the desired effects. Also, marking of newly manufactured chips does not address the aftermarket chip pedigree problem. The message predominantly received from semiconductor manufacturers is "let us innovate, don't regulate." Legible parts marking may not be the best, enduring alternative.

DARPA's Trust in Integrated Circuits Program, chartered in 2006, seeks to develop repeatable means to determine if chips are authentic. Protection of IP within the foundry network and especially as the IP migrates to secondary manufacturer's facilities is of particular concern for tampering. The U.S. whole-of-government must work to halt the supply of counterfeit parts flowing into the global supply chain, of which most come from China. The 2012 Congressional Study found more than 70 percent of suspect counterfeit parts originate from China, a country that currently does not discourage this trade.[84]

Clear opportunities exist to address risks and to improve the DoD supply chain. Focus is necessary beyond the traditional sourcing processes and must include the other supply chain processes such as plan, make, deliver and return. As the electronics criminals continue to learn how to attack our systems, we will need to continue to improve the security of our supply chain. Securing of our systems will continue to give us the competitive edge and retain world-class superiority in weapon systems. Mr. Andrew Adsit, Department of the Air Force, and Mr. Jeffery Kuss, Defense Contract Management Agency

Essay #3 – Government Policy to Improve Research and Development

Gordon Moore's prescient observation concerning semiconductor scaling trends quickly changed from a rule of thumb to become a marketing and business imperative driving the semiconductor industry since 1965.[85] Doubling transistor density on an integrated circuit every 18 to 24 months has challenged generations of engineers and scientists to solve the myriad problems that arise from each exponentially more complicated design. Unsurprisingly, extensive investment in research and development by both the government and private industry is the critical factor in maintaining this pace. American firms and academia have long been the epicenter of semiconductor innovation, and the U.S. has benefitted economically and militarily. In an industry that essentially reinvents itself every 2 years, the U.S. has made innovative technologies its true competitive advantage.[86] In recent years, however, this edge has begun to decay. U.S. government tax policy rewarding private investment in R&D has lagged and is no longer competitive with much of the industrialized world.[87] At the same time, increased competition has driven the industry to emphasize product development at the expense of basic research.[88] Finally, government support to academia and the remaining labs conducting ground breaking, fundamental research is under pressure due to budgetary constraints.[89] The timing could not be less auspicious. As the industry quickly approaches the underlying physical limits that will eventually give lie to Moore's Law and the search for what is beyond silicon intensifies, our non-competitive tax policies and unfocused approach to R&D funding is imperiling our innovation advantage.

In 1981, the U.S. government began an effort to kick start corporate research and development spending that had lagged during the economic doldrums of the 1970s. In the throes of economic stagnation, the U.S. took a bold step forward and became the first country ever to provide a tax credit for R&D spending.[90] While economists continue to argue about the actual effect of the tax credit on American firms' research spending decisions,[91] imitation is the sincerest form of flattery and, by extension, the best feedback. The rest of the world recognized the benefits and moved aggressively to match and eventually exceed America's innovative tax credit in their countries. The clear leader 30 years ago, the U.S. today ranks only 27th out of 42 countries surveyed by Information Technology and Innovation Foundation (ITIF).[92] India, China, Singapore and Taiwan all offer greater incentives for research and development. More insidiously, Congressional inaction has allowed the U.S. R&D tax credit to lapse thirteen times since inception,[93] introducing another element of uncertainty into an already risky venture.

The U.S. still spends the most on R&D and accounts for over 40% of worldwide spending.[94] Our firms continue to value investment in the future. The devil, as always, is in the details. Faced with a double whammy of high corporate taxes on income and limited credit for R&D conducted in the U.S., nominally U.S.-based firms are shifting their profits and R&D efforts overseas.[95] As an example, 9 of 12 IBM research laboratories are located outside the United States[96] in countries with an average 28% corporate tax rate and more lucrative R&D tax credits.[97,98] A recent study by the NSF found that U.S. multi-national companies "nearly doubled R&D employment overseas between 2004 and 2009. During the same period, domestic R&D employment by these same companies increased by less than 5 percent."[99] The trend is unmistakable and ominous. It is also reversible if the U.S. seizes the opportunity to reinvigorate its R&D incentives. Improving our R&D tax policy is only part of the equation.

