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The Dwight D. Eisenhower School for National Security and Resource Strategy
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ELECTRONICS 2014

ABSTRACT: The Eisenhower School Electronics Industry Seminar analyzed the global semiconductor industry to develop recommendations for policymakers to ensure the United States (U.S.) maintains a global competitive advantage and trusted and assured access to semiconductors for national security purposes. The seminar determined the U.S. semiconductor industry meets U.S. national securities requirements. However, several issues place the industry's ability to support national security over the long-term at risk. Issues identified during the analysis include: research and development (R&D), intellectual property protection, government tax policies and export controls, long-term human capital investment, Trusted Foundry Program, acquisition policies, and counter-tampering. The seminar recommends several actions for the United States Government (USG) to maintain the current competitive advantage of the domestic semiconductor industry and support national security. Recommendations include: reform corporate tax policy, R&D incentives; improve science, technology, engineering and mathematics (STEM) programs, strengthen the Trusted Foundry Program; adapt defense acquisition policies; and improve counter-tampering technology.

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PLACES VISITED

Domestic:
National Capital Region
Eisenhower School Seminar:
- Department of Commerce, Bureau of Industry and Security
- Department of Homeland Security (DHS), Office of Infrastructure Protection
- Electronic Design Automation Consortium (EDAC)
- Institute for Defense Analysis (IDA)
- International Business Machines (IBM) Research
- National Defense University, Center for Technology and National Security Policy
- Naval Research Laboratory
- Office of the Deputy Undersecretary of Defense for Industrial Policy
- Office of the Deputy Director Research and Engineering

BAE Electronic Systems, Manassas, VA
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National Security Agency (NSA), Fort Meade, MD
Naval Research Laboratory (NRL), Washington, DC
Semiconductor Industry Association (SIA), Washington, DC
California
eSilicon, San Jose
Defense MicroElectronics Activity (DMEA), Sacramento
Electronic Design Automation Consortium (EDAC), Sunnyvale (Cadence Design Systems; Mentor Graphics; Synopsys)
Intel Corporation, Santa Clara
Lam Research, Fremont
Semiconductor Equipment and Materials International (SEMI), San Jose
Stanford University Paul Allen Center for Integrated Systems, Palo Alto
New York
IBM Executive Briefing Center, Poughkeepsie
IBM Semiconductor Fabrication Facility, Fishkill
IBM Thomas J Watson Research Center, Yorktown Heights
International:
Taiwan
Taiwan Semiconductor Industry Association, Hsinchu Science Park
Industrial Technology Research Institute, Hsinchu Science Park
United Microelectronics, Hsinchu Science Park
Macronix, Hsinchu Science Park
Taiwan Semiconductor Manufacturing Company (TSMC), Hsinchu Science Park
Etron Technology, Inc., Hsinchu Science Park
Chipmos, Hsinchu Science Park
Inotera Memories, Inc., Kueishan,Taoyuan
American Institute Taiwan, Taipei
Shanghai, China
Semiconductor Manufacturing International Corporation (SMIC)
U.S. Consulate General, Shanghai

INTRODUCTION

"{The Department of Defense (DoD)} should advocate that a strongly competitive U.S. semiconductor industry is not only a DoD objective, but also a national priority."[1]

- Defense Science Board
"High Performance Microchip Supply"

This paper is the culmination of five months of extensive analysis of the semiconductor industry by the Electronics Industry Study seminar (Seminar) at the Dwight D. Eisenhower School for National Security and Resource Strategy, Class of 2014. Analysis from this paper stems from intensive seminar instruction, industry, academia and government visits in the National Capital Region, and field studies in New York, California, Taiwan and China. The Seminar analyzed the global semiconductor industry to develop recommendations for policymakers to ensure the United States (U.S.) maintains a global competitive advantage and trusted and assured access to semiconductors for national security purposes.

The U.S. semiconductor industry remains essential to U.S. economic health, global competiveness, and is a critical contributor to national security. Through unmatched research and development (R&D) that drives innovation, the semiconductor industry provides cutting-edge technologies and products which transform and contribute to a high quality of life enjoyed by the nation. The global demand for electronics will increase in the coming years driving greater levels of competition throughout the semiconductor industry. Competition, innovation, and consumer demand will push integrated circuit (IC) designers, manufacturers, and equipment makers to the physical boundaries of Moore's law, doubling the number of transistors on a chip every 18-24 months. The Seminar applied Porter's Five Forces Analysis to examine the environment of the semiconductor industry. The analysis revealed the industry is diverse, moderately competitive, capital intensive, and constantly evolving.

Issues identified during the analysis include: R&D, intellectual property protection, government tax policies and export controls, long-term human capital investment, Trusted Foundry Program, acquisition policies, and counter-tampering. The seminar recommends several actions for the United States Government (USG) to maintain the current competitive advantage of the domestic semiconductor industry and support national security. Recommendations include: reform corporate tax policy, R&D incentives; improve science, technology, engineering and mathematics (STEM) programs, strengthen the Trusted Foundry Program; adapt defense acquisition policies; and improve counter-tampering technology.

SEMICONDUCTOR INDUSTRY DEFINED

The seminar focused its study on semiconductors and the firms involved in the production cycle of integrated circuits (ICs) as opposed to the broader consumer electronics industry, which takes those ICs as inputs into finished products such as computers, televisions, and mobile phones. The seminar structured its analysis of the semiconductor industry into three main categories based on the IC production cycle: design, fabrication, and machine manufacturing. Other tasks associated with the production cycle including packaging, testing, and assembly of ICs were a secondary focus. The seminar defined the U.S. semiconductor industry as firms that are headquartered in the U.S., even though their operations may be distributed globally. Conversely, foreign-headquartered semiconductor firms with major U.S. operations are not considered "U.S. firms" for the purpose of this analysis.

Firm structure is one construct for examining the U.S. semiconductor industry, as firms continuously reexamine their core functions to position themselves for competitive advantage. Traditional Integrated Device Manufacturers (IDMs) are vertically integrated firms that design and fabricate – or manufacture – their own ICs. In 2013, the top three IDMs worldwide by revenue were Intel (U.S.), Samsung (South Korea), and Micron (U.S.).[2] IBM is a niche IDM capable of producing leading edge ICs on a customizable basis. However, IBM is not primarily a semiconductor firm and its IC manufacturing accounts for less than two percent of the firm's overall revenue.[3]

The IDM model has become more difficult to sustain in the face of sharply rising fabrication costs. As a result, many firms now focus solely on either the design phase or the fabrication phase. "Fabless" design firms contract the manufacturing of their ICs to "pure play" foundries. In 2010, U.S.-based fabless companies accounted for 77 percent of the $60 billion of fabless chip sales.[4] U.S. firms Qualcomm, Broadcom, and Advanced Micro Devices (AMD) lead the industry within the fabless design space. U.S. firms, by contrast, do not dominate the pure play foundry sector of the industry. Taiwan Semiconductor Manufacturing Corporation (TSMC) is the leading pure play foundry worldwide with its foundries all located in Taiwan. GlobalFoundries, an Abu Dhabi-owned firm, is the largest pure play foundry physically located in the United States.

Finally, semiconductor machine manufacturing encompasses the necessary equipment for IC production, including wafer-processing, assembly, testing and packaging. According to 2011 sales, three of the five leading semiconductor machine manufacturing companies are U.S. companies: Applied Materials, KLA Tencor, and Lam Research.[5] The Dutch firm ASML dominates lithography, which is one of the most critical technologies for fabricating ICs. These firms are important because of the symbiotic relationship between tool development and the industry's ability to move to more advanced nodes of manufacturing.

