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ELECTRONICS 2016

ABSTRACT: The United States' creation of the semiconductor created the world we live in today.[1] While the U.S. Semiconductor industry currently maintains 50% of the market, there are dramatic shifts on the horizon that will affect everything from the defense to the economy of the United States.[2] The government must act now to ensure the U.S. maintains this advantage.

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Industry Study Outreach and Field Studies

Domestic:
Semiconductor Industry Association (SIA), Washington, DC
BAE Systems, Manassas, VA
Micron Technology, Manassas, VA
National Security Agency, Ft. Meade, MD
National Institute of Standards and Technology (NIST), Gaithersburg, MD
Naval Research Laboratory, Washington, DC
IBM Watson Research Center, Yorktown Heights, NY
GLOBALFOUNDRIES, East Fishkill, NY
IBM Systems Executive Briefing Center, Poughkeepsie, NY
Northrop Grumman, Linthicum, MD
Advanced Micro Devices (AMD), Sunnyvale, CA
Intel Corporation, Santa Clara, CA
Semiconductor Equipment and Materials International (SEMI), San Jose, CA
Electronic System Design Alliance (ESDA), Mountain View, CA

- Mentor Graphics
- Cadence
- Synopsys
- IPextreme

eSilicon, San Jose, CA
Applied Materials, Sunnyvale, CA
Altera, San Jose, CA
Defense Innovation Unit Experimental (DIUx), Mountain View, CA
Defense Advanced Research Projects Agency (DARPA), Arlington, VA

Guest Presenters at the Eisenhower School, Ft. McNair, Washington, DC

IBM
Manufacturing Industrial Base Policy
Electronic System Design Alliance (formerly Electronic Design Automation Consortium)
Rochester Electronics, LLC
Institute for Defense Analyses
Qualcomm, Inc.
U.S. Department of Commerce/International Trade Administration

International:

Industrial Technology Research Institute (ITRI), Hsinchu, Taiwan
Taiwan Semiconductor Industry Association (TSIA), Hsinchu, Taiwan
ChipMOS Technologies Inc., Hsinchu, Taiwan
Inotera Memories Inc., Taoyuan City, Taiwan
United Microelectronics Corp. (UMC), Hsinchu, Taiwan
Taiwan Semiconductor Manufacturing Co. (TSMC), Hsinchu, Taiwan
Etron Technology Inc., Hsinchu, Taiwan

Realtek Semiconductor Co., Hsinchu, Taiwan
American Institute in Taiwan, Taipei City, Taiwan
U.S. Consulate General in Shanghai, China
The American Chamber of Commerce in Shanghai, China

- Apple
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INTRODUCTION

"We won't have the rate of progress that we've had over the last few decades. I think that's inevitable with any technology; it eventually saturates out. I guess I see Moore's law dying here in the next decade or so, but that's not surprising."
Gordon Moore, March 30, 2015

The Electronics Industry Team at the Dwight D. Eisenhower School of National Security and Resource Strategy included fifteen students from across the U.S. Government agencies and one each from the Mexican Navy and Jordanian Army. The team conducted an extensive, five month, study of the semiconductor industry through classroom instruction, lectures and visits to numerous government, industry and academic organizations. Students focused on individual areas within the industry and collaborated to define and identify key aspects of the semiconductor component of the electronics industry. From these, the team developed challenges, recommended goals and roles for U.S. Government policy and a long term outlook for the industry.

This paper is a short "Executive Summary" of what the team experienced and learned about the semiconductor industry. The team identified the current conditions of the industry, conducted an analysis using the Porter's Five Forces tool, and provided a five and ten year outlook for the industry. Each student chose a narrower topic within the industry to research in-depth. These topics reflect key issues affecting the industry. As the team visited government and industry partners, each captured key issues from their respective positions. The recommendations reflect a comprehensive understanding of these perspectives as well as in-depth research of the topics. The topics discussed in this paper include: Firm Consolidation, Research and Development, Taxation of the Industry, Trusted Foundries, Industry Workforce, Export Control, and Intellectual Property and Innovation Trends.

The semiconductor industry has dramatically changed every aspect of life throughout the world.[3] From defense, financial markets, the global economy and communications to commercial products, transportation, space exploration and more, integrated circuits are in everything we use today. Because of the ubiquitous nature of the integrated circuit, any change in the industry can have dramatic impact on how we live. Today the United States still enjoys a leading role in large segments of this market but, that is dramatically changing. Factors such as cost to manufacture in the United States, taxes, theft of intellectual property, export controls, and global markets affect the industry. Major shifts in the industry to Asia challenge the United States position as a global leader in the semiconductor industry as well as affect our national security and economic viability in the future. This paper identifies several challenges and provides recommendations that will enable a vibrant and successful U.S. semiconductor industry.

SEMICONDUCTOR INDUSTRY DEFINED

Definition: The Electronics Industry team narrowed its focus to the semiconductor industry. Originally the industry designed, manufactured and integrated semiconductors into products. Today the industry is broken down into many subindustries or segments. This includes: Design, Intellectual Property (collections of original design), manufacturing equipment, manufacturing facilities (fabs), design tools (Electronic Design Automation), packaging & testing (integrating semiconductor chips onto boards or in devices). The team visited businesses from each of these segments and integrated these experiences into this executive summary.

Industry History: With the invention of the transistor in 1947, then the integrated circuit in 1959, the semiconductor industry has changed the world in less than a century. Virtually all semiconductor companies can trace their roots back to the Fairchild Semiconductor Company.[4] In 1965, Gordon Moore, the head of research and development at Fairchild, observed that the number of transistors on an integrated circuit doubled every two years.[5] His prediction is still true today and became known as "Moore's Law." Although more of an observation than law, many researchers have used it as motivation to innovate and maintain the two year cycle. The best example of how Moore's Law has been realized through the decades is in the development of consumer electronics. By the 1970s, televisions were still analog, but many other items were transistor based such as pocket calculators, digital watches and the Atari game console. In the 1980s, Walkman radios, CDs, VCRs, electronic typewriters, IBM PCs, and many more items used transistors.[6] The 1990s brought smaller and more powerful integrated circuits, completely transforming how we communicate, travel, and live. Today, an iPad contains more computing power than a 1990s Cray supercomputer that was the size of a refrigerator.[7] We continue to see an exponential growth of the industry today.

In the 1980s the industry shifted to Japan. Japanese companies dramatically increased their market share between 1982 and 1988. This resulted in numerous policy changes concerning export controls, import tariffs, and other regulatory measures designed to keep the U.S. semiconductor industry healthy. Though the United States had regained its leadership role in the industry by the 1990s through innovation in microprocessors and other leading edge devices, the 1990s also saw new Asian-based semiconductor companies enter the industry and capture portions of the market.[8]

Another trend that began in the late 1980s and early 1990s was the shift from the Integrated Device Manufacturer (IDM) model, where integrated circuits are designed and fabricated in a single company, to a "Fabless" model, where one company creates the design specifications of a microchip and a separate production company builds the chip at their fab.[9] Today there are many fabless design companies that develop products for use by other companies. The intellectual property for these products is a key element of their business.

CURRENT CONDITIONS OF THE INDUSTRY

U.S. Semiconductor Industry

Today, according to the Semiconductor Industry Association (SIA), semiconductors are responsible for 30 percent of the innovation-led productivity gains to the United States. According to SIA, "Semiconductors are one of the nation's top exports, in line with automobiles, aircraft and petroleum products…a job in the semiconductor industry pays on average 2.5 times more than the average salary for all U.S. workers."[10] The industry supports approximately 1.25 million jobs in the United States. At $34 billion, the industry spends more on Research and Development (R&D) than any other U.S. industry. It produces over 74 billion chips a year equating to 230 chips per person in the United States.[11] The overall health of the U.S. semiconductor industry is strong, but there are several areas of concern that continue to impact the market. Below is a list of areas the Electronics Industry Team believe deserved their own analysis and assessment in order to understand the overall industry.