Analysis of several years of annual financial reports indicates a commitment on the behalf of American firms to extensive R&D. On average, fully 16.2% of aggregate revenue is reinvested towards these efforts.[100] However, discussions with multiple firms and industry trade representatives revealed that the vast majority of funding went to product-focused development. Cost-conscious and risk-averse CEOs have essentially done away with basic research and the clear swim lanes established in the wake of World War II by Vannevar Bush are a distant memory.[101] Evolution, not revolution, is now the goal. With some industry experts predicting only a few iterations of Moore's Law remaining before further density and processing gains from feature scaling become impossible and/or not economical, this constitutes a clear threat to continued American hold on the technological leading edge[102]. Industry executives clearly recognize the oncoming barrier but are unable to spare enough resources from the need to remain competitive in the face of near-term market pressures. As such, the U.S. electronics industry is confident the next, critical breakthrough will come from government funded and supported research.

Public dollars have long provided the lion's share of basic research funding. It is a quintessential example of a public good. While the exact share between basic research, applied research, and technology development has varied over time, federal R&D funding has generally increased each year. In the last 60 years, the two periods of declining support (1968-1970 and 1994-1996) corresponded with decreasing overall defense budgets.[103] While the decline in the early 90s was minimal (about 1.5%), the decline in the late 60s was large (about 7.5%) and may have played a role in the low productivity growth in the U.S. economy throughout the 1970s and 1980s.[104] Worrisomely, the projected cuts to federal R&D due to sequester impacts are close to 8% over the next 5 years, totaling close to $54 billion.[105] If enacted, the U.S. will be eating its seed corn.

Quick and decisive action is needed. Sequestration's near-term impact to readiness obscures the long-term harm to innovation and technology development. It is always hard to find tradeoffs in a declining budget share, but the U.S. cannot allow federal R&D support to wane. The U.S. has the world's largest military force by a large margin, and it does not face an existential threat at this time. Accordingly, the U.S. can afford to take risk in procurement today to avoid greater risk in future years due to shortchanging R&D.

To ensure that industry meets the government at least halfway, we recommend improving and simplifying our R&D tax credit to achieve rough parity with our competitors. First, double the tax credit from 20% to 40% and apply it to all research. Second, make the tax credit permanent in order to remove uncertainty for business. Finally, to protect small firms that might not show a profit for some time, remove the tax credit's tie to net income. The U.S. and its semiconductor industry are defined by innovation. Now is the time to put policies in place to reinforce our commitment to the industry. CDR Michael Farren, U.S. Navy

Essay #4 - Innovation Equals Global Leadership and Power - Investing in Human Capital and STEM Education in the U.S.

For the past five decades, the United States has maintained a dominant position as the most technologically advanced nation in the world. This holds especially true within the U.S. semiconductor industry, which enjoys a prominent role as the global technology leader and essentially the backbone of the trillion dollar consumer electronics industry. Despite this dominance, recent indicators are that the United States is losing its dominant role. Many attribute this to a lack of STEM graduates entering the workforce. The National Academy of Sciences provided an initial warning with 2007's release of *Rising above the Gathering Storm, Energizing and Employing America for a Brighter Future*, indicating the U.S. education system was failing; the nation was falling dreadfully behind other advanced nations.[106] Other recent studies have placed American students near the bottom of Western nations for STEM achievement.[107] As resources have continued to shift outside the continental U.S., there is mounting concern throughout various circles of academia, industry, and government that the U.S. is slowly ceding the knowledge race and will ultimately lose its competitive advantage, with significant national security implications. This essay will provide insight on the current status of STEM efforts, some noted challenges ahead and provide recommendations to meet those challenges with greater success.

The 2007 release of *Rising Above the Gathering Storm* was essentially a warning shot, fired across the bow of academia, industry and government. The publication was a call to arms. It was a modern day "Sputnik" moment to rally the U.S. education system to rise to the challenge of meeting the science and technology requirements of a modern workforce. Early focus was on the nation's K-12 system. The 2006 Program for International Student Assessment (PISA) scores demonstrated the U.S. had continued to decline in proficiency levels in math, and science. While many Asian countries, including China, were consistently increasing their ability and surpassing standards, the U.S. performed below the OECD average on both math and science proficiency. Yet, the 2009 PISA scores showed a halt in trend of lower scores, and a move in the positive direction consistent with the OECD average.[108] A potential positive step for K-12, the results of the 2012 test (available December 3, 2013) will be required to confirm continued gains in the right direction.