CURRENT CONDITIONS

The semiconductor industry's technological imperative is Moore's law, which projects chip capacity will double roughly every two years while the cost will halve. As a comparison, McKinsey Consulting noted "if the automotive industry had done the same over the last 30 years, a Rolls Royce would cost $40 and could circle the globe eight times on one gallon of gas."[6] The U.S. semiconductor industry is mature and its key dynamics include a highly cyclical market for ICs, steep competition, rising costs for the development and fabrication of each generation of ICs, and growing foreign competition.

The semiconductor industry contributes significantly to the United States' economy. Semiconductors are the second largest U.S. export after automobiles and engines. Global revenue in the semiconductor market topped $315 billion in 2013, up 5.2 percent from 2012 revenue of $299 billion. U.S. semiconductor revenues accounted for $155 billion, representing a 51 percent market share in this highly competitive global industry.[7] According to the Semiconductor Industry Association:[8]

- The semiconductor industry directly employs nearly 250,000 people, and supports an additional 1,000,000 American jobs, and

- On average, jobs in the semiconductor industry pay almost 2.5 times the average salary of U.S. workers.

The semiconductor market is highly cyclic due to its integration into the broader global economy and firms' capital investment decisions. "Semiconductor companies face constant booms and busts in demand for products. Demand typically tracks end-market demand for personal computers, cell phones and other electronic equipment."[9] As a result, semiconductor firms suffer when the global economy weakens as it did from 2008-2009. Second, investment decisions have to be made long before products can be sold. As a result, semiconductor firms have a tendency to oversupply the market. Even if prices fall below costs, they have an interest in keeping fabs running in order not to lose their heavy upfront investment and to recover the variable costs.[10]

These trends encourage a robust pattern of acquisitions in the semiconductor industry, as stronger firms purchase weaker firms that did not weather the latest downturn. Combined with the steep capital investment costs associated with fabrications, semiconductor firms keep a lot of cash on hand. The data in the below table provide a basis for comparison. Intel is still the worldwide leader, but Qualcomm, a fabless design firm, has the third highest revenue worldwide. From 1987-2007 fabless revenue grew much faster than the semiconductor industry as a whole with a compound annual growth rate (CAGR) of 26 percent vice 10 percent. Fabless firms now account for more than one-fifth the industry total.[11] The 2013 data below on Micron is for the firm's fiscal year, which ended in August. Annual estimates of Micron's revenue used elsewhere in this analysis include its acquisition of Elpida, a major Japan-based memory firm, which nearly doubled Micron's revenue.

	Revenue 2013	**Percent change from 2012**	**Income 2013**	**Long-Term debt to equity**	**Return on Investment 5-year average**
Intel	$52.71B	-1.2 percent	$9.62B	.24	17.4 percent
Micron	$9.07B	10.2 percent	$1.19B	.46	.6 percent
Qualcomm	$24.87B	30.2 percent	$6.85B	0	16 percent

Semiconductors are critical to maintaining a military technological advantage and the United States is dominant in the design space, with five of the ten largest IDM and fabless companies in the world. The United States is also home to the world's most advanced semiconductor fabrication facilities such as Intel and IBM able to produce the world's fastest and smallest chips. U.S. semiconductor firms invested $34 billion in R&D in 2013 alone – one of the highest percentages of revenue of any other industry.[12] Robust R&D investment and strong global demand projections augur well for the U.S. semiconductor industry.

In contrast, the risings costs of each new generation of ICs and the approaching limits of Moore's Law raise concerns about the long-term viability of current firm structures. As *The Economist* notes, firms are caught on a "technology treadmill" where competition forces them always to employ the latest technology, which increases output and puts downward pressure on prices.[13]

Building a leading edge fab in 1983 cost about $200 million, but today it is over $5 billion.[14] The cost of developing each process generation also is increasing sharply and very few firms are able to sustainably invest in leading-edge nodes. McKinsey assesses a firm would have needed $2.4 billion in annual revenue sales in 2004 to sustainably invest in then leading edge 90 nanometer (nm) process development.[15] To develop the 22nm node in 2012, that figure jumped to $6.5 billion. Only the largest firms can support these costs on their own, and the industry has responded by forming consortia to pool resources at least while R&D is at a pre-competitive stage.

These rising cost drivers coexist with the approaching limits of Moore's Law. Many industry experts, to include Intel's former chief architect Bob Colwell, conclude the industry may reach the physical limits of Moore's Law in the near future as electrical engineers manipulate circuits at the atomic level in current semiconductor designs. Over the course of the semester, the Seminar heard a different perspective: Moore's Law will become economically unfeasible before the physics does.

The semiconductor industry is highly globalized. U.S. firms operate distributed supply chains, face competition from foreign firms, and largely sell their products in foreign markets. U.S. semiconductor firms are no strangers to offshoring having started in the 1960s with chip assembly, progressing to fabrication in the 1980s and 1990s, and to an increasing degree in chip design in the twenty-first century. While a key motivator to offshore is cost cutting, it is not the only one. Drs. Brown and Linden, longtime observers of the semiconductor industry, identify three drivers for U.S. firms to globalize their activities: access to location-specific resources, cost reduction, and market development.[16] The Government Accountability Office echoes their assessment: "although a lower labor cost was initially a key factor that attracted firms to offshore locations, other factors such as technological advances, available skilled workers, and foreign government policy also played roles."[17]

Today, there is concern that much of the fabrication capacity to produce semiconductors is moving overseas. Indeed, much of the foundry capacity on 300 millimeter wafers has been added in Asia. However, the perception that most high tech manufacturing of semiconductors has been off-shored to Asia is false, as advanced semiconductor manufacturing in the United States remains strong and is expected to grow in the coming years.[18] "The majority of production from U.S. semiconductor firms is located in the United States, and the U.S. is home to more leading-edge process technology manufacturing facilities (i.e. 22 nanometer process technology or less) than any other country in the world"[19] In 2013, Intel spent $3.5 billion on semiconductor fabrication facilities in Oregon and Arizona, while GlobalFoundries spent $1.8 billion on its fab in New York.[20] Additionally, leading foreign semiconductor firms such as Samsung spent $2.5 billion on increasing the capacity of their fab in Texas. In 2013 alone, over $8 billion was spent on increasing semiconductor fabrication capability and capacity in the United States, which was twice that of China, Japan or Taiwan, and spending is forecasted to increase in 2014.[21]

Consistent with the industry's status as a leading exporter, much of the market for ICs is overseas. This is largely because ICs are a component of a broader finished product, and much of the assembly of electronic devices happens overseas. However, as end markets grow in Asia and particularly China, an increasing percentage of these electronic devices are destined for Asian end-use markets. According to Market Line, the global semiconductor market grew by 5.4 percent in 2013 to a value of $369.8 million with Asia-Pacific accounting for 67.1 percent of global market value.[22] Consumption in China is expected to account for more than 40 percent of global semiconductor revenues and by 2015 its share will reach 50 percent.[23]

PORTER'S FIVE FORCES ANALYSIS

Porter's Five Forces of Competitive Position Analysis provides a framework for examining the semiconductor industry. All of the forces are "moderate" when applied to the semiconductor industry as a whole, with the exception of "extremely weak" threat of substitution. The true value of five forces analysis comes from considering firms based on their structure.