Firm Consolidation:

The semiconductor industry has experienced an unprecedented wave of mergers and acquisitions in recent years that reached new heights in 2015. In fact, the combined value of announced mergers and acquisitions in just the first half of the year, approximately $72.6 billion, equaled nearly six times the annual average value of deals struck during the previous five years.[12] By the end of 2015, the total value of acquisitions exceeded $100 billion.[13]

There are several reasons driving this consolidation: exponential growth in the cost to build the newest fabs, low interest rates enabling the ease of purchasing other company's intellectual property, and China's desire to quickly build an indigenous semiconductor industry. The cost to build a fab with the leading edge technology is around $10 billion.[14] Because of these costs, companies that cannot produce at scale or afford to operate a fab can take advantage of the fabless model perfected in the 1990s. Fabs have consolidated dramatically at the leading-technology edge and consequently only four firms are currently manufacturing at 14nm or have the potential to go to the 10 and 7nm nodes: Intel, TSMC, Global Foundries, and Samsung.[15] In addition to fab costs, R&D is extremely expensive and innovative technology often comes from smaller firms. Larger firms purchase these smaller firms to obtain their intellectual property and/or gain their market share.[16] Lastly, China is planning to invest significantly in the semiconductor industry in order to create an indigenous, leading edge capability, leading to further consolidation in the industry. China realizes that it is simply cheaper to acquire intellectual property through mergers and acquisitions than it is to develop its own.[17] China will continue to play a leading role in driving the industry toward consolidation and globalization in 2016.[18]

Workforce:

The semiconductor industry cannot operate without very highly-educated and qualified workers in the science, technology, engineering, and mathematics (STEM) fields. Within the United States, the question of whether there is, or is not, a concern finding qualified workers seems to be a function of what the company does and where it is located. Typically, firms did not express any concern over finding qualified engineers, however, those companies that ran manufacturing facilities did find it more difficult to find qualified technicians. Management at one company said that unlike engineering jobs, these jobs do not call for a four-year undergraduate degree, but they do require a two-year degree in some sort of advanced manufacturing field. It is a bit counter-intuitive that there could be a manufacturing workforce shortage for an industry that has so few workers inside its factories. The fabrication of semiconductors is highly automated and therefore doesn't require large amounts of staffing like a typical assembly line, but each worker does need a certain level of math and technical skills in order to work with the computers and highly advanced machinery.

Every company in the semiconductor industry that was visited as part of the industry study said they utilize the H1B visa program and support it. Many expressed frustration at not being able to hire highly qualified foreign persons possessing STEM graduate level degrees. They are particularly vocal about the need for changes to both the STEM education system and the H1B visa program. The evolution of semiconductor development and production has progressed to a point where a chip is so complicated and complex that employees in this field need at least a master's degree, if not a PhD, in either electrical engineering or computer science to understand the concepts and theories used to design them. Such a need for very high levels of education really shrinks the pool of potential candidates. The failure of the United States to produce enough STEM-educated graduate level talent, coupled with problems in the H1B visa program, could leave the United States vulnerable in the future.

Research and Development:

The U.S. semiconductor industry will continue to be dominated by the private sector and driven by market forces. Over 98 percent of demand for semiconductors comes from the private and commercial sectors, not the U.S. Government or the defense industry. Consequently, the industry will continue to innovate to remain competitive in satisfying commercial consumer demand. Currently, it requires an average of 15-20 percent of annual revenues going toward R&D to remain at the bleeding-edge[19] - this translates to billions in private investment every year. In 2015, the approximate R&D by major U.S. semiconductor corporations such as IBM, Intel, Micron, Applied Materials, Altera, and AMD was more than $16B.[20] This funding far exceeds the U.S. Government Science and Technology budget in any specific industry focus area. Though the global semiconductor industry is facing technological and economic challenges, the United States remains the world's innovation leader and commands the world's market share in the tools for chip design with a whopping 93 percent.[21] The United States also leads the world in the in fab-specific tool development needed to reliably mass-produce semiconductors. Despite the lead in R&D currently enjoyed by semiconductor companies in the United States, foreign companies that benefit from large-scale, state-based funding could take the lead in the near future.

IP Protection:

An even greater worry within the U.S. semiconductor market is the threat against intellectual property. Within the FBI, counterespionage, including economic espionage and the theft of trade secrets, is second only to counterterrorism in priority rank.[22] Estimates of the loss to the U.S. economy range from $2 billion to $400 billion annually – a value that is difficult to determine – but nonetheless is a detriment to U.S. competitiveness in the global market.[23] In 2015, U.S. semiconductor businesses received nearly half (48%) of the total number of patents granted to the top 15 U.S. companies.[24] Additionally, three of the top five patent recipient companies were semiconductor companies: IBM Corporation (#1: 7,355 patents), Qualcomm (#2: 2,900 patents), and Intel Corporation (#4: 2,048 patents).[25] For the Electronic Design Automation (EDA) segment of the semiconductor industry, revenues generated from semiconductor IP became the largest revenue source in the fourth quarter of 2015.[26] In FY 2015, the U.S. Customs and Border Patrol (CBP) seized 520 critical technology components and 262 consumer electronics, combining for 17 percent of the total items seized under the "Health, Safety, and Security" category (see Table 2 in the Appendix).[27] According to a 2011 investigation by the Senate Arms Services Committee (SASC), approximately 1,800 cases of suspect counterfeit electronic parts were uncovered, totaling over one million individual suspect counterfeit electronic components.[28] Also in the 2011 SASC investigation, it was reported that 70 percent of the counterfeit parts could be traced to China.[29]

By supporting national IP protection strategies, the U.S. government can help strengthen America's creativity and innovation.[30] As a valuable contributor to the United States economic growth, protecting IP in the semiconductor industry is a significant matter of national security.

Trusted:

Access to trusted and reliable semiconductors is a concern to the U.S. government. The Trusted Foundry Program (TFP) [31] was established to address two distinct needs: to provide an accredited network of Trusted Suppliers to protect against counterfeit sources and malicious insertion *and* to assure access to manufacturing capabilities for legacy and cutting-edge applications.

The network of accredited suppliers maintained by the TFP operate under the growing pressures of the commercial marketplace and will require added attention from DoD Program Managers as costs to maintain the viability of their trusted supply chain increase. The commercial market's dramatic increase in size, profitability and access to leading-edge technology has dwarfed the DoD segment of the global microelectronics industry. This makes it increasingly difficult to develop and manufacture lower quantities of DoD-specific integrated circuits. The rapidly escalating cost of foundries has also driven their consolidation, exacerbating the pressure to abandon smaller markets like defense.

Guaranteed access to the leading-edge silicon foundry processes is critical to the nation's security in order maintain the technological edge and dominance enjoyed by U.S. Armed Forces on the modern battlefield. These processes make possible not only the development of new capabilities in navigation, sensing and electronic warfare, to name only a few, but the upgrade and maintenance of legacy systems for all warfighting domains.