Despite K-12 education challenges, the U.S. still produces a significant amount of U.S.-born graduates with STEM degrees. Students entering Science and Engineering (S&E) programs persist and complete undergraduate degrees at a higher rate (63%) than non-S&E students (55%).[109] Baccalaureate degrees are the most common in S&E, accounting for greater than 70% of all degrees awarded in S&E. Rising steadily from 366,000 in 1993 to 505,000 in 2009, students continue to pursue S&E degrees which account for roughly one third of all baccalaureate degrees.[110] Despite the continual increase in S&E degrees, many studies continue to insist the U.S. is under producing STEM talent. Three out of four students who score in the top math quartile divert early and do not pursue a STEM major.[111] Additionally, "nearly two-thirds of workers with undergraduate degrees in a STEM field are working in non-STEM occupations."[112] Solving this issue may be one of the clues to solving the U.S. perceived STEM shortage and ensuring a greater supply of undergraduate STEM workers.

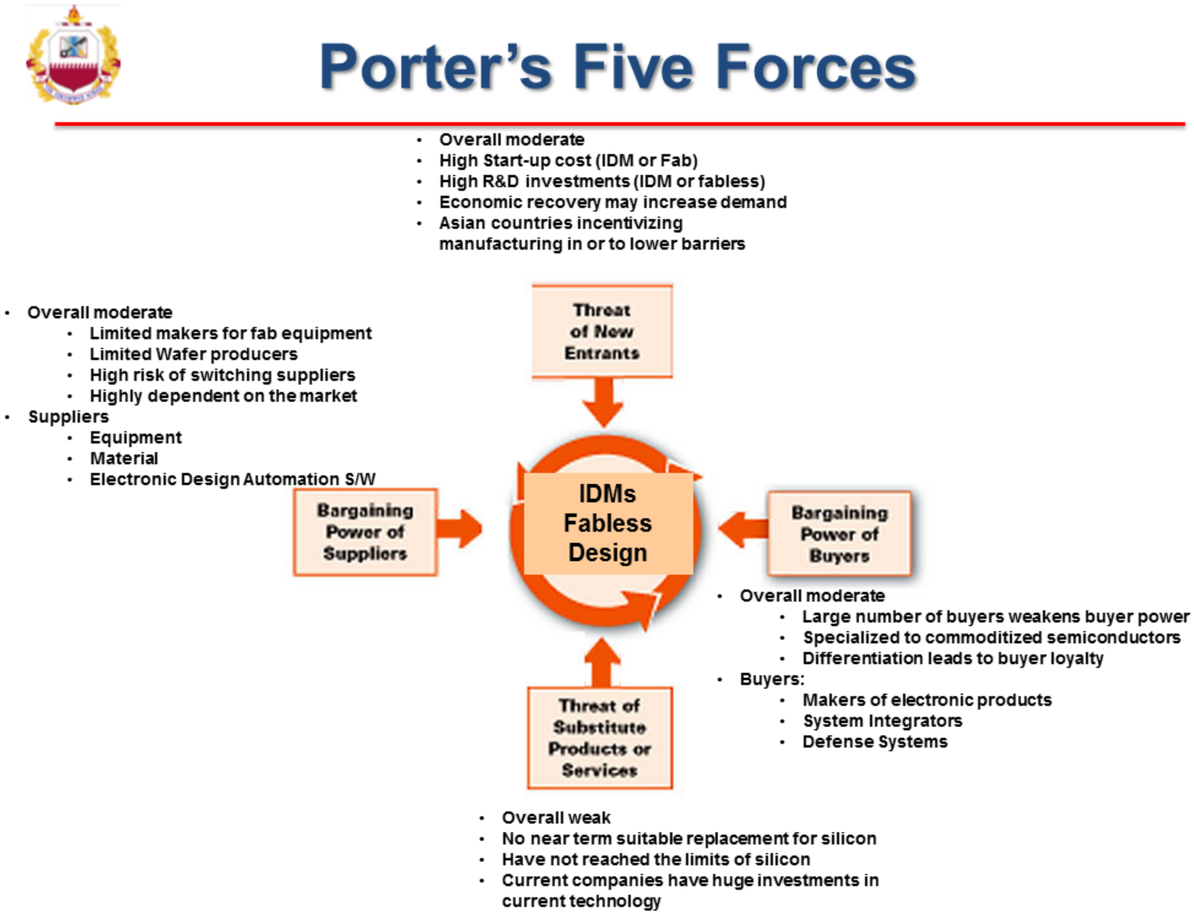
Diversion continues with advanced degrees as well, where fewer U.S. born students choose to pursue either a masters or doctorate in STEM. Foreign born students continue to choose the U.S. to complete their advanced degrees, representing roughly 32% of graduate enrollment (2009), with engineering majors showing the most growth in the STEM fields.[113] Many of the foreign born students would like to stay legally in the U.S. after obtaining their advanced degree. U.S. law caps the number of H-1B Visa at 65,000.[114] Currently, one in five STEM workers in the U.S. is now foreign born.[115] Studies have indicated that foreigners who immigrated to the U.S. with advanced technical degrees have made a tremendous positive impact on the U.S. economy. Between 1995 and 2005 fifty-two percent of Silicon Valley start-ups were founded or co-founded by immigrants.[116] As U.S.-born students continue to forego advanced degrees for other pursuits, industry views immigrants as a critical link within their workforce. In order to sustain economic growth, it is critical that the U.S. continue to analyze and reform its immigration laws, such as the proposed increase to 180,000 H-1B Visas. While this helps industry maintain access to the best and the brightest, it does pose a challenge for government and DoD research labs requiring U.S. born workers.