Power of suppliers and buyers. Suppliers of cutting-edge semiconductor machinery manufacturing equipment and sophisticated electronic design software remain limited and those companies possess considerable industry bargaining power. In contrast, suppliers of fabrication inputs such as aluminum manufacturing, chemical product manufacturing, copper rolling, drawing and extruding manufacturing, and raw materials have minimum leverage due to greater availability.[24] The seminar's visits confirmed this as suppliers reported their percentage of overall semiconductor revenues remained consistent despite growth overall. According to Forbes, the semiconductor industry outsources roughly one-third of its IC manufacturing to foundries.[25] Foundries possess greater bargaining power over fabless firms, which are wholly reliant on them for production, than over IDMs who use foundries for excess capacity.

Because semiconductors exist in a wide range of electronic products, the number of potential customers remains relatively high, which tends to weaken buyer power. However, a small number of large customers account for a substantial part of revenues among all semiconductor manufacturers and hold more bargaining power. As a result, buyers are able to sustain consistent downward pressure on the price of ICs. Semiconductor firms must recoup costs through expanding markets as opposed to being able to charge proportionally more for each generation of chips – especially in the consumer electronics industry.

Competitive rivalry and threat of entry. Competition takes varied forms in the semiconductor market. On one level, competitive rivalry directly correlates with threat of entry. For fabless design firms, low barriers to entry result in a large number of firms.[26] By contrast, for firms responsible for fabrication, the high capital costs result in high barriers to entry but an imperative to capture as much market share as possible to recoup investment costs.

A different way to assess competition is through concentration. Overall, concentration in the semiconductor industry is low; IBISWorld lists 837 firms in the U.S. sector, with the four largest accounting for 35.8 percent of market share.[27] This suggests firms try to establish competitive advantage through product differentiation, a finding supported by the seminar's visits. Although the cost of fabricating each new generation of IC continues to skyrocket, not all ICs need cutting edge technology. Over the course of the seminar's visits, especially in Taiwan and China, firms discussed the cost-benefit analysis of producing at more sophisticated technological nodes and identified viable markets that could be captured profitably with older technology processes. This finding supports the reality that concentration can be much higher in specific product categories. For example, Intel's 80 percent market share of microprocessors has forced nearly every other competitor into niches or different product lines altogether, except Advanced Micro Devices.[28]

Threat of substitution. Companies do not fear the unexpected arrival of a significant alternative to the silicon-based semiconductor. However, firms face a substantial threat of substitution for their discrete products. Samsung will lose a major foundry customer if Apple switches production of the main IC in its iPhones to TSMC instead. Threat of substitution can also come from broader shifts in the consumer electronics industry. Intel's revenue has decreased as consumers buy fewer computers – a market it dominates – and more mobile devices, a market it does not.

OUTLOOK

The overall outlook of the global semiconductor industry and in particular for U.S. based firms, remains positive with numerous forecasts citing continuing growth across specific semiconductor markets. The Semiconductor Applications Forecaster managed by the International Data Corporation predicts "semiconductor revenues will grow 2.9 percent year over year in 2014 to $329 billion and log a CAGR of 4.2 percent from 2012-2017, reaching $366 billion in 2017."[29] The majority of industry growth is expected to result from advances in mobile technology and the evolution of faster Advanced Reduced Instruction Set Computer Machine (ARM) processors, the basic foundation of most mobile telephones and devices. Despite the strong growth forecasts, the competitive semiconductor IC environment requires companies to overcome challenges associated with silicon-based component scaling, enhancements on computational speed, and the demanding requirement to reduce energy consumption to remain competitive. Both the industry and the USG must strongly consider advanced and emerging technologies enablers when defining future business objectives, national security interest, and decision frameworks rather than the predictable Moore's Law development cycles in the past. Conversely, as security interests and threats evolve, national R&D objectives will require resourcing to facilitate technology developments necessary to meet future threats.

Semiconductor technology over the past decade experienced significant technical and innovative advances based on Moore's Law. The environment consisted of companies within the industry striving to maintain competitive advantages by overcoming particular challenges in reducing component size, integrated device speed, and operational integrity of smaller feature sizes. These advances span the semiconductor device manufacturing spectrum, specifically through innovative design techniques, improved fabrication machine technology, improved integrated packaging, and interconnectivity. The basis of innovation centers on the foundational element and physical characteristics upon which devices are grown, mainly silicon structures now at the atomic level. The industry is approaching the physical scaling limits of silicon-based processes and structures. Companies must develop advanced manufacturing techniques, apply different component structures, or use new substrate materials to overcome these limitations.

5 YEAR OUTLOOK

The semiconductor industry will accelerate near-term development, through innovation, of current manufacturing process technologies in response to increased consumer demand. Industry leaders with access to capital, such as Intel, GlobalFoundries and Samsung, will advance IC design and fabrication to a 10nm chip by late 2015 (Figure 1).[30] Experts predict within the next five years scaling will likely remain on silicon, but the potential exists for new IC substrates to emerge. Therefore, development of new or optimization of existing design tools or processes; based upon advanced System-on-Chip (SoC) designs, 3D IC integration techniques, and Fin-shaped Field Effect Transistor (FinFET) structures, remains a likely focus for most manufacturers. Additionally the migration to 450mm wafer based manufacturing, for certain component structures like static or dynamic random-access memory, may occur as early as 2016.[31] Based on Seminar travels to Silicon Valley, Taiwan, and China, the industry projects a more likely production target for 2018 (Figure 2).[32] However, because migration to 450mm comes with a steep investment in R&D and new equipment costs, some skepticism remains for the 2018 target.

10 YEAR OUTLOOK

Further assessing the outlook for the industry through 2030, specifically with monolithic silicon substrate based semiconductor processes, future forecasts remain difficult to predict and depend upon the R&D and innovation successes within the industry. Despite those challenges, the long-term outlook for the semiconductor industry remains promising. As the global market transitions from networked computing devices to the Internet of Things (IoT), driven by exponential growth in global connectedness, demand for distributed advanced sensor capabilities and pervasive computing, will result in growing demand for semiconductor components. Interconnected or networked devices, specifically in the mobile markets, will also drive the demand for radio frequency applications and mixed signal components that facilitate user and device control applications.[33] Additionally, wearable and biotech applications will also drive further evolutions in new component materials and packaging within the industry.[34] Lastly, the IoT further escalates the need for improved data access and processing, fostering a new age of high speed correlation and data processing structures, based upon optimized parallel processing and real-time data stream analysis and management.