Trusted sources for leading-edge silicon technology were limited to a single source, IBM in 2014. IBM's sale of its semiconductor fabs to Abu Dhabi-owned GlobalFoundries represented a potentially critical blow to DoD's ability to access technologies at 65-nanometers and below. The deal struck by the TFP to form GlobalFoundries 2, maintains access to new processes down to the 14-nanometer node and appears to provide a current and near-term capability. But the long-term viability of this arrangement is questionable in the face of pressures to achieve commercial profitability within these facilities.

The objectives of developing trusted sources, protecting IP, and maintaining access to fabrication methods to assure supply chain security are shared by the government along with the commercial industry and a number of dedicated development efforts are underway that can be leveraged to achieve these objectives. This remains an issue however, that demands greater attention for the U.S. government.

Export Control:

From the perspective of the U.S. semiconductor industry, a greater problem than 'Trust' in the market is export controls. A broad-based interagency review of the U.S. export control system directed by President Obama in August of 2009 determined that the current export control system is overly complicated, contains too many redundancies, and, in trying to protect too much, diminishes the ability to focus efforts on the most critical national security priorities. More specifically to the semiconductor industry, Semiconductor Equipment and Materials International (SEMI), a global industry association serving the semiconductor industries, argues that export controls on semiconductor equipment and materials are out of date and need reform.[32] Under President Obama's Export Control Reform Initiative, the U.S. Executive branch worked to move items previously controlled by the State Department under its International Traffic in Arms Regulations (ITAR) to the export control jurisdiction of the Department of Commerce under the Export Administration Regulations (EAR). This will still allow some items to be controlled as military items, but in a more flexible way with respect to NATO and other U.S. allies. This will reformat the remaining ITAR controls into a more accurate list of items that warrant individual license reviews even for use by NATO, other U.S. allies, and partners. However, export controls under both the EAR and the ITAR remain highly technical, complex, and administratively burdensome, both to comply with by industry and to implement by the Executive branch. Put simply, export controls are easy to add, but very difficult to remove and grow in complexity as various parties strive to clarify and "limit" what cannot be removed. Despite the U.S. government's efforts to reform it, ITAR remains a four letter word in the industry.

Taxes:

Taxes is another area where the government is taking steps to improve U.S. competitiveness. On 18 December 2015, President Obama signed the Consolidated Appropriations Act of 2016. Added to this act was the Protecting Americans from Tax Hikes (PATH) Act which made permanent the availability of Research and Development Tax credits.[33] While this was hailed by the Semiconductor Industry Association President and CEO as "Huge" for the semiconductor industry, significant issues remain. Tax watchdog groups continue to highlight $2.1 trillion in overseas corporate accounts avoiding taxes.[34] Conversely, corporations, lobbyists, and some in congress point to the fact that the U.S. corporate tax rate is the 2nd highest in the world.[35] Many companies visited commented on the high corporate taxes. No matter which side of the issue one finds oneself, everyone involved agrees the corporate tax system needs to be reformed. This year little is expected to change primarily due to the presidential elections.[36]

ASIAN SEMICONDUCTOR INDUSTRY

The Asia-Pacific semiconductor market has become the manufacturing epicenter for the industry. The Asia-Pacific region "is the fastest growing market as consumer demand, packaging of semiconductors, and electronic systems production has shifted to this region."[37] Initially drawn by government incentives in the 1980s and now closest to the supply chain, the fabrication locations are going to remain in Asia for the foreseeable future as South Korea, Taiwan and mainland China continue to grow and invest in new fabrication capability and U.S. companies continue to migrate to the fabless model and invest in manufacturing overseas rather than in U.S. fabs. South Korea's Samsung continues to heavily influence the market as a key producer for Sony, Apple, Dell, Hewlett-Packard, Verizon, and AT&T. Samsung is also one of only four companies in the world able to manufacture using 14nm technology.[38] Taiwan boasts the largest and most technically advanced fabrication capabilities in the region with names such as Taiwan Semiconductor Manufacturing Corporation (TSMC). Taiwan and South Korea represent the number one and number two markets for semiconductor manufacturing equipment exports respectively for 2015-2016.[39]

In 2014, China was the largest global market for semiconductors representing 50 percent ($168 billion) of the $336 billion market – *yet* Chinese companies supplied only 4 percent of that share.[40] As a result, China is looking to reduce its dependence on foreign semiconductors by advancing its own semiconductor industry to meet its domestic needs.

China is aggressively pursuing its "Made in China in 2025" modernization plan, driving toward 14nm technology capability by 2020.[41] "Made in China 2025" is a costly national plan that will use mandates, subsidies and other methods to persuade manufacturers to upgrade their factories in order to make China a green and innovative "world manufacturing power" by 2025.[42] China attempted to create a semiconductor business in the 1980s, but the effort stalled. China is once again making concerted efforts to grow its integrated circuit (IC) and semiconductor manufacturing.[43] In 2014, the Chinese government released its "National Guideline for Development of the Semiconductor Industry," calling for accelerating the nation's efforts in 14 nanometer (nm) chip making, advanced packaging, MicroElectroMechanical Systems (MEMS), and memory chips;[44] part of the plan also created a $21 billion national government fund to invest in domestic IC manufacturing.[45] The goal of the "Made in China in 2025" program is to increase domestic components in ten key areas: information technology, robotics, aerospace, shipping, railways, energy systems and vehicles, power equipment, materials, medicine, and agricultural machinery.[46] These guidelines set targets for a China National IC investment fund to spur industry at annualized growth rates above 20 percent through 2020 and include IC manufacturing, design, packaging and test, materials and equipment. SEMI estimates investments could reach $100 billion when central, regional and local government funding is counted.[47]

This drive will significantly impact the industry as their 1.3 billion people grow into the middle class, creating a demand for Internet-of-Things chips and vastly increasing China's overall demand for semiconductors. U.S. companies must figure out how to maneuver into these markets if they are to stay competitive or risk being left behind. American companies are desperately seeking to enter into and compete in China, sometimes paying exorbitant legal fees and acquiescing to questionable anti-competition laws to do so. At the same time, China wants to build its own domestic semiconductor market as it weens itself off of foreign imports.

China is making progress and it's only a matter of time before they are able to dominate their own domestic market, but their ability to dominate the global sector will be limited by China's ability to quickly innovate and stay at the bleeding edge. China is already the largest semiconductor market in the world. Due in part to increased national security concerns following the Edward Snowden leaks, China is also striving to become the world's leader in semiconductor manufacturing. For now, China's biggest challenge is developing the innovation, technology and intellectual property indigenously. Companies like Apple, Micron and ARM are keeping most of their innovation and IP in the west, while using the fabless model to take advantage of the existing fabrication throughout Asia.

