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ELECTRONICS INDUSTRY STUDY

ABSTRACT: The U.S. semiconductor industry has been the soul of U.S. economic growth for the past fifty years by contributing 30 percent to innovation productivity gains in the U.S. economy.[1] Asia, and specifically, China seek to usurp U.S. leadership in this little known, yet vital industry. The industry embodies the U.S. economic growth model characterized by unrelenting innovation, virtuous risk-taking, prolific collaboration, fierce competition, and yes, magnificent success. The U.S. government must engage with policies and resources that re-level the global playing field in order to maintain U.S. technological innovative leadership.

Mr. Adam P. Barker, Dept. of the Navy
Ms. Mary F. Comans, Dept. of Homeland Security
Mr. Stanley H. Darbro, Dept. of the Army
Col Elvert L. Gardner, U.S. Air Force
CDR Matthew J. Gevo, U.S. Navy
LTC Michael L. Haggard, U.S. Army
COL Jered P. Helwig, U.S. Army
CAPT Joker L. Jenkins, U.S. Navy
COL George M. Kyle, U.S. Army
Mr. William D. Miles, National Geospatial-Intelligence Agency
COL Mohammad M. Al Nuaimi, International Fellow - Jordon
Lt Col Jay B. Reeves, U.S. Air Force
Lt Col Tyler R. Schaff, U.S. Air Force
Mr. Andrew K. Sherr, Dept. of State
COL Sujatmiko G. Sriyatno, International Fellow – Indonesia

Col (Ret) Kenneth Stefanek, Faculty Lead
Col Paul Gillespie, Faculty

PLACES VISITED

Domestic:
Micron Technology, Manassas, VA
BAE Electronics Systems, Manassas, VA
National Security Agency, Fort Meade, MD
Naval Research Laboratory, Washington, DC
Semiconductor Industry Association (SIA), Washington, DC
IBM, Watson Research Center, Yorktown Heights, NY
IBM, Semiconductor Fabrication Facility, East Fishkill, NY
IBM, Executive Briefing Center, Poughkeepsie, NY
Semiconductors Equipment and Materials International, San Jose, CA
- KLA Tencor

Intel Corporation, Santa Clara, CA
Altera Corporation, San Jose, CA
Electronic Design Automation Consortium, Mountain View, CA
- Cadence Design Systems
- Mentor Graphics
- Synopsys
- ARM (Advanced RISC Machine) Holdings

eSilicon Corporation, San Jose, CA
Stanford University Paul Allen Center for Integrated Systems, Stanford, CA
Lam Research Corporation, Fremont, CA
Defense MicroElectronics Activity (DMEA), Sacramento, CA

International:
American Institute, Taipei, Taiwan
Industrial Technology Research Institute (ITRI), Hsinchu Science Park, Hsinchu, Taiwan
Taiwan Semiconductor Industry Association (TSIA), Hsinchu Science Park, Hsinchu, Taiwan
Taiwan Semiconductor Manufacturing Co, Hsinchu Science Park, Hsinchu, Taiwan
ChipMOS Technologies LTD, Hsinchu Science Park, Hsinchu, Taiwan
Etron Technology Inc., Hsinchu Science Park, Hsinchu, Taiwan
Inotera Memories, Inc., Hwa-YA Technology Park, Guishan Dist., Taoyuan City, Taiwan
Realtek Semiconductor Corp, Hsinchu Science Park, Hsinchu, Taiwan
United Microelectronics Corporation, Hsinchu Science Park, Hsinchu, Taiwan
American Chamber of Commerce, Shanghai, People’s Republic of China
U.S. Consulate, Shanghai, People’s Republic of China
Semiconductor Manufacturing International Corporation (SMIC), Shanghai, People’s Republic of China

"By 2020, achieve annual [semiconductor] industry-wide revenue growth of at least 20 percent; become global leader in mobile end-product devices, network communication, cloud computing, IoT [Internet of Things] and Big Data…By 2030, become global leader in all primary segments of the IC [semiconductor] industry supply chain."[2]

INTRODUCTION

The epigraph may read like an ambitious United States goal to dominate the global electronics industry, but it is in fact taken from the People's Republic of China (PRC) "Guidelines to Promote National IC [Semiconductor] Industry Development" published in June 2014. China and other countries covet the United States' leadership role in the semiconductor segment of the electronics industry, and as well they should. The semiconductor segment of the electronics industry in the United States is a central ingredient of U.S. economic growth and therefore, important to national security.

Semiconductors are microchips, or brains, for almost all devices with an electronic component. They power the communication, travel, entertainment, energy, medical, automotive, aircraft and scientific industries just to name a few.[3] For example, the iPhone is not part of the industry but the microchips that allow it to operate are included in the industry. Though small and hidden, they are significant.