Technological advancements beyond silicon substrate structures will spur increasing cooperative R&D business alliances, or consortiums, such as the G450C consortium, among traditional competitors, to help minimize costs and risks. Seminar discussions and analysis in the National Capital Region, Silicon Valley, and Taiwan underscored the fact industry along with government and universities collaborative R&D over the long term are required for the evolution of new materials and device structures such as epitaxial graphene, nano-technology, photonics, electron-spin, and, ultimately, biotechnology. The long-term outlook also shows more than a tenfold growth in demand and an increasing dependency on semiconductor components that will also generate significant competition alongside collaboration making the industry even more complex than it is today.[35]

Comparison of Process Roadmaps (for Volume Production)

	2011	2012	2013	2014	2015	2016
Intel	22nm tri-gate transistor			14nm	10nm	
GlobalFoundries		28nm		20nm; 14nm finFET, 20nm BEOL	10nm 14nm BEOL	
Samsung		28nm		20nm; 14nm finFET, 20nm BEOL		10nm
TSMC	28nm		20nm	16nm finFET, 20nm BEOL		10nm
UMC		28nm		14nm finFET, 20nm BEOL		10nm

Source: Companies, conference reports, IC Insights

Figure 1

Summary Table of ITRS Technology Trend Targets

Year of Production	*2013*	*2015*	*2017*	*2019*	*2021*	*2023*	*2025*	*2028*
Logic Industry "Node Name" Label	"16/14"	"10"	"7"	"5"	"3.5"	"2.5"	"1.8"	
Logic 1/2 Pitch (nm)	40	32	25	20	16	13	10	7
Flash 1/2 Pitch [2D] (nm)	18	15	13	11	9	8	8	8
DRAM 1/2 Pitch (nm)	28	24	20	17	14	12	10	7.7
FinFET Fin Half-pitch (new) (nm)	30	24	19	15	12	9.5	7.5	5.3
FinFET Fin Width (new) (nm)	7.6	7.2	6.8	6.4	6.1	5.7	5.4	5.0
6-t SRAM Cell Size(um2) [@60f2]	0.096	0.061	0.038	0.024	0.015	0.010	0.0060	0.0030
MPU/ASIC HighPerf 4t NAND Gate Size(um2)	0.248	0.157	0.099	0.062	0.039	0.025	0.018	0.009
4-input NAND Gate Density (Kgates/mm) [@155f2]	4.03E+03	6.37E+03	1.01E+04	1.61E+04	2.55E+04	4.05E+04	6.42E+04	1.28E+05
Flash Generations Label (bits per chip) (SLC/MLC)	64G /128G	128G /256G	256G / 512G	512G / 1T	512G / 1T	1T / 2T	2T / 4T	4T / 8T
Flash 3D Number of Layer targets (at relaxed Poly half pitch)	16-32	16-32	16-32	32-64	48-96	64-128	96-192	192-384
Flash 3D Layer half-pitch targets (nm)	64nm	54nm	45nm	30nm	28nm	27nm	25nm	22nm
DRAM Generations Label (bits per chip)	4G	8G	8G	16G	32G	32G	32G	32G
450mm Production High Volume Manufacturing Begins (100Kwspm)				2018				
Vdd (High Performance, high Vdd transistors)[**]	0.86	0.83	0.80	0.77	0.74	0.71	0.68	0.64
1/(CV/I) (1/psec) [**]	1.13	1.53	1.75	1.97	2.10	2.29	2.52	3.17
On-chip local clock MPU HP [at 4 percent CAGR]	5.50	5.95	6.44	6.96	7.53	8.14	8.8	9.9
Maximum number wiring levels [unchanged	13	13	14	14	15	15	16	17
MPU High-Performance (HP) Printed Gate Length (GLpr) (nm) [**]	28	22	18	14	11	9	7	5
MPU High-Performance Physical Gate Length (GLph) (nm) [**]	20	17	14	12	10	8	7	5
ASIC/Low Standby Power (LP) Physical Gate Length (nm) (GLph)[**]	23	19	16	13	11	9	8	6
*** Note: from the PIDS working group data; however, the calibration of Vdd, GLph, and I/CV is ongoing for improved targets in 2014 ITRS work*								

Figure 2

THE GOALS AND ROLES OF U.S. GOVERNMENT POLICY

The demand for commercial products drives the semiconductor industry today. From a national security perspective, the goal of USG policy remains twofold; to ensure the domestic industry sustains the current global competitive advantage and that the United States maintains trusted and assured access to semiconductors products for national security purposes.

In December of 1947, Bell Telephone Laboratories developed the first transistor and ushered in the age of microelectronics. The Pentagon awarded Bell Labs the first military contract for transistors less than 18 months later starting the historical partnership between the military and the industry. Throughout the 1950s and 60s, federal contracts grew, as well as, funding for R&D with the USG dominated the fledgling semiconductor industry, shaping its direction. In 1970, the United States completely dominated the semiconductor industry. By 1987, with strong government support, the industry experienced a shift in dominance from the United States to Japan with five of the top ten semiconductor producers being Japanese companies. The industry evolved into a multi-polar industry with Japan's economic decline and growth throughout Asia. Today, four of the top ten producing foundries in the world are in Taiwan.

Policy and government support remain an essential component of U.S., Japanese, and Taiwanese companies competitiveness in the semiconductor industry, but far less than in the past. For example, today, the market share of USG purchases in the semiconductor industry consists of less than two percent with the DoD, a huge driver of a fledgling microprocessor industry, now only accounting for less than one percent of total sales. Despite the relative lack of buying power influence, USG still wields significant impact on the semiconductor industry in many ways, but mostly through policy. Policy, laws, and regulations impact R&D funding, tax policy, protection of intellectual property rights and export control regulations which directly affect the health and competitiveness of the domestic semiconductor industry.

DoD's program to guarantee trusted and assured access to IC components is the USG's Trusted Foundry Program, managed by the Defense Microelectronics Agency (DMEA). The Trusted Foundry Program ensures ICs needed for critical defense hardware remains secure, readily accessible, and free from tampering. In addition, the program's agreements with industry allow USG access to leading edge technology at lower volumes than commercially obtainable, a traditional DoD requirement for weapon systems and traditional system procurement. Beyond providing access and reliability, the Trusted Foundry Program also protects designs for classified government projects from development through production and implementation. Today, the USG certified 56 companies as suppliers or foundries within the program and is fairly healthy. One major weakness, however, the only supplier for 32, 45, and 65 nanometer feature size within the trusted foundry program is IBM. The next closest trusted foundry is Cypress Semiconductor, which can produce down to 90 nanometers, arguably several generations older than the more advanced technology.[36] In addition, based on Seminar travel and news reports, IBM intends to sell its semiconductor fabrication division, which eliminates a sole supplier and significantly impacts the Trusted Foundry Program. Furthermore, if a foreign buyer emerges, the Committee on Foreign Investment in the United States will have a difficult decision to protect national security verses economic interests of the nation when deciding whether to approve the sale.

CHALLENGES, ASSESSMENT AND POLICY RECOMMENDATIONS

Challenge 1: Maintaining U.S. competitive advantage in the highly globalized semiconductor industry is critical to the health of our high technology sectors and our national security.

Assessment: The semiconductor industry currently employs 245,000 U.S. citizens.[37] The industry also directly supports the number two U.S. export sector (electronics at $165 billion in 2013) and provides the core technology that gives U.S. advanced weaponry its edge on the battlefield.[38] Through unmatched innovation, the electronics industry has historically provided cutting-edge technologies at progressively less cost essential to the nation's global economic and military competitive advantage. As a comparison, the McKinsey Consulting noted about the growth in the industry, "if the automotive industry had done the same over the last 30 years, a Rolls Royce would cost $40 and could circle the globe eight times on one gallon of gas."[39]

Global semiconductor revenue surpassed $315 billion in 2013. Other nations are pursuing aggressive economic growth policies intended to pull significant portions of this profitable industry to their shores. For example, China's semiconductor consumption has grown to 52 percent of the global market in 2012 and continues to grow at a rapid pace.[40] Competitive advantage is not guaranteed and leadership – whether by countries or firms – has changed several times over the last thirty years.[41] Historically, the United States domestic semiconductor industry has maintained an edge through innovation and many U.S. firms are global leaders.