OTHER REGIONS SEMICONDUCTOR INDUSTRY

The burgeoning indigenous Chinese semiconductor market is not the only threat to the U.S. industry as other key countries and companies in Europe and the Middle East are making a run at grabbing a share in the $355 billion global semiconductor market.[48]

In Europe, countries such as Germany and France have emerged as contenders in both the hardware and software development industries. In Germany, for example, their tremendous strength and reputation in the global automotive industry has made them well-positioned to take advantage of the cyber-related technologies now being embedded in cars and trucks. Companies such as Mercedes-Benz, BMW, and Volkswagen, are emerging as frontrunners in smart-auto development – combined with Germany's other positive attributes in education, geography, and its strong work ethic, result in the ingredients for another Silicon Valley-like incubator.[49] The biggest question mark, however, may be that Germans tend to be risk-averse, which is not necessarily consistent with a society that leads in innovation.[50]

The Middle East region is also showing promising signs within the tech industry. In Israel, for instance, in 2014 there were 140 scientists, technicians, and engineers for every 10,000 employees – compared to 85 per 10,000 in the United States.[51] This technical capacity is fueled by a significant level of R&D investment by the Israeli Government. Israel invests the largest amount of funding in R&D in relation to gross domestic product in the world (4.2 percent),[52] and over 40 percent of the funding is used for national, bi-national, government, and university research.[53]

But perhaps the most intriguing country to watch in the region is the United Arab Emirates (UAE). The UAE's government knows it must decrease its reliance on petroleum-based revenue and has publically committed to transition to a knowledge-based economy by supporting and promoting innovation initiatives and research & development. In 2015, it announced plans to increase current R&D expenditures from 0.5 to 1.5 percent of GDP, and with non-petro real GDP growth from 3.5 to 5 percent within the next five years.[54] This, coupled with recent investments in established semiconductor companies such as GlobalFoundries' acquisition of IBM's microelectronics semiconductor manufacturing, has shown that the UAE is serious about diversifying its oil dependent economy into a tech industry future. "Today we have significantly enhanced our technology development capabilities and reinforce our long-term commitment to investing in R&D for technology leadership," said Sanjay Jha, GlobalFoundries' Chief Executive Officer, when referring to the IBM microelectronics acquisition.[55]

EMERGING TRENDS

Innovation leadership will continue from the private sector, but it will be more nuanced, complicated and expensive. This trend is driving collaboration and strategic alliances among global competitors in the industry to innovate silicon-based solutions in the near-term, and explore leap-ahead technologies in the long-term. This may potentially have adverse implications to the United States' technology advantage. Despite economic and technological challenges to the semiconductor industry as a whole, the United States remains the world's innovation leader and holds the world's market share in the design and in the development of the tools to reliably mass-produce semiconductors.[56] There are three potential paths to get to the next significant gain in chip performance: 1) continue scaling using new materials and devices to extend core logic and memory technology, 2) build new architectures with or without devices, and 3) develop new computational paradigms.[57] All major American semiconductor and computing companies such as IBM, Intel Corporation, and Advanced Microelectronic Devices (AMD) are investing in these areas as well as academia and the U.S. government.

PORTER'S FIVE FORCES ANALYSIS

For the purpose of using the Porter's Five Forces Analysis tool on the semiconductor industry, the industry is defined as the manufacture and sale of semiconductors and related products.[58] Named after economist Michael E. Porter, the analysis tool uses five competitive forces to determine the overall strengths and weaknesses of an industry. The five forces include competition within the industry, potential of new entrants into an industry, the power of suppliers, the power of buyers, and the threat of substitute products to the industry.[59]

The competition within the industry is characterized as intense, primarily due to the presence of large, multinational players.[60] Firms tend to compete on differentiation, where one may have a strong position in the personal computer market, another may dominate in the mobile device space.[61] Though some of the larger players have diversified portfolios, like Samsung Electronics and Toshiba, others like Intel and Texas Instruments are more limited and thus far more dependent on their semiconductor revenue. This makes for a high degree of competition from within the industry.[62] Ultimately it is these already established and entrenched companies that hold the most power within Porter's model, which adds to the intensity of the competition at this level.

The potential threat for new entrants is very low due to the enormous capital expenses required to enter the market. The rising barriers to entry and complicated R&D requirements make entry more difficult.[63] The only real threat from new entrants is from fabless companies that avoid the high costs required for production facilities.[64]

The overall power of suppliers is moderate.[65] Though suppliers do have leverage because the inputs are highly specialized and the buyers are limited in number, in-house production by the larger semiconductor companies dilutes this leverage.[66]

Buyer power is also characterized as moderate as the wide range of buyers includes computer and network hardware, industrial controls, defense systems, automotive, and consumer electronics. This wide range of customers weakens buyer power.[67]

There is virtually no threat to the market from substitutes as semiconductor end-users currently have no alternative. Though the threat of breakthrough technology persists, from nanotechnology for example, the only real threat of substitution is from less costly, inferior counterfeit semiconductor technology.[68]

Despite the current landscape in the global semiconductor market as described by the Porter's Five Forces analysis tool, all of this has the potential to change quickly with the realization of a heavily subsidized, protected, and state-financed indigenous, semiconductor industry that is immune to the forces of the market economy.

OUTLOOK

The industry continues to rush toward what appears to be an end to Moore's Law in the traditional silicon sense. Moore's second law (also known as Rock's law), which states that the cost to manufacture Integrated Circuits doubles every four years,[69] is increasing its rate of change as Moore's Law slows. This makes entry into the integrated circuit fabrication and manufacturing market too expensive for all but a very elite few companies. As the industry observes this dynamic, many are looking for alternative, non-traditional means to keep the essence of Moore's law alive. Others are looking at markets or products that can use the current leading edge technology (14-7nm). With the emergence of the Internet-of-Things, people are increasingly connected with their homes, cars and environment. Many companies are looking to capture a portion of this market. Despite the deep and historical roots between the integrated circuit and the defense industries, the emergence of the consumer electronic market and the dynamic, ever-changing technologies in the industry are rapidly leaving the defense sector behind and make it vulnerable to relying upon obsolescent technologies.

Five Year Outlook:

In the near term, the industry will continue its current trajectory. Firms will continue to consolidate in an attempt to capture market share and/or intellectual property. The industry workforce will continue to be led by engineers from all over the world, trained primarily at U.S. universities. This will continue to stress the H1B visa program, and calls for reform should gain momentum. As other nations gain a larger portion of the market, U.S. intellectual property protection will become more critical. President Obama's Export Reform Initiative should continue, as will calls for changes to export controls, but little change will likely occur in the near term. Reform to corporate tax policies will rely on congressional support and will likely not change dramatically in the near term. The Department of Defense will experience further constrained budgets which will exacerbate the struggle to maintain weapon systems and programs with older integrated circuit technology.

Companies will continue to use the current silicon technology, but will look for opportunities such as the Internet-of-Things and new technologies to garner profits. These companies will continue to lead all industries in R&D spending in an attempt to maintain Moore's law. New methods, processes or materials will emerge as possibilities to extend Moore's law.

The Asian-Pacific region will continue to grow, and governments in the region will support growth through investments, partnerships, and incentives. China, Japan, South Korea, and

Singapore represent four of the top five markets for semiconductors, and Taiwan, South Korea, China, Japan, and Singapore represent the top five markets for semiconductor manufacturing equipment, according to the U.S. Department of Commerce International Trade Administration for 2015-2016.[70] The epicenter of the industry will continue to shift toward the Asia-Pacific as regional revenues for semiconductors push toward $210 billion in 2015, far outpacing the Americas and Europe.[71] In China, the government has made no secret about its goal to transform its semiconductor industry to world class status. Coupled with a growing middle class that drives demand for consumer electronics, China represents a huge economic opportunity. Via its massive semiconductor market and its burgeoning semiconductor manufacturing capability, China is set to become the economic center of the industry in the next five years.[72]

Ten Year Outlook:

Longer term outlooks will observe the physical limits of silicon and the slowdown of Moore's law, but will also see a more diverse use of the current technology. More dramatic changes will occur as new technologies appear and move the industry beyond silicon and back on Moore's law trajectory. Firm consolidation will slow as other nations achieve technological parity with U.S. industries. Workforce training will continue in the United States and more favorable H1B visa policies and domestic STEM programs will continue to encourage foreign and domestic students to flock to American universities. The workforce demand will continue to increase in Asia and will compete with the U.S. workforce. The pace of intellectual property theft will slow as other nations achieve parity in the silicon technologies. IP theft will focus on defense systems and new technologies that will go beyond silicon. The Department of Defense may benefit from a slowdown of Moore's law as the gap between current defense technologies and leading edge technologies could decrease, leaving the sector better able to deal with the threat of obsolescence.