STEM professions have witnessed substantial growth over the last few decades. In 2010 there were 7.6 million U.S. STEM workers, representing nearly 1 in 18 workers nationwide.[117] As the demand for STEM grows across many non-traditional occupations, many feel that another segment of STEM workers are not being tracked.[118] These "middle-skill" workers, who require some college education and strong basic skills in math, science, and other technical areas, form the backbone of the U.S. manufacturing capability with an estimated 47 million middle-skill job openings by 2018.[119] CDR Michael Mullins, U.S. Navy, and Colonel David Kim, U.S. Army

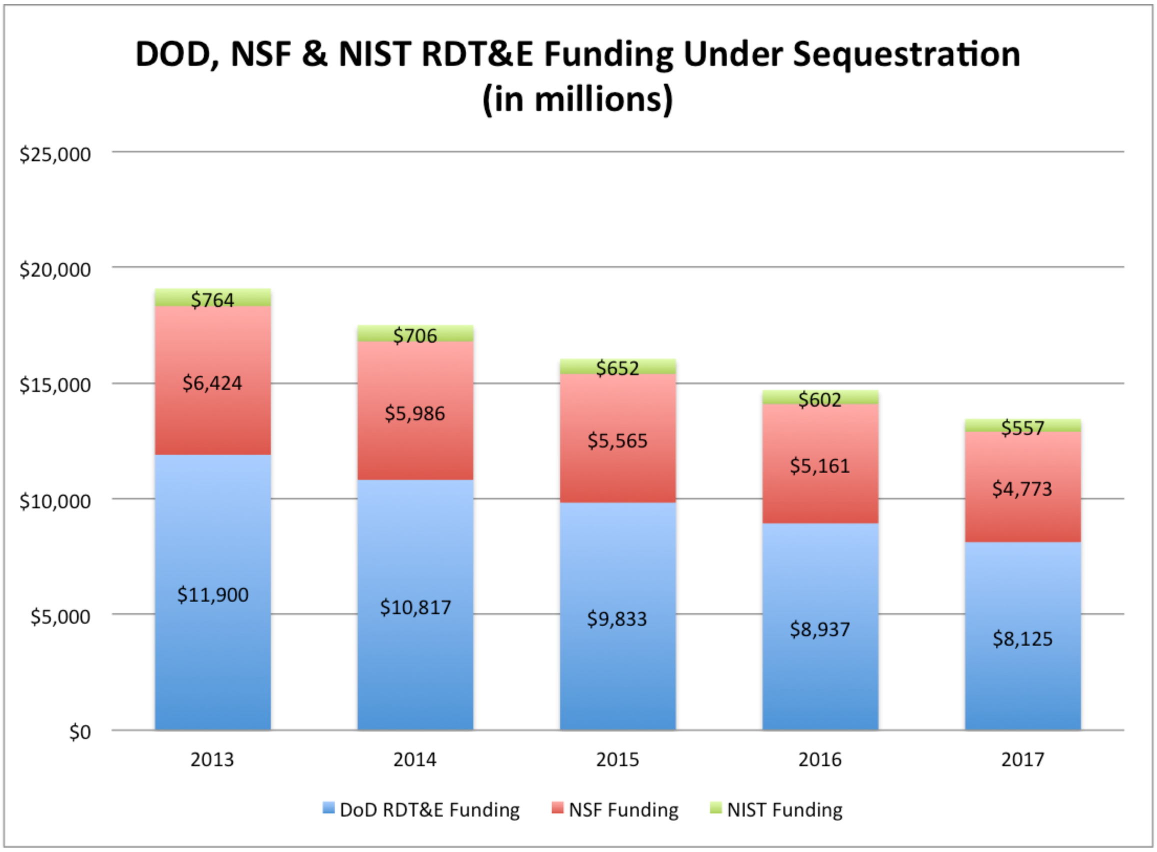
CONCLUSION

Our seminar analyzed the domestic and international industries that support the research, design, and manufacture of semiconductors for use in current and future electronic systems. Our findings include DoD's continued dependence and declining influence over the consumer-driven, commercially-dominated microelectronics industry, obsolescence problems caused by incorporating microelectronic components with 18-24 month life cycles in DoD weapons systems designed to last for decades, the continued challenge of counterfeit parts, and the difficulties of accessing leading edge technologies in an era of declining resources. This paper described the electronics industry with a focus on microelectronics, analyzed the current conditions and future outlook and highlighted five challenges: microelectronics life-cycle costs and sustainment, obsolescence, supply