Policy Recommendations:

1. **Drive innovation through R&D and intellectual property reform.** To maintain a competitive advantage within the semiconductor industry, the USG should implement a series of policies to foster an environment that incentivizes innovation through increased R&D investment. To protect those investments, the USG must also guard new ideas en route to the market via intellectual property and patent protection.

2. Globally competitive tax and export control policies. The USG must improve tax and export control policies to allow domestic companies to fairly compete in global markets. Policies such as a lower corporate tax rate and repatriation holidays will incentivize both U.S. and foreign firms to onshore R&D, innovation and capital investment within the United States that promotes second order effects and benefits. USG export control policy currently lags behind changes ongoing within the semiconductor industry to include the technological developments likely in the 5 and 30 year outlooks previously discussed.

3. Long-term human capital investment through immigration and education reform. The United States needs a responsive and flexible path to citizenship for foreign students who graduate with highly desirable doctoral degrees in STEM programs. Specifically, policy must target those who hold a H1-B visa and work in key U.S. semiconductor industry jobs. Furthermore, to improve our long-term competitiveness, the USG should increase efforts to improve basic STEM education and promote STEM college graduates' placement in critical innovation fields.

Challenge 2: The USG requires trusted and assured access to semiconductors and integrated circuits. Trusted is defined as "the ability to maintain protection of classified designs, integrity of mission critical components and operating life."[42] Assured is defined as "guaranteed access to special military technologies, quick response for time critical designs, parts availability for the life of a system."[43]

Assessment: The USG must expand the Trusted Foundry Program to protect national security, and institute policy changes to protect and optimize the programs. The Trusted Foundry Program resides in the Office of the Secretary of Defense, Assistant Secretary of Defense for Research & Engineering. DMEA manages the program through the NSA's Trusted Access Program Office. The program manages the IC designed, fabricated and assembled and integrated into critical USG capabilities at secure locations. These capabilities range from weapons systems, aircraft, communication systems, and intelligence collection and processing systems to any sensitive capability with electronic architecture. The ICs produced in the Trusted Foundry Program and components obtained from the trusted supply chain ensure a high degree of confidence in chip quality, reliability under a variety of harsh conditions, and free from defect or nefarious code embedded within the firmware.

The Trusted Foundry Program protects the design and fabrication of semiconductor ICs through secure sources.[44] The Trusted Foundry Program allows the defense industrial base strategy to support national security by mitigating the risk from counterfeit parts and supply chain interdiction. Although it does not eliminate the risks due to from counterfeit or nefarious ICs, the Trusted Foundry Program provides significant protection of essential weapons platforms and equipment. The program also reduces an adversary's ability to attack, or for USG entities to unwittingly place, counterfeit ICs into sensitive weapons or equipment that increase vulnerabilities.

Policy Recommendations:

1. Expand the Trusted Foundry Program. The USG should expand the number of high-end trusted foundries from one to two suppliers to further support national security. To remain a viable resource for trusted semiconductors, the Trusted Foundry Program should expand production of ICs for use outside the DoD and intelligence communities.

2. Adapt current defense acquisition policies. The shift toward a more efficient global supply of semiconductors has raised concerns among senior U.S. defense and political leaders about the need for U.S. Defense acquisition policies that preserve the U.S. semiconductor industrial base. The DoD's acquisition leadership must further commit to raising increased awareness among its workforce on the risk from counterfeit components and partner with industry to develop policies to create meaningful improvements as the industry changes over the near- and long-term future.

3. Expanded R&D of counter-tampering technology. The USG and DoD investments in R&D funding should increase to improve counter-tamper technology. Tampering with ICs can take many forms including substituting good components with inferior ones, physically altering a device, or manipulating the logical operations of code or instructions used to provide electronic component functionality which all impact national security.

ESSAYS

DRIVE INNOVATION THROUGH R&D AND INTELLECTUAL PROPERTY REFORM

To maintain a competitive advantage within the semiconductor industry, the U.S. must drive innovation through increased R&D investment while safeguarding new ideas en route to the market via intellectual property (IP) protection. In the face of budget constraints, robust funding for basic research – the seed corn of innovation – is at risk. Sustaining federal R&D funding and developing new public-private partnerships at the state and local level remain essential components for the domestic industry to maintain its global competitive edge. The United States semiconductor industry, which invests heavily in corporate R&D, has called upon the government to provide better IP enforcement and authorities to limit the negative impact of "patent trolls."

The United States leads global R&D investment writ large, but risks falling behind China by 2020 in many key areas.[45] In 2013, U.S. R&D funding totaled $423 billion, with $128 billion funded federally and $261 billion funded by private industry.[46] Although total U.S. R&D funding continues to grow at roughly one percent per year, federally funded R&D fell $10 billion from 2010 to 2012 and expected to remain flat through 2020.[47] Meanwhile, China increases government funded R&D by 11 percent annually and expects to exceed the U.S. R&D budget by 2020.[48] Congress should remove the federal R&D funding cap and increase R&D levels by three percent annually to keep pace with inflation and reduce the growing gap between domestic and foreign spending. R&D resources should focus on basic research, which is normally conducted at universities and national labs, to maximize the potential to create paradigm shifts or revolutionary change. Although scientists traditionally share basic research as a common public good, it still underwrites U.S. dominance in technological innovation.

In addition to federal funding, state governments create public-private ventures to pool basic research funds with industry at local universities to tackle semiconductor industry challenges together. The G450C consortium at New York's College of Nanoscale Science is one prominent example of public-private ventures with Intel, Samsung, GlobalFoundries, IBM, and Taiwan Semiconductor Manufacturing Company. This consortium collaborates to conduct pre-competitive research on 450mm wafer production. Another public-private venture is the Analog Center of Excellence, a partnership between the state of Texas, Texas Instruments, and the University of Texas-Dallas to collaboratively develop analog integrated circuits.[49] The federal government should encourage states to pursue or expand public-private partnerships with universities and national laboratories via federal grants and matched funding.

In addition to the basic research, industry largely funds complementary applied research to develop products. Applied research yields IP and trade secrets as the firm develops new products. The semiconductor industry invests heavily in R&D due to market demands and the imperative of Moore's Law, with the top ten firms in 2013 dedicating an average of 15.8 percent of sales annually.[50] A key measure on the return of investment is the generation of new patents. Currently, IBM maintains a historic 21-year position as an industry research leader when measured by annual submissions for new patents. Last year alone, IBM applied for a record 6,809 patents, a 31 percent lead over second place Samsung.[51] By comparison, Intel – a leader in R&D spending – registered for 1,455 new patents in 2013.[52]

A semiconductor firm's success depends on the ability to protect their IP long enough to sell products to consumers before cheaper versions flood the market from fast followers. The U.S. maintains a vibrant legal system to protect IP that includes legal recourse to settle disputes. However, international enforcement of intellectual property rights (IPR) varies widely, causing an estimated loss to the U.S. economy of up to $300 billion annually.[53] By most accounts, China, the largest source of IPR violations, is responsible for between 50 to 80 percent of all IPR violation cases.[54] The World Trade Organization's Agreement on Trade-Related Aspects of IPR legally protects IC designs, but lacks enforcement capability. The United States must establish policies to support international and domestic laws and regulations to alter the cost-benefit calculus from IP theft significant enough that violators cannot compete in the marketplace.