This paper unveils the impact of this little-known industry and how it contributes to U.S. national security. The analysis is the result of six months of in-depth study into the semiconductor industry as part of the Eisenhower School's industry study curriculum. The study resulted in a powerful understanding of the link between industry and national security. The curriculum enlightened students through an academically interdisciplinary approach along with hands-on experience that included industry guest speakers, domestic and international sight visits, and interaction with related government agencies. This paper provides a definition of the industry, current conditions, challenges, opportunities, future outlook, and policy recommendations. The policy recommendations are designed to sustain U.S. global leadership by reinvigorating research and development, growing innovative U.S. human capital, gaining Sino market access, and securing access to trusted semiconductors for national security applications. Overall, the seminar discovered a dynamic and innovative industry that is at the core of long-term U.S. economic growth and technological leadership.

"The semiconductor industry lives - and dies - by a simple creed: smaller, faster and cheaper."[4] This obscure industry epitomizes all that is envied in the American capitalist model: unrelenting innovation, virtuous risk-taking, prolific collaboration, fierce competition, and yes, magnificent success. Economists Ferguson and Wascher argue persuasively "Productivity improvements are the building blocks for increases in the standard of living. The experience in the United States suggests that extended periods of strong productivity growth are characterized by innovations in technology…"[5] Indeed, semiconductor innovation fueled the explosive U.S. productivity increases over the past half century. Today, U.S. firms lead the world semiconductor industry in innovation and enjoy an impressive 50 percent share of revenue from the $305 billion global semiconductor market.[6] U.S. leadership, however, is fragile with no future guarantee, and leadership certainly has not always been the norm.

ELECTRONICS INDUSTRY DEFINED

Industry History: The United States created and led the semiconductor industry until the 1980s when the U.S. lost global market share to Japan, plummeting from 60 percent to only 37 percent in 1990.[7] The U.S. industry rallied in the 1990s by restructuring itself around innovation while also fragmenting the industry into four central segments: (1) design, (2) equipment manufacturing, (3) chip manufacturing, and (4) package/test. It turned to its own hero, Gordon E. Moore the Chairman Emeritus of Intel, for inspiration. In 1965 Gordon Moore predicted that the number of transistors on a microchip would double every two years, thereby doubling processor speeds.[8] His prediction is known as Moore's Law and is the driving force in semiconductor innovation to this day. Just as the U.S. space industry rose to President John F. Kennedy's "extraordinary challenge" in 1961 to land a man on the moon, the U.S. semiconductor industry rose to the challenge in the 1990s to regain U.S. technological innovation leadership in the manufacturing process. Additionally, the Department of Defense poured $500 million over five years to start a Semiconductor Manufacturing Technology (SEMATECH) research consortium in 1987 made up of U.S. semiconductor companies.[7] Through its collaborative approach on R&D, SEMATECH sparked an unprecedented level of innovation, rocketing the United States global sales over a decade from $77.3 billion in 1993 to $305.6 billion in 2013, an average annual rate of over 7 percent.[9] SEMATECH had an additional benefit of catapulting the design segment of the industry into global leadership through similar collaborative efforts combined with U.S. innovation. Viewed in this light, SEMATECH is largely responsible for catalyzing the globalization of the semiconductor industry and reasserting the U.S. as the global semiconductor heavyweight champion.

U.S. Industry Overview: In 2013 the semiconductor industry was the third largest U.S. export, valued at $42 billion.[10] Semiconductors live up to the 1990s BASF slogan, "We don't make things, we make things better."[11] Giorgio Scuro is an automotive electronics expert as an engineer and general manager with 40 years of experience in the automotive industry. In his article, "Automotive industry: Innovation driven by electronics," he astutely observed that modern growth of the automotive market is tied to electronic innovations, and specifically, microelectronics [semiconductors].[12] As an example, Google in 2011 had over 200,000 miles on public roads testing self-driving cars thanks to innovations provided by semiconductor technology.[13] Semiconductors power alarm clocks, coffee makers, cell phones, cars, computers, and even park tickets to Disney World. In 2014 the U.S. industry generated $79.5 billion with over 832 businesses.[14] It attributed to almost 245,000 direct jobs and an additional one million U.S. jobs.[15] Major U.S. companies include the global market leader, Intel Corporation, as well as Micron Technology and Qualcomm Incorporated.