chain security, tax policy and a trained workforce. By critically examining the challenges, we offer policy recommendations for strengthening the U.S. electronics industry and, ultimately, our national security. Our key recommendation to appoint a DoD lead tasked with electronics life-cycle cost and sustainment decision-making offers the best opportunity to address the challenges presented in this paper. Additionally, the USG and DoD have policy levers to address obsolescence, strengthen supply chain security, fund basic research to spur innovation, and invest in human capital to ensure a skilled workforce. Although the playing field is slowly being leveled, the U.S. remains the leader in the semiconductor industry, its universities still provide the premier educational experience, its U.S. companies continue to heavily invest in R&D and innovation, and it fields and maintains the most advanced military in the world. To maintain these advantages, the USG and DoD should create economic conditions for success and then challenge industry to meet government needs with innovative leading edge technologies as well as secure, trailing edge components.

Attachment 1 – Diagram of Michael Porter's Five Forces

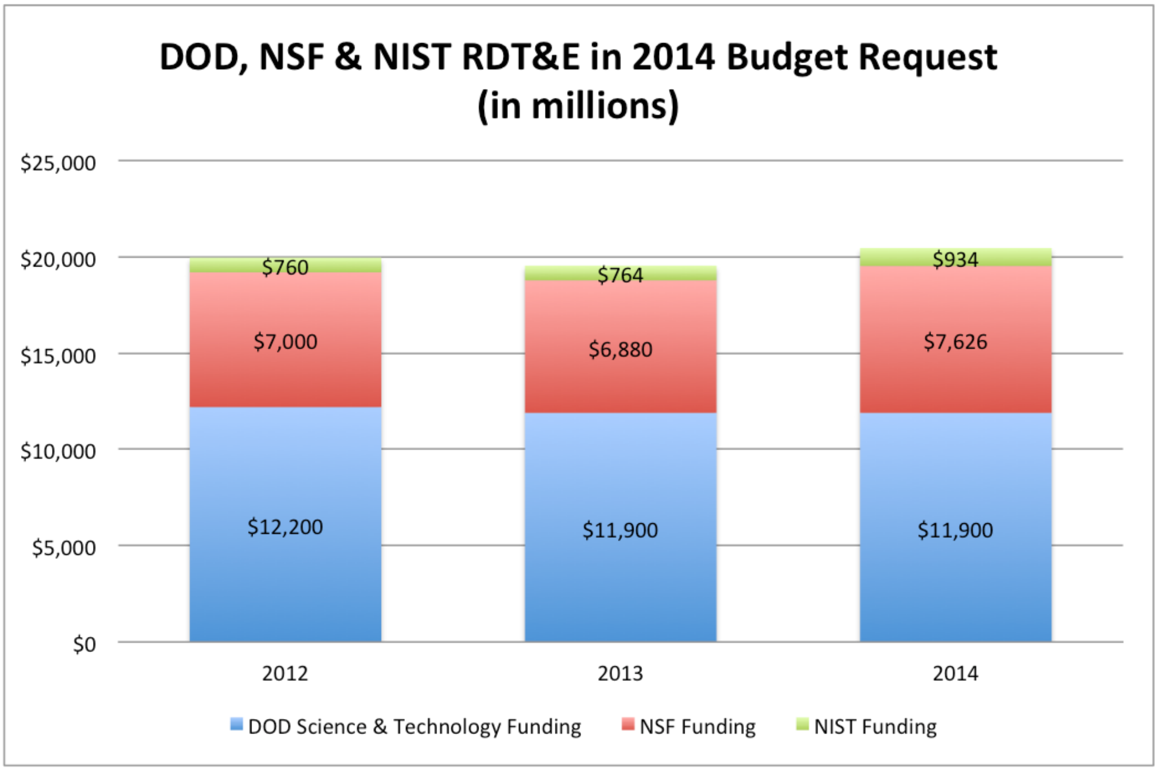


Attachment 2 - RDT&E under Sequestration



Source: Matt Hourihan, "Federal R&D and Sequestration in the First Five Years," American Association for the Advancement of Science, September 27, 2012, 1-20, http://www.aaas.org/spp/rd/fy2013/SeqBrief.pdf, accessed April 20, 2013.