Looking forward beyond the next five years to ten years out, China and the greater Asia-Pacific region will continue to shape and influence the global semiconductor market. China is betting big and making huge investments in the industry to incorporate the entire supply chain while developing and growing capability in IC design, and innovation. Due to its deliberate shift toward a more market based economy and its Made-in-China-2025 program, China could potentially dominate the future with their continued emphasis on development and collaboration across the entire semiconductor ecosystem.

The end of the next decade may see dramatic changes or disruptive shifts in the industry because of new technology. This new technology will allow the industry to move away from silicon and will provide a marked advantage to the nation or company that achieves it. The U.S. budget will continue to be taxed by debt and mandatory spending. The dramatic increase in the cost of health care and social security will be more pronounced. Changes to tax policies will likely occur to account for these increases which have the potential to negatively impact the U.S. semiconductor industry.

CHALLENGES AND POLICY RECOMMENDATIONS

Challenge #1: Moore's Law in silicon-based microchips reaching its limit

Integrated circuit design has traditionally used a planar (or two-dimensional) structure, with a metal gate mounted across a flat, conductive channel of silicon. The gate controls the electric current flowing from a source electrode, at the one end of the channel, to a drain electrode at the other end. Small voltage applied to the gate lets current flow through the transistor. When there is no voltage, the transistor is switched off. These two binary states, on and off, are the ones and zeros that define the digital language of computing.[73]

When transistors are miniaturized beyond a certain point, specifically at the atomic level, electrons flowing from a power source can tunnel their way through the insulator protecting the gate, instead of flowing direct into its drain. This current leakage wastes power and raises the temperature and can cause the device to fail. Leakage becomes a serious problem when insulating barriers within transistors approach thickness of a few nanometers (~3nm or so). Below that size, the potential for leakage increases exponentially and risks making the transistor useless.[74] This physical limitation is forcing the industry to investigate *how* to achieve the next sequential step in Moore's law while remaining economically feasible.

Companies will continue scaling using new materials and devices to support core logic and memory, build new architectures, with or without devices, and develop new computational paradigms to contend with the physical limits of Moore's Law.

Challenge #2: Economies of Scale

While the cost per transistor is almost inversely proportional to the number of transistors crammed in a chip, there comes a point where the decrease in yield begins to outweigh the benefits of the chip's increasing complexity. Moore's Law has always been as much about reducing the cost of transistors as about increasing performance, yet as transistors get smaller, the risk of more defective chips during production increases. Therefore, there is a trade-off between complexity and cost that feeds into the economic decision to produce the next generation of chips.

Challenge #1 and #2 Policy recommendation: Fund E.O. 13702[75]

The National Strategic Computing Initiative is a positive policy effort to start moving American computing innovation in the right direction. However, it requires programmed funding to provide enabling financial mechanisms and laws to protect America's intellectual capital, the engine behind innovation. The U.S. government should take steps to protect the U.S. industry's intellectual property, which is critical to maintaining its global leadership in the industry. The U.S. government should also pursue a meaningful dialogue with industry to identify those technologies that may have potential dual use (military and commercial) to increase mutual benefits in defense off-sets and economic gains. The government and industry should also discuss those technologies that may be only for commercial use but may have adverse consequential disruptive effects to our national security interests.

The key for the government is to accept the fact that is not going to lead the effort financially but should set the conditions, through effective policies and communication with industry, to enable a sustained national technology advantage. This technological superiority is an essential element of our national defense.

Challenge #3: Chinese Challenges

As discussed earlier in the current conditions section, China will continue to grow as a semiconductor manufacturing center and a very large semiconductor market. Their large investment, designed to build a self-sufficient industry within China, will influence the semiconductor industry globally. From mergers and acquisitions to obtain key technical knowledge, to increased capacity through investment in fabrication facilities, China's goal of reducing foreign dependence appears to be within reach. Combined with a growing Chinese middle class, the demand in China for semiconductors will continue to grow.[76] China is aggressively pursuing its "Made in China in 2025" modernization plan and will very likely achieve the goal of 14nm technology capability by 2020 as it continues to close the gap with countries at the "bleeding-edge."[77]

Two issues arise as China increases its share of the semiconductor industry. First, China's production could flood the market, deflating prices and making it difficult for competition to maintain viable alternatives. Second, China's relatively closed market will continue to prove difficult for U.S. companies to enter. Qualcomm is a recent example, where, in February 2016, they were assessed a questionable $975 million fine by Chinese authorities, but paid the fine to stay in the market.[78] Because of the huge Chinese market, many companies may be willing to accept otherwise unreasonable demands to gain, and maintain, access to the Chinese market.

Challenge #3 Policy Recommendation:

The U.S. government must continue to stress to the Chinese government that it must respect international rule of law as it relates to IP protection and punish those who might steal it to bolster their industry. President Obama did this in his recent meeting with Chinese President Xi Jinping, but little appears to have changed as Chinese companies continue to hack U.S. businesses for their IP and products. Second, the U.S. government must continue to set the conditions for U.S. company success, not by protecting them, but by providing tax incentives, encouraging STEM education, and investing in the infrastructure necessary for keeping the development and manufacture of products in the United States.

Challenge #4: Intellectual Property

IP protection is a national security matter as theft and counterfeit electronics in the commercial and military supply chain risk the reliability and functionality of both. There are federal criminal laws that cover the theft of trade secrets, a form of IP, but resources are limited to significantly curtail the problem, and the laws that protect IP could go further. The Defend Trade Secrets Act of 2015, which passed the Senate and is awaiting House approval, would provide private companies federal civil remedies for trade secret misappropriation.[79,80]

Counterfeit electronics in the commercial and military supply chain pose risks to the health, safety, and security of unsuspecting consumers and pose an even greater threat to U.S. national security. From 2009 to 2016 there were six federal prosecutions involving trafficking in counterfeit military electronics. This represents only a small fraction (approximately 0.3 percent) of counterfeit and suspected counterfeit electronic parts in the DOD supply chain.[81,82,83,84,85,86] According to a 2011 investigation by the Senate Arms Services Committee (SASC), approximately 1,800 cases of suspect counterfeit electronic parts were uncovered, totaling over one million individual suspected counterfeit electronic components.[87] The DOD's process for preventing, monitoring, detecting, and reporting counterfeit parts in its supply chain is ineffective. Several anti-counterfeiting methods are in research and development, but none have been successfully implemented.

Challenge #4 Policy Recommendations

As reported in the 2011 SASC investigation, 70 percent of discovered counterfeit parts could be traced to China.[88] The majority of trade secret theft and intellectual property cases are attributed to Chinese actors, and there is more than enough evidence that the Chinese are using illegal means to acquire technology in order to catch up with U.S. industry. The U.S. government should be more proactive in dealing with this problem, whether it means applying directed sanctions against known bad actors, or enacting clauses in trade deals that require foreign companies to respect and adhere to U.S. trade secret and intellectual property rights, and copyright and patent laws. The U.S. government needs to make it more painful for the Chinese, or others, to steal intellectual property and work with international governing bodies to do the same.

Another policy recommendation is to control the export of electronic waste (e-waste). The United States exports nearly 800,000 tons of e-waste annually.[89] Much of that material becomes feedstock for counterfeiters to reuse, remark and resale. Without enforcement laws, discarded chips will likely continue to be repurposed for U.S. commercial or military supply chains by malicious actors. Realistically, this policy might only impact half the supply of e-waste as the U.S. exports over 51 percent of its chips and can only control what is done with the waste domestically. However, it could influence other nations who may also be dealing with the same counterfeit supply chain issues to adopt similar measures.