In addition to individual companies, there are also associations. The Semiconductor Industry Association (SIA) is the main U.S. industry voice. SIA's mission is "…focused on keeping the U.S. semiconductor industry the global market leader."[16] SIA pursues U.S. and global policy that will help meet its mission to maintain U.S. industry leadership. The primary global industry association is the World Semiconductor Council (WSC). The WSC's purpose is to "…promote cooperative semiconductor industry activities, to expand international cooperation in the semiconductor sector in order to facilitate the healthy growth of the industry from a long-term, global perspective."[17] The semiconductor industry has gone through large changes over the past decade as leading firms shifted production to the Asian market, taking advantage of low-cost labor and access to new markets.[18]

Asia Industry Overview: What Japan lost during industry fragmentation, Asia gained. The industry fragmented from a vertical, Integrated Design and Manufacturing (IDM) model to multiple segments divided into (1) design, (2) equipment manufacturing, (3) chip manufacturing, and (4) package/test. The rise of the Asian semiconductor industry thrived from fragmentation, causing even greater industry consolidation of companies within the four segments. The Asian semiconductor industry is currently dominant by quantity in the production and manufacturing segment using the latest 300mm wafer sizes.[19] Samsung in Korea continues to be an industry leader, embracing an agile business model based on customer needs.[20] Pure play foundries in China (SMIC) and Taiwan (TSMC) are increasing production capability and technology, while attracting more business from global design firms.

Taiwan is a top chip producer and China is aggressively pursing leadership. A growing semiconductor industry is foundational to China's economic growth plan. The Chinese government subsidizes many domestic semiconductor industry activities in an attempt to shield vulnerable new global start-ups. This model has been unsuccessful in the past due to misuse of funds, but could find victory this time due to increased investor oversight.[21]

The Asian semiconductor industry and market are set to outpace all other regions in growth and market size for the foreseeable future. Industry expansion and the associated elements of "market pull" will be seen in China, Taiwan and South Korea. The current regional strength is the manufacturing, test and packaging processes, but some Asian companies are entering the highly specialized, innovative design segment.

Europe Industry Overview: The European semiconductor industry is also fragmented. European firms generally fall into three broad segments: design, equipment manufacturing, and chip manufacturing.[22] The industry provides 250,000 direct and 800,000 indirect jobs to European countries while enabling the generation of at least 10 percent of European GDP.[23]

Currently, Europe's greatest competitive advantage is its 20 percent global market share of equipment.[24] ASML in the Netherlands is the global leader in lithography equipment manufacturing which is the integral piece of equipment that allows billions of transistors to be placed on a single chip. British design firm ARM Holdings, specializes in licensing its low-power chip architecture that powers most mobile devices today. Chip manufacturing in Europe is two to three technology nodes behind the U.S. and Asia. This is telling of a struggling European chip manufacturing industry.

The European semiconductor industry once captured as much as 15 percent of global production in the 1990's, but today produces less than 10 percent, falling behind Japan, South Korea, Taiwan, and the U.S.[25] However, Europe claims a social and economic competitive advantage that could renew European competition.[26]

In May 2013, Neelie Kroes, vice president of the European Commission (EC) challenged the European semiconductor industry to "double the economic value of the semiconductor component production in Europe by 2020-2025."[27] Although, the European semiconductor industry has been in decline over the past two decades, it believes through a unified determination it can leverage its areas of competitive advantage and reemerge as a global leader of semiconductors. This is unlikely.[28]

CURRENT CONDITIONS

The global demand for semiconductors continues to rise; however the U.S. market is highly volatile. The U.S. industry experienced a contraction in 2012 but recovered strongly in 2013, producing growth nearly three times faster than the global semiconductor industry.[29] Asia-Pacific is the largest customer segment with 67 percent of market share in 2013, compared to the U.S. as the second largest market at 15 percent and Europe the third largest with 10 percent.[30] U.S. companies operate in an extremely competitive global industry characterized with rapid price reductions, high research and development costs and significant capital requirements in the manufacturing segment.[31] International competition is pressuring the U.S. industry; nevertheless, profits following the large drop from the 2008 U.S. financial crisis are strong.[32] Another area of concern is U.S. imports. They have increased as U.S. companies offshore the manufacturing of lower-value semiconductors thereby, decreasing revenue for many U.S. companies.[33]

Because of the high R&D costs associated with the industry's unquenchable thirst for innovation, the industry has undergone significant consolidation as few companies can raise the required capital it takes to compete in the global market. This is especially true in the manufacturing fabrication factories, known as "fabs." A typical fab costs billions of dollars, pricing out smaller companies and forcing consolidation of remaining companies. An additional aggravator to company survival is that the industry is in the mature stage of its life cycle.[34] For this reason the industry's contribution to the U.S. economy is expected to only grow at approximately the projected rate of GDP growth over the long-term, meaning the industry has little value-added to real GDP growth.[35] However, this is misleading and fails to consider the intrinsic value of the industry. Narrowly viewing real GDP contribution misses the incalculable impact of technological innovation on workforce productivity, a factor that directly drives U.S. GDP growth. Still, this translates into competitive times for individual semiconductor companies, but high value-added to the economy overall.