In addition, the United States should increase detection capability to enforce laws and make the consequences of IP theft more costly. The Defense Logistics Agency's decision to require DNA-marked chips to hold suppliers accountable for counterfeits offers an example of policy changes to protect IP. Other initiatives include increasing the Justice Department's capacity to investigate and prosecute cases of IP theft and increasing the Commerce Department's authorities to coordinate seizure and impounding of imports suspected of benefitting from stolen IP. Currently processes remain hampered by lengthy time delays which inhibit effective cross boundary government coordination. In addition to faster response times, the Commerce Department must coordinate with the Department of Treasury to deny an offender's access to the U.S. banking system.

In 2011 President Obama signed the Leahy-Smith American Invents Act to help streamline the process when applicants apply for new patents. The Patent Abuse Reduction Act of 2013 (S.1013), still in Congressional committee, mitigates the use of excessive litigation tactics and provides protection from "Patent Assertion Entities" (PAE) or "patent trolls." Like theft, PAE reduces the competitive advantage of developing new ideas and impacts innovation.[55] To further improve the situation, Congress should build on the Leahy-Smith American Invents Act and expedite and approve the proposed Patent Abuse Reduction Act to add additional financial penalties for patent abuse.[56]

GLOBALLY COMPETITIVE TAX AND EXPORT CONTROL POLICIES

Many semiconductor firms operate globally, with design, manufacturing, and assembly and test operations located around the world. The electronics industry in 2013 exported $165 billion and represents 10.5 percent of all overseas sales from the United States.[57] Despite the high level of exports from the industry, the U.S. corporate tax policy inhibits further sales due to a high corporate tax rate. This discourages firms who generate profits overseas to return funds back to the United States for reinvestment. Instead they tend to remain at the overseas location and fund other activities locally, such as R&D, which benefits the host nation.

In 2015, $225 billion of the projected $327 billion global semiconductor sales are predicted to be within the Asia-Pacific.[58] U.S. firms face a decision whether to repatriate foreign-earned revenue for onshore R&D and capital investment or leave the dollars offshore for foreign investment. High standard corporate tax rates and the requirement to pay the differential on repatriated earnings dissuade firms from bringing substantial revenue back into the United States. Reducing the corporate tax rate from its current 35 percent to 25 percent would bring the United States in line with rates of the top ten global economies.[59] Furthermore, offering a repatriation tax holiday as done in 2004 would incentivize industry to return offshore dollars to the United States for reinvestment. [60]

In addition, a significant disparity exists between U.S. and foreign tax incentives. Countries including Taiwan, China, and India offer break to promote construction and tax incentives to draw the semiconductor industry from the United States to their shores.[61] The combined effect of China's 25 percent corporate tax rate, 150 percent R&D tax "super-deduction," and other incentivizes can often yield greater than $1 billion in savings on an advanced R&D or fabrication facility.[62] By contrast, the U.S. R&D credit is 20 percent and Congress has let the credit lapse fifteen times since its inception.[63] The uncertainty surrounding the permanence of the R&D credit hurts semiconductor industry planning and incentivizes firms to invest R&D dollars overseas where the credits are larger and permanent. Making the R&D credit permanent and raising it to 50 percent would encourage firms to sustain high levels of R&D in the United States.

A final challenge to the U.S. semiconductor industry is the outdated U.S. export control policy that stifles global sales of dual-use technology. The Export Administration Regulations control exports that can be used for either military or civilian purposes (dual use). The Department of Commerce administrates exports through the Commerce Control List. The International Traffic in Arms Regulations, on the other hand, resides in the State Department, and controls the export of specific defense technology through the U.S. Munitions List. Rather than preventing the spread of defense-related technology, these Cold War-era regulations are an anchor dragging down the competitiveness of U.S. industries.

Regulations slow or prevent the export of technology to markets where the 'protected' technology is readily available from foreign competitors. After all, given the rapid pace of technological turnover stemming from Moore's law, new inventions can be out of date within two years. The Obama administration made export control reform a priority in 2009, intending to 'build a bigger fence around a smaller yard,' and the results are starting to take effect. The electronics category revision is expected to be released in 2014, ideally with significant easing of restrictions on dual-use semiconductors that are readily available globally and reform of hardware encryption regulations.[64,65,66] After the 2014 revision, it is key to update the list biannually at a minimum to keep pace with this industry. In the absence of these updates, U.S. firms are incentivized to pursue advanced R&D in Europe or Asia, where restrictions are relaxed.[67]

To ensure the success of the U.S. semiconductor industry and long-term economic growth, the United States must implement more globally competitive tax and export control policies that protect the U.S. technological advantage without stifling global market access. Taken together, these aggressive strategies will sustain the U.S. industry's global competitive advantage and reward on-shoring R&D and capital investments that are vital to both long-term U.S. economic growth and the military's advanced weaponry.

LONG-TERM HUMAN CAPITAL INVESTMENT THROUGH IMMIGRATION AND EDUCATION REFORM

The United States needs a responsive and flexible path to citizenship for foreign students who graduate with highly desirable doctoral degrees in STEM programs. Specifically, policy must target those who hold a H1-B visa and work in key U.S. semiconductor industry jobs. Furthermore, to improve our long-term competitiveness, the USG should increase efforts to improve basic STEM education and promote STEM college graduates' placement in critical innovation fields.

The U.S. semiconductor industry is facing increasing competition from overseas firms for the top talent graduating from premier U.S. education programs. This human capital is an integral component of the industry and must be strengthened if the United States is going to maintain its dominant position. One area of contention in human capital is current U.S. immigration policy. Reform efforts over elements of the current immigration system are required if the U.S. semiconductor industry hopes to attract and maintain the world's brightest minds.

H-1B visas are non-immigrant visas that allow employers to temporarily employ foreign workers in specialty occupations.[68] The current H-1B limit is 85,000 total visas per year, with 20,000 reserved for master's degrees or higher.[69] H-1B visas are valid for three years and can be extended for an additional three years and there is no guaranteed transition to the current lengthy green card process.[70] For permanent residence, employment green cards are broken down into preference levels based on qualifications.[71] Current regulations cap the number of employment green cards per country at seven percent of the total available, hurting efforts to recruit and keep top talent from high skill countries like India and China.[72]

For the U.S. semiconductor industry to remain competitive, the current country cap on employment green cards should be eliminated for foreign workers who graduate from U.S. STEM doctoral programs and work for U.S. firms. Providing a clear path for this small number of highly trained workers is important for U.S. semiconductor companies and their future innovation efforts.

Looking to the long-term, the United States must improve STEM education at all levels. At the high school level, the United States participates in the Program for International Student Assessment (PISA), a system of international assessments conducted at the age of 15 in mathematics, science, and reading.[73] For the 2012 PISA, only 9 percent of U.S. students tested scored at the highest levels in mathematics and 7 percent in science. By comparison, the Organization for Economic Cooperation and Development average was 13 percent and 8 percent, and the highest score was Shanghai-China with 55 percent and 27 percent. The U.S. scores have stayed consistent since 2000.[74]

This data reinforces the point that the current U.S. average high school education in STEM is not sufficient if the United States is to remain competitive in technological fields. A federal and state partnership to encourage college students to pursue teaching positions in STEM education can help reverse this trend. A primary attraction for college graduates is the repayment of costly student loans. The federal and state governments should create tuition repayment programs for college graduates who take STEM teaching jobs immediately after graduation. The fiscal year 2015 federal budget begins to address this with $60 million dollars set aside to recruit and retain teachers in STEM education.[75]

The second key long-term imperative is to address the diversion of STEM graduates into non-STEM fields. A 2011 report from the Georgetown University Center on Education and the Workforce found many STEM degree holders often transferred into better paying fields such as architecture, medicine, healthcare, and finance.[76] For employees with a bachelor's degree, STEM occupations pay $78,550 per year, healthcare professionals earn $110,090, and managerial and professional occupations earn $102,070.[77] Addressing this dynamic will primarily fall to industry, not government.