Intellectual property fuels the semiconductor industry. It is imperative for the nation's economic security that protection of intellectual property is provided by the federal government. The industry and government must work together to find an effective solution to the counterfeit chips in the commercial and military supply chains. With so much evidence pointing to the Chinese as the main perpetrators of the stolen IP and counterfeit chips, the United States needs to adopt enforcement policies to hold them accountable. Finally, controlling the export of e-waste could be a first step in stemming the tide of counterfeit parts in the microelectronic supply chain.

Challenge #5: Trusted Parts/Access

Access to trusted sources of legacy and leading-edge semiconductor technology manufactured through assured methods is a critical enabler of the nation's security and continued dominance of U.S. forces on the modern battlefield. The recommendations below are suggested methods to address counterfeits as well as the more daunting challenges of ensuring the defense industry's long-term access to cutting-edge technology.

Challenge #5 Policy Recommendation (Countering Counterfeits)

To address the issues of counterfeit parts infecting legacy system supply chains, current policy guidance and accreditation methods developed as part of the Trusted Foundry Program provide a workable approach assuming adherence by all levels of suppliers in this chain. However, even if all parties try to follow the TFP standards, it does not guarantee the supply chain against nefarious actors as the capabilities of those proliferating counterfeit chips and deliberatively inserting malicious content appears to be increasing faster than cost-effective countermeasures. The sanctity of the U.S. supply chain demands new detection methods such as those introduced by DARPA via their Trust[90] and IRIS[91] programs that could provide for better commercial intellectual property protection.[92] These programs need to be sponsored and promoted by the U.S. government and its key allies and industrial partners to ensure that they become the industry standard to protect the supply chains of both the defense and commercial markets. Solving this problem in the commercial market would minimize the need to impose further government requirements and could entice private investment in secure commercial applications for such industries as banking, power distribution, and safety applications, to name but a few. DMEA and TAPO could be appropriate organizations to support the promotion of these capabilities if they could build the necessary relationships, but it will likely require the development of a much stronger advocacy group to make these concepts basic industry standards.

Challenge #5 Policy Recommendation (Leading-Edge Technology Access)

The development of advanced government-specific semiconductor solutions requires continued access to the latest process technologies that the Trusted Foundry Program may, or may not, provide to the government and defense industry. The level of support provided for the recently established contract with GlobalFoundries 2 has not been disclosed, but if it is expected to remain a viable alternative for the duration of the 10-year agreement, it will need to grow in accordance with the costs of the previous contract established in 2006 and the associated increase in cost of these advanced processes. Based on this analysis, current investments levels would need to be in the

$100M's and grow to a figure in excess of $1B/year by 2020. Without deliberate intervention and active coordination of government-wide requirements to defray these costs across multiple programs, this path will prove unviable within a short period of time and alternative paths must be developed. The following are recommendations for maintaining defense sector access to critical technology:

Near-Term: Robustly support the current Trusted Foundry Program access to 14-nm technology through GlobalFoundries 2. Continue to subsidize R&D access to Multi-Project Wafer (MPW) runs and aggressively coordinate government use of TFP lines to maximize utilization rates and extend access if possible. TFP is the only near-term mechanism that gives DoD access to these technologies and the leverage for continuing this partnership is diminishing as the process technology advances to the next level of performance. Sound commitment in the form of funding to offset the direct cost to legacy and advanced program access to this line will be needed until such time that alternatives can be developed.

Mid-term: Reevaluate the definition of access to trusted designs fabricated through on-shore foundries and aggressively pursue the establishment of ASIC fabrication through Intel (Altera) and Micron to establish and bolster secondary sources through aggressive R&D funding. This approach must be taken in conjunction with the broader U.S. strategy to maintain and grow the United States' continued leadership in the global semiconductor market.

Long-term: Develop technologies that couple hardware with software design to make the circuitry secure-by-design, such that it can be released for fabrication in the global marketplace. Utilize emerging methods for virtual design, drawing upon digitally "fingerprinted" IP and potentially exploiting their anonymity to obscure functionality. Explore semiconductor fabrication methods to support small-scale production required of government-specific applications.

The efficacy of the Trusted Foundry Program is tenuous as it seeks to maintain assured access to a broad range of semiconductor manufacturing capabilities critical to the DoD. The limited number of sources, growing diversity in DoD requirements, and economic pressures of the global marketplace threaten its long term viability. The issues for maintaining access to the technologies for legacy systems are well established and promising new methods are in development to deter counterfeits from corrupting these supply chains. Access to leading-edge technologies through the Trusted Foundry Program faces a different set of challenges. GlobalFounderies 2 provides access to the latest technology node, but longer term access is not assured. Substantial work will be required to develop methods that redefine our understanding of "trust" in order to leverage the strengths of the global marketplace. Although the United States still retains a leading position in many segments of the industry, new approaches are needed to ensure the United States maintains this lead and that the defense industry continues to have access to it.

CONCLUSION

The United States created, and continues to lead, the semiconductor industry. However, the United States is losing its positon in the industry. As discussed in the above paragraphs, many events have influenced the industry throughout its 70 year history. Moore's first and second law (also known as Rock's Law) profoundly changed the industry.

Moore's first law, the idea that semiconductors will double in capacity each 18-24 months, was vigorously pursued by the industry as almost a self-fulfilling prophecy and Moore's quote at the beginning of this paper alludes to its end. What he refers to is the physical limits of silicon chip technology; however most of the companies visited are actively pursuing new technologies or materials that will effectively keep Moore's law alive.

Moore's second law, the idea that the cost of chips increases exponentially as the technology gets smaller, is also in full effect. The cost to manufacture integrated circuits with the latest technology is so prohibitively expensive that relatively few companies can produce enough volume to remain viable. This trend is part of the reason fabrication facilities moved from the United States to other areas of the globe (primarily Asia). This trend is expected to continue.

The defense industry relies on a low volume of primarily old-technology integrated circuits to support national defense systems. Maintaining older, low volume fabrication facilities is no longer economically viable for most companies. The lack of U.S. fabrication facilities increases the risk to trusted supplies of integrated circuits. Trusted supply chains are not just a department of defense issue as many commercial companies are also working alternative methods to verify authenticity of an integrated circuit and maintain the integrity of their intellectual property. These methods may be an alternative to a U.S-government owned fabrication facility which is most likely financially unsustainable at the cutting edge given the large amounts of financial support required and U.S. budget constraints.

As discussed in detail in previous sections, China is aggressively pursuing an indigenous leading-edge semiconductor capability. Its actions to obtain the requisite technology through intellectual property, hire a capable workforce, and grow Chinese companies will likely result in a relatively closed Chinese market in the long-run. Any restrictions into such a large market hurts the remaining global industry, including U.S. companies. The United States must set the conditions for U.S. companies to succeed through fair trade, tax and workforce policies.

The Electronics Industry Team identified several other issues that may improve the U.S. semiconductor and defense industries. First, policies that support H1B visas and U.S. STEM programs will ensure that the United States continues to have the technical workforce needed to continue to innovate and lead the industry. Second, clearer export controls will ensure maximum competitiveness in the market, yet also maintain security of the most sensitive technology. Third, the research and development tax credit is a great step toward maintaining the U.S. lead in the industry. Further tax reform will make U.S. companies more competitive in the global market.