Significant capital investments add to the competitive nature of individual companies within the industry. In 2014 it is estimated that $0.43 goes toward capital investment for every dollar that is spent on wages.[36] This is almost three times higher than the overall economy.[37] Likewise, semiconductor manufacturers typically invest 30 percent of annual revenue in R&D and capital expenditures.[38] These large investments are required to keep pace with the constant innovation that drives "…increased performance, miniaturization, cost reduction or ever shortening life cycles."[39]

The People's Republic of China (PRC) follows mercantilism trade practices with foreign semiconductor companies in hopes of growing its domestic semiconductor industry.[40] The PRC also heavily subsidizes its own semiconductor companies to help them move up the technology ladder.[41] Like the U.S., the PRC understands the security and economic benefits of the industry.[42] Unfortunately, for U.S. companies, this means unfair competition.

China also poses several risks for U.S. companies. One such risk is the theft of intellectual property. This becomes a cost imposing strategy for U.S. companies as they spend thirty percent of revenue on intellectual property while China steals IP. Other problems primarily found in Asia are counterfeit parts and the black market. This brings risk of phony parts into the semiconductor supply chain. These combined practices add to the volatility of the future health of the U.S. industry. This sense of volatility is clarified by looking at Porter's five forces model.[43]

Porter's Five Forces Analysis: Each segment of the U.S. semiconductor industry is currently strong due to the overall U.S. economy coming out of recession and the growing demand for electronics and increased demand for additional functionality. Additionally, the industry is benefiting from other industries and interests groups. Environmental issues in the U.S. for example are driving demand for electronics with reduced power consumption, heat dissipation, and overall efficiency.[44] The five forces analysis paints an industry with strong internal rivalry, moderate threat of new entrants, power of suppliers and buyers, and a very weak availability of substitutes.[45]

Buyer power is moderate because of the large, and ever-expanding customer base.[46] The large buyers consist of electronic products, computers, the defense industry, and the automobile industry.[47] Buyer power is enhanced because of rapidly advancing technology combined with fungible products at similar or lower costs.[48]

Even though suppliers are generally not vertically integrated in this industry, their power is still only moderate.[49] This is largely due to the trend of transferring matured technologies to low-cost countries in the Asia-Pacific.[50] However, there are some specific suppliers that do hold more power, like ultrapure semiconductor wafer manufacturers because of their limited numbers.[51]

The threat of new entrants is assessed as moderate because of extreme barriers to entry from high capital investment costs and significant R&D and intellectual property requirements.[52] However, this is mitigated somewhat due to the entrance of the new design-only model developed in the 1990s that outsources the actual manufacturing process to a fab. This alleviates the investment barrier but does not necessarily solve the intellectual property barrier.[53]

The threat of substitutes is assessed as very weak simply because there are no alternatives to semiconductors.[54] However, one consideration is the "copy-cat suppliers" that reverse engineer products after companies have spent millions or even billions on R&D.[55] U.S. policy-makers are considering making the possession of counterfeit components a criminal offense to help with this issue.[56]

Finally, the rivalry among companies is strong due to the unforgiving, rapid pace of innovation at significant costs. Another industry descriptor is "better, faster, and cheaper than what redefined the state-of-the-art industry only a few months before."[57] The numbers of companies are relatively small and are pressured from the Asian market. Competing in this industry brings fierce rivalry that seeks to out-pace the other company with the next cutting-edge technology while operating within a volatile business environment.[58] The fierce internal rivalry for the U.S. industry is only compounded by additional challenges.

CHALLENGES

Over the past 50 years the semiconductor industry has provided consumers with incredible revolutionary products that have defined the modern lifestyle. There is no doubt that innovation will continue but there are significant headwinds that are developing in the industry and the DoD. This section examines four challenges, two specific to industry and two specific to the DoD.

Challenge 1: Migration to a new paradigm. The first challenge to the industry is the migration away from Moore's Law to a new paradigm. Moore's Law has driven the industry throughout most of its history. This was accomplished through scaling down the sizes to an unimaginable level over the years. Today, billions of transistors are placed on a microchip the size of a thumbnail. The question is whether there is an economical way to continue scaling. Something new must be developed to get past single atom transistors. The true challenge goes beyond silicon. Chip-makers have perhaps become lethargic while blindly following the classic Moore's Law timeline. Soon, the future will require a courageous leap into the unknown if U.S. technological leadership is to continue.