The USG should promote STEM retention in jobs that have a direct impact on the Defense Industrial Base. An important facet of this effort is providing direct scholarship funds to students who major in STEM programs. A federal scholarship system for STEM graduates who take federal government R&D positions in our national laboratories would attract students into important STEM jobs. This program would be similar to the military Reserve Officer Training Corps scholarship program. Currently, national laboratories run programs individually. A united program funded with federal STEM funds would attract more students to STEM education knowing that a government STEM position is available upon graduation. This program could also incorporate the DoD research laboratories. These recommendations will keep critical STEM talent fully engaged for U.S. firms and strengthen our position for the future.

EXPAND TRUSTED FOUNDRY PROGRAM

The USG should expand the number of high-end trusted foundries from one to two foundries to eliminate the risk associated with a single source supplier. A high-end trusted foundry produces 32, 45, and 65 nanometer features within the semiconductor for sensitive USG capabilities such as weapon systems, secure communications, intelligence collection systems, and aerospace systems. Additionally, the USG should explore options to certify non-U.S.-owned firms to join the trusted supply chain. These two actions will strengthen the USG's ability to provide trusted and assured access to semiconductors and ICs.

To remain a viable resource for trusted advanced semiconductors, the Trusted Foundry Program should expand the number of high-end trusted foundries from one to two. The program relies on IBM as its sole high-end trusted foundry. Relying on a sole source high-end trusted foundry presents risk. The USG will lose trusted and assured access to high-end semiconductors and ICs if IBM sells its New York trusted foundry to a non-U.S. firm or a U.S. firm which will not do business with the USG. National security is at risk with no means for the USG to access trusted high-end ICs for integration into sensitive capabilities. Secure, reliable ICs remain an essential component of national security and the risk assumed by using commercial suppliers does not outweigh the assumption of risk. Additionally, the USG should evaluate if current guidelines, requiring use of ICs produced at trusted foundries, sufficiently meet national security needs. By expanding the number of high-end trusted foundries, and mandating broader use of trusted semiconductors, economies of scale will help drive the cost per unit lower improving the return on invested capital. Presently, trusted foundries possess the ability to manufacture chips using multi-project wafer technology allowing them to satisfy the needs of customers with low volume demands.[78] Through multi-project wafer technology, trusted fabs can efficiently use the full capacity of large size (300 mm) wafers to gain efficiency and cost effectiveness in facility operations while satisfying the needs of multiple customers or a single customer with many chip variations.

An additional reason for a second high-end trusted foundry is the fact as the USG enters into an era of the IoT the demand for secure ICs will increase. U.S. National Security Strategy stresses a correlation between the digital electronics boom and national security described as, "Our digital infrastructure, therefore, is a strategic national asset, and protecting it…is a national security priority."[79] There is greater potential to use trusted resources in a variety of other USG and industry products supporting homeland security, economic prosperity, and consumer safety—all areas requiring high mission assurance reliability. With the IoT driving more sophisticated consumer-centric electronic devices onto the Internet, networks and infrastructure, the Trusted Foundry Program should expand and include other critical areas requiring trusted computing such as banking, energy, transportation, health, and safety. While many of these areas already employ network safeguards, they lack standards with no guarantee the commercial electronic devices remain risk free, especially in cases where older generation or obsolete platforms remain in use and operating critical infrastructure or systems. Trusted foundries provide a service to minimize the threat to our national security both within and external to DoD.

ADAPTING CURRENT DEFENSE ACQUISITION POLICIES

The DoD's acquisition leadership must further commit to raising increased awareness among its workforce on the risk from counterfeit components and partner with industry to develop policies to create meaningful improvements as the industry changes over the near- and long-term future. At the heart of the Department's policy to preserve a trusted IC industrial base is a contract with IBM and a collection of smaller DMEA-certified suppliers. However, adversary threats to U.S. weapons platforms have increased as global capability grows and policies aimed at protecting them rely on antiquated policy that originated in 2003 with the Defense Trusted IC Strategy. The challenges associated with detecting counterfeit or compromised electronic components have grown ever more complicated since early policies were first released. Furthermore, as prime defense contractors incorporate an increasingly "complex web of parts suppliers and contractors," the problem will compound in the future.[80] According to Undersecretary of Defense for Acquisition, Technology and Logistics, Frank Kendall in his 2013 report to Congress on the health of the U.S. industrial base, the forces of the consumer market and the threats brought by globalization continue to confront today's acquisition managers and implies greater risk in the future.[81]

Beginning in 2004, DoD assigned defense acquisition programs a Mission Assurance Category (MAC) to reflect the criticality of the program relative to the achievement of DoD goals and objectives, particularly warfighters' combat mission.[82] For example, DoD assigned a MAC level 1 for systems handling information determined as "vital to the operational readiness or mission effectiveness of deployed and contingency forces in terms of both content and timeliness" and therefore, require the most stringent protections to reduce risk.[83] These MAC 1 programs required trusted, reliable sources for all parts and procurement, and includes those defined through the Department's Trusted Foundry Program. However, in addition, many components for programs below MAC 1 also require access to protected procurement to reduce risk from counterfeiting, IP theft, and anti-tampering to ensure their ability to operate effectively.[84] The challenge for defense program leadership across all mission categories is to ensure ICs perform in a system as anticipated, reliable and assured from future compromise or tampering.

From an acquisition policy perspective, two sets of instructions issued in 2008 set the expectations for defense acquisition program managers to employ the Trusted Foundry Program when integrating ICs requiring high levels of assurance into weapons platforms. A December 2008 release of DoD Instruction 5000.02, which governs defense acquisition, included the regulatory policy requirement for a program manager to formally submit a program protection plan at milestone B and again at milestone C.[85] A program protection plan includes the program's strategy for assured access and use of electronic components specific to its MAC. At milestone B a program receives formal approval for entry into the engineering and manufacturing development phase, and at milestone C, a program gains approval for entry into the production and deployment phase. Without this documented and coordinated program protection plan, a program cannot move forward through these formal milestone reviews.