In summary, the United States maintains a leading role in the global semiconductor market. However, the market continues to shift toward Asia. Increasing fabrication costs, unfair trade practices, intellectual property theft and U.S. tax policies are a few reasons for this shift. In order for the United States to maintain its leading role, it must protect intellectual property, fight unfair trade practices and educate its workforce. As the physical limits of Moore's law draw near, the costs of manufacturing integrated circuits increases. Government and industry partnerships in research and development will drive the industry beyond Moore's law and, if done properly, can ensure the United States maintains its leading role. Historically, the defense sector enjoyed significant influence in the industry. That is not the case today. Therefore, access to trusted, cutting-edge fabs are at risk and new approaches are required to ensure trusted supply chains are available to the defense industry for the foreseeable future.

ESSAYS

IP Protection Essay

IP protection is a matter of national security, specifically as it affects our economy and military. The U.S. semiconductor industry contributed to the national economy, providing over $65 billion to the U.S. gross domestic product (GDP) from 1987 – 2011.[93] America's ability to resource its national security lies in its financial strength. Any threat to the U.S. economic engine is therefore a threat to U.S. national security. Furthermore, the threat of counterfeit semiconductors in electronic devices puts the American public's health, safety and security at risk. The theft of IP in critical defense systems could compromise U.S. strategic advantage. Finally, counterfeit semiconductors have been found in components in the U.S. Department of Defense (DOD) supply chain.[94] This is a national security threat for many reasons, including questions of quality, reliability, and tampering.

The next looming challenge are cloned chips, which are more difficult to detect.[95] They are essentially "advanced" counterfeits in that the perpetrators reverse-engineer the IP and manufacture the chips on their own.[96] It is a more costly approach, but according to one industry representative, the Chinese have courses at universities teaching students in this process.[97] Presently, U.S. chip designers are still innovating faster than adversaries can clone the process, but the danger of clones in the U.S. supply chain looms near and an effective solution is urgently needed.

DoD Requirements and Obsolescence Essay

Since the 1950s, DoD's requirement for a technological advantage to counter adversarial strengths led to the first and second offset strategies that produced long-range nuclear delivery capability for nuclear deterrence, aircraft stealth technology, precision guidance munitions, and intelligence, surveillance, and reconnaissance dominance. "In 1963 almost 100 percent of the U.S. production of ICs went to the military, 95 percent in 1964."[98] Today, DoD is less than two percent of the IC market.[99] The commercial market is driving this industry.

Modernization Effort:

In recognition of the growing need for ICs and broad span of DoD requirements, the Defense Microelectronics Activity (DMEA) was created in 1997.[100] The mission of DMEA is, "to research current and emerging microelectronics issues, with a focus on warfighters needs, and to leverage advanced technologies to extend the life of weapon systems by improving their reliability, maintainability and performance, while addressing the problem of diminishing manufacturing sources."[101] DMEA works with the acquisition community and their industry partners to support fielded system, ensure a modular design approach is being implemented to spiral in new technology and verify/validate future designs. DMEA works with the science and technology community for applied research and integration of emerging IC technologies; and the logistics community to address part obsolescence issues. DMEA manages and certifies IC manufacturers as part of DoD's Trusted Foundry program.

Trusted ICs: The Trusted Foundry program plays a vital role in the nation's national security by ensuring U.S. weapon systems receive certified, reliable and affordable semiconductors. DoD's policy has evolved over the past 25 years to address the threat to the supply chain from counterfeit chips and malicious code insertion into the chip's software. The first of such policies was Department of Defense Instruction (DoDI) 5200.39, Critical Program Information (CPI)

Identification and Protection within Research, Development, Test, and Evaluation, released in 2008.[102]

Third Offset: On 15 November 2014, former Secretary of Defense Chuck Hagel launched an innovation initiative to ensure the U.S. military maintains a technological competitive edge with adversaries seeking disruptive technologies.[103] The innovation initiative is known as the third offset and is being headed by the Deputy Secretary of Defense, Robert Work. The 14nm-and-below semiconductor technology required to produce this third offset is being driven by the consumer electronics, not the DoD, market. However, without funding, the third offset strategy will die on the vine. Currently, about $1 billion of the 2017 budget request sets aside funding targeting the third offset while tradeoffs are being made in the Future Years Defense Program (fiscal years 2018-2022).

Obsolescence: The United States has enjoyed a military competitive advantage while pushing the envelope on technological advancements for several decades. This advantage has allowed the United States to engage threats with a focus on capability rather than capacity. In recent years, that competitive advantage has been steadily shrinking due in part to globalization, the information technology explosion, and rampant espionage affecting both the commercial and military sectors.[104] The constant pursuit of cutting-edge technology to ensure military competitive advantage exposes weapons systems to an accelerated obsolescence of the weapons subsystems. These subsystems are largely semiconductor driven and are unique, low-volume endeavors highly susceptible to technological advances and the associated issue of obsolescence.

The Driving Force Behind Obsolescence: The largest companies, competing in cutting edge technology, invest several billion dollars in semiconductor manufacturing equipment capable of complex and high volume production.[105] To remain competitive, companies must generously invest in R&D while quickly providing newer more advanced products to the market, in high volumes. DoD interest in low volume and highly specialized solutions is incompatible with industry's commercial market strategy.[106] This mismatch creates an environment where obsolescence can thrive. In the case of defense systems and avionics it is estimated that between 70 – 80 percent of the electronic components become obsolete before the weapons system is fielded to an operational unit.[107]

Potential Obsolescence Solutions:

Modularity. Better Buying Power (BBP) 3.0 initiatives prioritize several new efforts to reduce cost and risk associated with DoD acquisitions. Select BBP 3.0 concepts, such as focusing on modularity and open systems architectures, could counter effects of obsolescence.[108] When using modular components, rapid changes in semiconductor technology can evolve autonomously within the weapons system.[109] This facilitates addressing obsolescence with Form-Fit-Function (FFF) replacements, emulation or redesign options with reduced impact on the overall weapon system.

Government Support of Lower-Cost Minifab Efforts. As competition drives companies to push the boundaries of Moore's Law to deliver newer more advanced products, industry is largely uninterested in obligating resources to the unique low volume efforts synonymous with DoD efforts.[110] One solution may be government support of lower-cost minifab efforts. Minifabs provide (1) small, flexible and agile production (2) quick build up to meet market needs (3) optimum-volume manufacturing and (4) a low-cost option.[111]

Shorter-Life Weapon System Developments. As major weapons systems are designed and developed for 30-40 year life cycles they are increasingly vulnerable to the effects of Diminishing Manufacturing Sources (DMS) which translates into increased obsolescence. One solution is to design shorter-life systems which can take advantage of newer technology more often. Solutions which rely on rapidly evolving technologies are opportunities for this approach, including for systems such as aircraft and ships.[112] Adopting such a strategy requires a significant reduction in the system development timeline to maximize a systems operational use.[113] If the DoD accepts 10-15 year life cycles rather than the 30-40 year life cycles currently used, the impacts of obsolescence could potentially be reduced.[114]

Conclusion:

The commercial market drives the semiconductor industry today, the DoD must adjust its policies to ensure weapon systems do not become obsolete before their lifecycle ends. In order to deliver bleeding-edge capability to the warfighter and achieve a third offset, DoD Project Managers will have to continue to rely upon DMEA's trusted program for suppliers and upon organizations like Defense Innovation Unit – Experimental (DIUx) to bridge the gap with industry, while DoD acquisition policies continue to evolve to decentralize control and empower the Service Chiefs. Furthermore, DoD must consider multiple potential obsolescence solutions for in-depth analysis, and potential pursuit in order to mitigate this threat. Modular designs, supporting mini-fab manufacturing efforts and the procurement of shorter-life weapons systems are all options requiring serious consideration for the long-term. Congress, DoD and industry must work collectively to analyze the merits of these solutions to identify the best cost effective methods capable of meeting DOD's weapons system needs of the future.