Challenge 2: Counterfeit parts and IP theft. A second challenge for the industry concerns the proliferation of counterfeit parts and the theft of intellectual property (IP). As the majority of semiconductor manufacturing has migrated overseas the industry has dealt with an increase in counterfeit products. Much of the e-waste finds its way back to foreign facilities where it is stripped down and repurposed. This calls into question the reliability of components and is of a particular concern to the DoD. Additionally, Counterfeiting has become increasingly sophisticated as some counterfeiters actually manufacturing their own chips. This also raises serious reliability concerns since proper testing is not accomplished.

Closely related to counterfeit products is IP theft. Most foreign companies have close ties to the governments in their countries. Pressures to compete globally lead to an environment conducive to stealing IP in order to maintain competitiveness on the cheap. U.S. companies are lucrative targets because of their leading edge IP. Additionally, IP theft harms U.S. competitiveness by passing on billions of dollars of R&D IP to some competitors for free. This is a significant concern to U.S. technological leadership.

Challenge 3: Assured access for DoD. The third challenge focuses on assured access for U.S. interests, specifically the DoD and other government organizations. Of note, DoD has lost a voice in this industry. Originally inventing and consuming almost 100 percent of the microchips produced, today the DoD accounts for less than 1 percent of the market.[59] Until recently, the DoD has relied upon IBM's foundry capacity to manufacture microchips as part of the Trusted Access Program. It should, therefore, be no surprise that DoD is concerned with the October 2014 IBM announcement of a deal with Globalfoundries Inc., an investment arm of the government of UAE, that allows it to divest its manufacturing facilities. Globalfoundries gains access to prized manufacturing IP as well as access to the engineers that are at the leading edge of microchip design.[60] The sale calls into question the long-term viability of the DoD trusted foundry program in which the government pays an incentive fee to U.S. companies to guarantee the access and reliability of components that are important to national defense.

Challenge 4: Industry Requirements Diverging from DoD. The final challenge for the DoD relates to how its requirements have diverged from commercial consumers. Consumer electronics increasingly focus on power management and connectedness with less concern on a long life cycle and survivability under rigorous or extreme conditions. While the DoD is interested in power management, it is generally more concerned with prolonging the mean time to failure and survivability in systems that must last much longer than the average smart phone under conditions that are far harsher. The lengthy process of weapons procurement also virtually assures that many of the chips in the system will be obsolete by the time of fielding. This is a spare parts challenge for sustainers. Unfortunately, the DoD and government are insignificant players in the semiconductor market, which makes it difficult to apply leverage to industry.

OPPORTUNITIES

With challenge comes opportunity. While there are obstacles, opportunities also exist to sustain U.S. leadership in the semiconductor market through creative innovation and foresight.

Opportunity 1: Internet of Things. The Internet of Things (IoT) promises to further revolutionize modern life with infinite possibilities to connect anything and everything to the web. This will facilitate greater productivity and convenience. Many in the semiconductor industry see this as a market that will blossom over the next decade by driving demand for low powered chips that allow connectivity to the web. Production capability largely exists through the smart device base. Many smart home features are already on the market. Cars are increasingly marketed like cell phones rather than like traditional industrial-era products. Much of the opportunity is in innovative ideas to incorporate microchips into society. As an example, microchips placed inside a baby diaper can alert a parent's smart phone when the baby is wet or alert a doctor when their body temperature is high. This is an opportunity because devices require an innovative culture like the one found in the U.S.

Opportunity 2: Data as a Natural Resource.[61] Closely related to the first opportunity is the growing need to access, understand, and use the vast amount of data available. Indeed, data is becoming a natural resource that could be as important to the health of a future economy as natural gas. This is a strategic opportunity for the United States. The country that is able to collect, sift through, and act upon data the fastest will hold an asymmetric advantage over others. Imagine the U.S. intelligence community with an automated computer system, powered by sophisticated microchips, that produces actionable knowledge to prevent terrorist attacks before they even get started. Or, consider a medical community that can tap into data that facilitates cures for cancer. The industry is working to produce specialized chips that can fill the gaps in human processing limitations. This offers U.S. companies and government agencies an opportunity to gain a strong technological lead.

Opportunity 3: U.S. Innovative Culture. Finally, the innovative culture that exists in the U.S. remains a huge opportunity for further growth in semiconductors. Silicon Valley, and other clusters of expertise throughout America, offers something that is the envy of many countries. The partnership between education, industry, and government has produced a climate that is well developed to produce the next best thing. This unique culture of risk-taking and tolerance for failure is a U.S. jewel that is unparalleled and difficult to replicate. This should be nurtured and not taken for granted so America can continue to lead in the semiconductor industry.