This key acquisition policy requirement originated from the release of DoD Instruction 5200.39, in July of 2008 by the Undersecretary of Defense for Intelligence, James Clapper, and expanded the Department's policies on the protection of critical program information (CPI).[86] The policy refers to elements of an R&D or formal acquisition program that, if compromised, "could cause significant degradation in mission effectiveness; shorten the expected combat-effective life of the system; reduce technological advantage; significantly alter program direction; or enable an adversary to defeat, counter, copy, or reverse engineer the technology or capability."[87] The Department's Instruction 5200.39 levied the initial requirement for programs with CPI to submit a program protection plan for review and approval by the appropriate milestone decision authority or science and technology equivalent. Further, DoD Instruction 5200.39formally documented the Department's policy to minimize the compromise of "elements or components being integrated into DoD systems by foreign intelligence, foreign terrorist, or other hostile elements through the supply chain or system design."[88]

Spurred by language in the fiscal year 2011 and 2012 National Defense Authorization Acts, more recent acquisition policies signed out by Undersecretary Kendall focused largely on counterfeit prevention. The 2012 authorization included a provision targeted at counterfeit electronic parts. Section 818 requires the Department to adopt procedures that levy electronic counterfeit prevention obligations on defense contractors, including requirements that describe how contractors are to establish and validate trusted suppliers.[89] Early versions of the provision suggested the USG will hold prime defense contractors to "open-ended liability" for counterfeit parts discovered in their products leading to a flow down of obligations to subcontracted suppliers.[90] Ultimately, the cost burdens transferred to contractor will likely trickle down to smaller companies that may decide the compliance infrastructure creates an environment of too much risk compared to potential return on investment. Further, companies might refrain from bidding on future defense projects creating a market with less competition and desirable choices for innovative skills and technologies.

However, after inviting comments from experts in the government and the private sector regarding electronic parts avoidance, the SIA applauded the final version of section 818 released for implementation on May 6, 2014.[91] The final ruling requires defense firms and their subcontractors to establish a counterfeit electronic part and avoidance system, subject to audit, includes procedures to show use of original manufacturers and authorized distributors prior to turning to other outlets.[92] Further, early analysis of corresponding changes to the Defense Federal Acquisition Regulation (DFAR) resulting from the new section indicates requirements only apply to defense firms operating under larger contracts with formal cost accounting standards. By default the current situation results in an exemption for small businesses and contracts in the acquisition of commercial items.[93] Therefore, while initially praised by the industry's largest association, the exact second and third order effects to the USG's large defense firms and smaller-tiered suppliers remain to be seen.

RECOMMENDATIONS FOR FUTURE ACQUISITION POLICIES

Providing the DoD workforce with anti-counterfeit education and training is critical to ensuring trusted ICs for future defense programs. The weapon systems not affiliated with the DoD's Trusted Foundry Program are reliant on oversight based on contract specifications to produce trusted electronic components. In this case the USG replaces highly skilled experts who assist in coordinating with a dedicated foundry or an accredited supplier with less experienced government program teams. The teams attempt to navigate through critical protection processes and program protection plans with little appreciation for the risks assumed in the procurement of compromised chips. Therefore, the Department's acquisition policy makers cannot simply levy requirements for a secure industrial base on suppliers, it has to improve the awareness level and skill sets of its workforce. Yet, the reality is that acquisition program managers in charge of those systems identified below MAC 1 invest little time to understand the mechanics of information assurance strategies. One solution is to add a dedicated case study on the electronics industrial base to the more than 90 program cases that make up Defense Acquisition University's senior joint program managers course, known as PMT 401. The historical cases in the 2011 Senate Armed Services Committee hearing on the defense supply chain, such as the US Navy's SH-60B helicopter or the US Air Force's C-27 offer real-world lessons, which would allow senior program managers to see that program protection is more than program documentation.[94]

To strengthen the IC industrial base, key stakeholders must participate in ongoing dialogue to update policy. Today, prime defense contractors face similar challenges to those within DoD, as counterfeiters target aerospace and defense products intended for use over prolonged periods of time. The threat makes prime contractors vulnerable to the obsolescence of parts and limited visibility into supply chains which introduced further risk into the system.[95] Therefore, follow-on regulations must include input from companies throughout industry beyond just those who operate in the military industrial complex. An example is industry feedback, if not buy-in, on any restitution policies forthcoming in the next round of changes to the DFAR on counterfeit prevention. Involving industry partners up front could prevent unnecessary costs from being passed on to future government acquisition programs.

Further, industry and USG collaboration might prevent innovative, lower-tiered electronics firms from leaving the defense market altogether. More importantly, collaboration likely fosters a more trusted environment where major defense contractors openly report instances of counterfeit activity in their supply chains based on a partnership rather than a prosecution-based relationship. In addition to industry partnership, the U.S. Commerce Department must adopt an expanded role in helping the defense acquisition community gauge the strength and health of a sector before embarking on any new policies that might have unintended negative impacts. The U.S. Commerce Department's industry surveys help acquisition program teams and policy makers understand current challenges facing private sector firms today, ensuring new USG policies achieve their intended effects. The USG newly released changes to section 818 of the National Defense Authorization Act for 2012 builds on existing defense policy that generates more valuable input from their industry counterparts.

EXPANDED RESEARCH AND DEVELOPMENT OF COUNTER-TAMPERING TECHNOLOGY

To mitigate risk to U.S. national security, the USG must partner with industry and academia with all parties increasing their investment in R&D to develop counter tampering technology. Tampering with ICs can take many forms. Examples include reverse engineering to extract IP or discover sensitive data such as cryptographic keys, inserting malicious functionality such as Trojans or kill switches, substituting good components with inferior ones, physically altering a device, or manipulating the logical operations of code or instructions used to provide electronic component functionality.[96] In 2005, the Defense Science Board recommended the DoD initiate steps to enhance counter-tamper proficiency.[97] Using trusted sources, marking internal components, and embedding anti-tamper technology into the hardware provides DoD the initial means to thwart malicious intent. However, with the growth of the semiconductor industry, the expansion of skills among adversaries and/or vindictive insiders requires continued vigilance. Hardware malware built today possesses a risk as early as the design stage of building an IC and may lie dormant for years, or be hidden in maintenance or test logic code only to execute at an opportune moment or activity to maximize damage to the larger device.

The USG must continue to identify adversary tactics, techniques, and procedures (TTPs), adapt lessons learned and develop doctrine to counter the risk due to tampering. The United Sates intelligence community must commit resources to illuminate and expose tampering activity and TTPs. Once adversary tampering TTPs are identified, the intelligence community must disseminate them to trusted points of contacts within industry and academia. This allows for a collaborative development of a variety of means and methods to defeat current and emerging tampering technology. Furthermore, DoD must establish a cross-boundary working group comprised of counter tampering experts from government, industry and academia with the mission to protect critical advanced technologies employing ICs. This working group should lead the effort representing each of the entities they are from and ensure effective cooperation between members of the working group representing government, industry, and academia. The majority of funding for this effort should come from the federal government with partial funding from industry and academia given they will benefit from the success of the effort.

CONCLUSION

This paper provided and overview of the global semiconductor industry, and an analysis of the U.S. semiconductor industry and its ability to meet national security needs. In the analysis we identified two major challenges the U.S. faces now and in the future: maintaining current competitive advantage and trusted and assured access in support of national security. We provided details on the key areas of concern: counterfeit chips, obsolescence, supply chain interdiction, and intellectual property protection. By extensively examining the challenges, we offered policy recommendations for sustainment and continued growth of the U.S. electronics industry in the areas of technological innovation, R&D, human capital, and government financial support for public-private partnerships. While semiconductor challenges will persist now and in the future, the U.S. electronics industry remains the world leader in innovation visionaries, intellectual property development, and education of the world's best and brightest. This intellectual advantage will continue to benefit the U.S. economy and more importantly our national defense. To maintain this advantage and remain "all-in" on innovation as described by

President Obama in his 2014 State of the Union address, the USG must adopt policies and ensure economic conditions that guarantee the viability of the electronics industry. Our ultimate goal is for U.S. semiconductor firms to remain leaders in the global market place, producing the most technologically advanced chips in the world and able to meet the national security needs of the United States.[98]

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