Export Controls Essay

Multilateral Export Control Regime Environment

Prior to 1994, the United States and its western allies maintained an embargo against the Soviet Union and other communist countries under a single regime known by its acronym CoCom (Coordinating Committee for Multilateral Export Controls).[115] After this date, the CoCom control list was retained under a new regime called the Wassenaar Arrangement.[116] This arrangement promotes greater regional and international security and stability through implementation of national policies such as export controls.

The second export control regime impacting the electronics industry is the Australia Group (AG). AG members endeavor to ensure that exports of chemical and biological items do not contribute to the development of chemical or biological weapons.[117] Among those items are high purity pumps and valves used in semiconductor process tools to direct and control the flow of chemicals and cleaning and polishing solutions used in silicon wafer processing. Finally, the Nuclear Suppliers Group (NSG) seeks to prevent the proliferation of nuclear weapons through implementation of a common set of guidelines and control lists, including controls on pressure transducers used to measure absolute vacuum in semiconductor processing tools.[118]

Legal and Regulatory Implementation of Dual-Use Export Controls

These export control regimes are important because of the way export controls on dual-use items and technologies are implemented pursuant to the Export Administration Act of 1979 (EAA),[119] Export Administration Regulations (EAR),[120] and the Commerce Control List (CCL)[121] for reasons of national security, foreign policy, and/or short supply.

Wassenaar dual-use items, including certain integrated circuits and wafers, semiconductor processing tools, chemicals and other materials, encryption and cryptography items, and related software and technologies, are controlled under the EAR for "national security" reasons.[122] In contrast, AG dual-use items, including certain pumps, valves and chemicals, are controlled under the EAR for "foreign policy" reasons.[123]

This distinction has some important consequences. First, only items controlled for national security reasons are subject to foreign availability determinations by the Department of Commerce pursuant to the EAA so as to allow for their decontrol or reduced control. Secondly, due to its history as the inheritor of the old COCOM export controls, the Wassenaar Arrangement's dual-use control list tends to be a grab bag of miscellaneous controls which often overlap with other regimes and is overly broad and all inclusive.

Reauthorize and Update the Export Administration Act (EAA)

The complexity and faults of the current system are due at least in part to Congress's failure since 1994 to reauthorized and update the EAA. The current structure of "national security" controls for certain types of items and "foreign policy" controls for other types of items under the 1979 EAA legal and regulatory framework handicaps the Executive branch's ability to reduce complexity, eliminate redundancies, and focus export controls on the most critical items.

Expand Validated End-User (VEU) Program to Include Entire Global Supply Chain

Under the validated end-user (VEU) program, foreign companies and foreign subsidiaries of U.S. companies located in China or India can **apply** for **eligibility** to receive certain items via export, re-export, or transfer (in-country) directly under a general authorization instead of a license.[124] According to SEMI, the VEU program makes U.S. companies more competitive in China by reducing the licensing burden for sales to important Chinese customers,[125] and to date twelve validated end users have been approved in China.[126] However, the electronics industry is global with a global supply chain and therefore the VEU program should be expanded to include the electronic industry's entire global ecosystem, not just China and India.

Transition Export Control System Toward More End User/End Use Controls

In early March 2016, it was announced in the New York Times[127] that one of China's largest international electronics firms, ZTE, was found to have violated U.S. sanctions by selling U.S. goods to Iran, and, as a result, ZTE would be blocked from buying anything, including technology, that is subject to the EAR.[128] As a major manufacturer and seller of cell phones, ZTE must purchase access to U.S. intellectual property (IP) in order to make its cell phones function properly and in late March a temporary general license, valid until June 30, 2016, was issued that in effect temporarily removed two of the four newly-listed ZTE entities from the entities list pending improved behavior by ZTE and its management.[129] And in early April 2016, ZTE's board of directors announced that it would select and approve a new management team.[130]

As demonstrated by the ZTE case, it is possible to catch foreign entities making transfers contrary to U.S. national security or foreign policy interests without putting everything, including the kitchen sink, on an export control list. This is the essence of the EAR's current end-user and end-use based controls under Part 744.[131] The use of such controls should be expanded so that lower risk items can be decontrolled.

Workforce Essay

For the United States' greater advanced manufacturing industry, the general claim is that there is a lack of sufficiently qualified STEM workers. Many government reports and studies support this premise.[132] The *Wall Street Journal* recently reported that fiscal year 2017 applications for H1B visas far outstripped the allowable supply for the third year in a row. U.S. companies applied for 236,000 visas, while the current law only allows for 85,000.[133] This simple demand and supply equation would certainly seem to indicate that there is a skills gap within the United States that the current pool of unemployed persons is not able to fill.

Our research determined a company's concern with finding the right type of workers was very dependent on what the company does and where it is located. Typically firms did not express any concern over finding qualified engineers, however, those companies that ran manufacturing facilities did find it more difficult to find qualified technicians. Within the semiconductor industry, there is one group that is particularly vocal about the need for changes to both the STEM education system and the H1B visa program – this is the Electronic System Design Alliance. This alliance is made up of companies that design computer-based tools that are subsequently used by chip designers.

Recommendations: Science, Technology, Engineering and Math (STEM) and H1B Visa

One of the first recommendations regarding STEM education is the creation of a national standard of just what "STEM" means with regard to education and the workforce. It is clear that there are many definitions used and therefore incompatible and insufficient data is often collected with regard to programs, graduation rates, employment, and even job needs.[134] This national standard definition must be officially adopted not only throughout the federal government but by state and local governments, and subsequently academia, and the business community writ large.

The second recommendation is for regions around the country to create *ecosystems* involving local industries, educational institutions, local governments, and other organizations. A detailed National Academies study and observation of five distinct regions around the country found that the leaders in the business community and universities need to find ways to formally create highly visible, interactive, enduring and sustainable partnerships.[135] Such partnerships, facilitated by local governments and other organizations can help academia create qualified graduates with the skills industry needs.

The third recommendation for increasing the number of U.S. students pursuing STEM degrees is for universities, local, state, and the federal government to enact scholarship programs that reward high school students who perform well in STEM and agree to pursue a STEM degree, especially women and some minorities.

The H1B visa program must be reformed to not only allow more highly-skilled workers to come to the United States, but also to absolutely prevent an American worker from being replaced. All the semiconductor-related companies we visited support the H1B visa program and wish it would be expanded. A DoD study also advocated its expansion.[136] There is a clear disconnect between allowing nearly 150,000 foreign students to be enrolled in graduate programs in U.S. universities,[137] and the H1B visa program that allows only 20,000 visas for foreigners with advanced degrees.

One of the senior briefers who addressed the Electronics Industry Study Team suggested that the H1B visa program should be skills-based, rather than numbers-based. Perhaps this type of change would help prevent certain abuses, and the importation of skill sets that are not needed or considered "high tech", such as what occurred at Disney and other companies.[138] Requiring companies who hire H1B visa employees to transparently provide them with equal benefits and salaries, as their American counterparts, should strengthen protections for American workers. Lastly, the "contractor" loophole must be clearly eliminated.

Through better definition and support of U.S. STEM and an increase in numbers and types of H1B visas, the United States can maintain sufficient technical degrees to support the industry. This will also enable innovation that keeps the U.S. industry ahead of other global competitors.

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