OUTLOOK

Near term: The five-year outlook for the U.S. semiconductor industry is promising as the U.S. is still the clear leader in cutting-edge semiconductor technology. Optimistic analysts forecast the industry to increase by approximately 28 percent over the years 2013-2018 with an annual growth rate of 5.2 percent.[62] U.S. industry has increased R&D efforts that are sure to support the insatiable appetite of innovation demands within the global market.[63] Porter's five forces analysis should largely hold true over the next five years with rivalry continuing as the strongest force. In fact, competition within the U.S. industry is expected to increase as international competition grows.[64]

Demand for semiconductors is expected to increase, especially in the Automotive, wireless technology, and mobile computing markets.[65] Automobiles are becoming more than just transportation, they are becoming an integral part of daily life with features like infotainment, navigation, and connectivity, all powered by semiconductors that are included even in base models. Additionally, the demand for increased wireless connectivity across the globe is driving demand for more semiconductors and the need for an entire infrastructure that can support high data volumes, security, low power, privacy and security.[66]

Another factor that will drive stability for the U.S. industry over the next five years is the ability to continue to follow Moore's law. The end of Moore's law is approaching as the amount of transistors on a computer chip reaches the single atomic level, but this will not occur within five years.

Mid term: The ten-year outlook for the U.S. semiconductor industry is less certain, but still expected to be strong. In January 2015, Google announced a one billion dollar deal with SpaceX to launch satellites that would provide worldwide wireless access.[67] This move is among others that support an ever-increasing demand forecast for semiconductors. The next ten years do not appear to change the Porter's five forces analysis for the industry as internal rivalry is expected to continue to dominate. The U.S. industry is expected to feel increased pressure from Asian-Pacific companies and could struggle if unsuccessful at breaking into the giant Chinese market. One technology that could make or break the U.S. industry is the proposed transition from the 300mm diameter silicon wafer to the 450mm wafer. The larger wafer would increase yield and in turn, per unit price competitiveness. However, the technological transition is significant and will cost billions of dollars to pursue. For that reason, the industry is hesitant to transition and will only be feasible for major companies.[68]

Long term: The 15-year outlook for the industry is anyone's guess. It is at this point where Moore's law ends and the next big thing arises.[69] The economic principle of creative destruction could play a role in this area. Joseph Schumpeter coined the term, creative destruction, in 1942 to describe how old industries are usurped by new industries, not by evolution, but instead through total destruction, much like the automobile industry destroyed the horse-drawn buggy industry.[70] However, this theory is controversial in the semiconductor industry because of the significant R&D and intellectual property required to design the next big thing. Another argument in favor of the U.S. industry surviving the next big thing is the powerful cluster in Silicon Valley. This hub of intellectual property combined with significant venture capital and a culture that thrives on failure in pursuit of success is a dominant force in the U.S. corner.

GOVERNMENT GOALS AND ROLE

The goal of the United States government should focus on maintaining U.S. technological leadership, which in turn will sustain U.S. economic growth. This means supporting the U.S. semiconductor industry. Asian countries are making a play for global leadership in this industry for one simple reason- they understand its importance. The U.S. government must recognize this as well, and engage. In this context several policy recommendations are presented to foster future U.S. competitiveness.

Policy Recommendation 1: Reinvigorate Research and Development.

Issue: The U.S. semiconductor industry is competing on a non-level playing field in the global market. Other countries have large government R&D funding as well as advantageous tax benefits and even government subsidies. While the United States leads the world in R&D spending, China is catching up by significantly increasing its investment in R&D with a goal to move from its current level of 1.8 percent GDP to 2.2 percent by the end of 2015.[71] The PRC's goal is to become an innovation driven economy by 2020.[72] Maintaining the lead in R&D is central to U.S. success.

Recommendation to U.S. Government 1: Increase funding of the SRC. The Semiconductor Research Corporation (SRC) leverages the resources of semiconductor companies to fund precompetitive research. Increasing support for SRC will keep America competitive.

Recommendation to U.S. Government 2: Increase funding to basic research. Most U.S. firms do not have the capital to fund basic research that does not provide a return on investment for 10 to 20 years. Federal spending on R&D has been in decline since the 2008-2009 timeframe. The most critical aspect of flat or declining R&D spending is the long-term negative consequences to future innovation.