Attachment 3 – RDT&E in 2014 Budget Request



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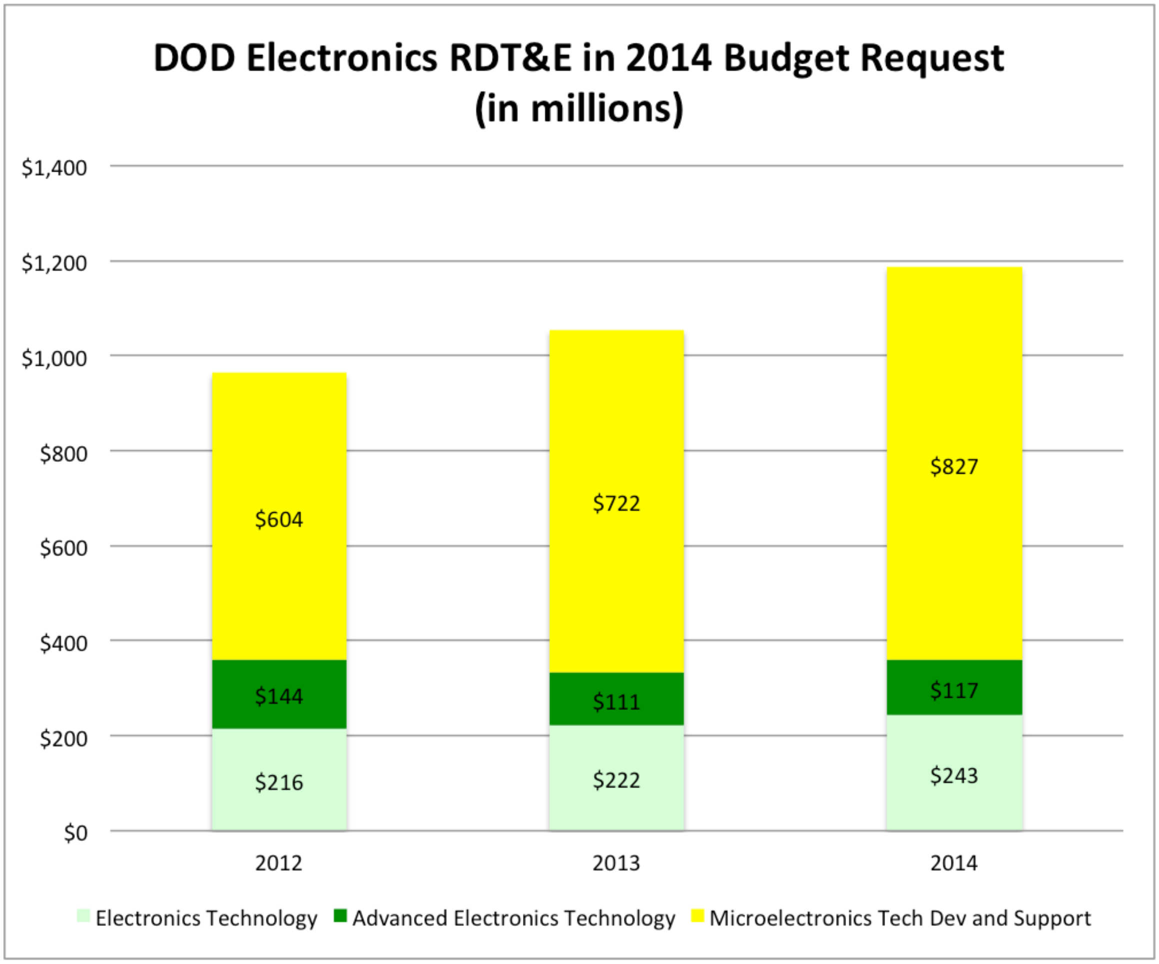
Attachment 4 – DoD Electronics RDT&E in 2014 Budget Request



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