Recommendation to U.S. Government 3: Promote Basic and Regular Research Tax Credits. Because of unfavorable U.S. tax policy, U.S. companies are hesitant to bring dollars back to the U.S. to feed industry's heavy R&D appetite. This is admittedly politically sensitive, yet nonetheless, important to future U.S. competitiveness. Basic and regular research tax structures are ill-suited to support R&D because the calculation assumes a reliable 3-year funding stream, the credit of 20 percent is comparatively small, and its annual renewal adds uncertainty to long-term projects. Resolve research tax deficiencies and it will boost company-level R&D.

Recommendation to U.S. Government 4: Promote Corporate Tax Reform. At 39.1 percent, the U.S. corporate tax rate is among the highest in the world. Three specific reforms for the semiconductor industry include: changes to the policies on depreciation, the U.S. international taxation system, and capital repatriation. Changes to the depreciation rules can reverse the disincentive of U.S. foundry investors by defraying upfront multi-billion dollar capital investments and potentially reversing the offshore trend in manufacturing.

Policy Recommendation 2: Human Capital.

Issue: Human capital is the largest competitive advantage for the US semiconductor industry.[73] To obtain and retain the requisite levels of human capital there must be a concerted effort focused on science, technology, engineering or math (STEM) education and immigration reform.

Recommendation to U.S. Government 1: Promote STEM Education. The semiconductor industry requires employees with advanced specialist degrees in electrical engineering and computer science. The United States should expand government grants to promote STEM programs. They are critical to maintaining minds capable of sustaining the U.S. innovative competitive advantage.

Recommendation to U.S. Government 2: Promote Immigration reform. It is in the best interest of the U.S. to recruit and retain engineers and technicians capable of driving innovation in the near term. This is precisely where immigration programs such as the H-1B Visa program become important. The current annual limit on H-1B visas is capped at 85,000.[74] In 2014, the U.S. received 172,500 H-1B petitions, over twice the cap limit, in the first five days of the filing period and had to stop accepting applications.[75] Although efforts are underway to increase the H-1B visa cap to 195,000 per year, this is not enough.[76] As an example, the U.S. should be fighting to keep the niche, foreign electrical engineering PhD from Stanford upon graduation. This directly increases U.S. productivity, thereby increasing overall potential GDP.[1]

Policy Recommendation 3: Access to Sino Market.

Issue: As the fastest growing market for electronics, China is leveraging its economic might to shape its market through a number of policies. The first is to force foreign companies to exchange IP for access to their consumer market. The second is to require that products sold in the market be manufactured locally. Both of these issues place U.S. companies at a distinct competitive disadvantage and dampen open market activity.

Recommendation to U.S. Government: Continue to pull China into the Global Commons. China's participation in the World Trade Organization placed them under the Agreement on Trade Related Aspects of Intellectual Property Rights or TRIP. There is evidence that this policy has opened up a positive dialogue on intellectual property rights. In fact, China has passed a number of laws to increase the IP protection in response to WTO disputes.[77] U.S. policy makers should continue to promote China's involvement in international organizations that promote trade transparency and work to strengthen IP rights.

Policy Recommendation 4: Trusted Access

Issue: National security organizations like the DoD require access to trusted and high-tech microchips to maintain U.S. asymmetric advantage. The IBM sale of its manufacturing facilities to the UAE's GlobalFoundries is a concern to national security for three reasons: (1) potential transfer of valuable intellectual property to a foreign company, (2) loss of access to low volume, highly critical state of the art (SOTA) military microchip processes only available at IBM foundries, and (3) loss of trusted access to high-tech microchip manufacturing. During industry visits, some voiced concern that GlobalFoundries purchased IBM's fabrication facilities simply for their intellectual property and access to their engineers. Due to the unprofitability of the facilities, it is thought GlobalFoundries will close down the fabs, leaving DoD without access to certain SOTA microchip processes. Today, this is primarily a national security organization concern; however, it is anticipated that trusted access will eventually become an industry concern that will impact revenue.

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[1] Potential GDP (Gross National Product) is defined using the common definition of number of workers plus productivity.

Recommendation to U.S. Government 1: Preserve access. The IBM deal is currently undergoing Committee on Foreign Investment in the United States (CFIUS) review.[78] The U.S. must preserve access to critical SOTA microchips. This can be accomplished by making the CFIUS deal contingent upon a 5-year contract with GlobalFoundries that guarantees the fabs remain open and the U.S. government maintains access until an alternative solution is found. Five years is within the current IBM 10-year contract deal with the DoD for trusted access and also allows time for DoD to develop alternatives.

Recommendation to U.S. Government 2: Explore alternatives for trusted access. The DoD, in conjunction with industry should study the vulnerabilities and probability of counterfeit or malicious chips entering the supply chain. Some believe that design is the primary area of vulnerability.[79] Since the U.S. today maintains the lead in design, it is possible for DoD to establish a trusted program with design firms. Manufacturing is more difficult as it is quickly shifting overseas. However, if manufacturing is indeed a decreased vulnerability then a trusted program at an overseas fab may be feasible. This requires further study. If so, DoD may be able to work with friendly nations for a trusted program. This could even include U.S. on-site, oversight if required.

Recommendation to U.S. Industry: Anticipate the commercial need for trusted access. Trusted access is not just a DoD problem. As microchips become ubiquitous in modern society, it is increasingly important for public health and safety that chips do what they are supposed to do, and do not do what they are not supposed to do. U.S. industry will have a first-mover competitive advantage if processes and designs are developed to ensure trusted access to semiconductors.

CONCLUSION

The U.S. semiconductor industry is the soul of U.S. economic growth and therefore, important to national security. The industry spurs workforce productivity, which increases U.S. GDP. It supports growth in multiple industries like automobiles, wireless technology and mobile devices. The U.S. is the father of the industry and remains the world leader in semiconductor technological innovation. However, leadership should not be taken for granted. United States policy should promote future industry health. China, Taiwan, Korea, India and Europe are making a play to take over global semiconductor technology leadership. This places U.S. companies in an intensely competitive environment, one that requires the U.S. to adopt policies and practices that will sustain U.S. leadership.

The smaller, faster, cheaper nature of the industry has largely driven U.S. manufacturing overseas in order for companies to maintain competitiveness. During the electronics seminar semester of study it was clear that the off-shoring trend within the industry could spread from manufacturing into design and equipment manufacturing, leaving the U.S. industry in its wake. The U.S. lost the manufacturing lead to Japan in the 1990s. Today, the U.S. has lost the lead in manufacturing quantity. If the U.S. also loses the design and equipment leads to Asia it will mean a complete loss of U.S. leadership in this industry. It is not alarmist to say that the U.S. could lose its technological innovative leadership and without it, break the long-sustained U.S. economic growth model. Therefore, the United States should implement the recommended policies to ensure sustained U.S. global leadership. Reinvigorating research and development, growing innovative U.S. human capital, gaining fair access to the Sino market, and maintaining a trusted supply of semiconductors for national security applications are reasonable policies that not only support the semiconductor industry, but benefit U.S. innovation overall.

Further study is recommended in several areas. For the DoD it is recommended that the acquisition community, operators and industry combine efforts with the Defense MicroElectronics Activity to develop a roadmap for a new trusted access paradigm. Additionally, the Government Accounting Office should study the impact of future semiconductor technology on U.S. economic growth. In this anonymous industry, knowing really is half the battle.

ESSAYS ON MAJOR ISSUES

ESSAY 1: Policy Initiatives to Preserve U.S. Technological Leadership

Introduction: Sputnik shocked the United States as Cold War tensions were at there highest.[80] What followed was a United States government (USG) shift from a hands-off, lassie-faire policy to one with a heavy influence in public and private sector technological research and development (R&D) in order to support national security objectives. Enabled by large spending, the resultant effect was the U.S. became the dominant military and the world's economic and high-tech innovation leader.[81] In the 1980s the domestic and world environments changed. The fall of the Soviets, reduced federal budgets, increased industry competition, a growing globalized commercial market, rapid technology advances, and diffusion of technology, diminished America's technological and economic lead.

As part of America's high-tech industry, semiconductors lie at the heart of the military's systems, platforms, and weapons. Once consuming almost 100 percent of the microchips produced, today the military accounts for less than 1 percent of the market.[82] Regardless, DoDs access to reliable current and advanced chip technology for national security remains. Apart from directly designing and manufacturing chips, which is cost prohibitive, there are ways the USG can maintain its technological edge in the global market. Specifically, it can connect the broader U.S. technology R&D environment with high-tech industry to meet national security needs. Another way is to maintain a trusted supply chain of electronic parts by reducing the risk of counterfeit parts and maintaining the Trusted Access Program in the face of market globalization. Outlined will be two technology investment programs and two federal tax policies significant to domestic R&D and industry, their notable deficiencies, and possible policy changes. Revitalizing a technology development program and tax reforms are complementary approaches intended to address different levels in the R&D-industrial commercialization lifecycle to maintain technological innovation leadership, build high-tech industrial capacity, and to meet our military and economic national security interests.

Supply Chain Security: Counterfeit semiconductor chips pose a significant threat both to the economic health and national security of the United States. Depending on the end-product use, counterfeit chips can cause production downtimes, maintenance delays diminished company credibility, lawsuits, and even loss of proprietary intelligence.[83] These grey market chips can find their way into the supply chain in a variety of ways. The first way is through the practice of reselling, where companies harvest older technology chips from discarded electronic devices and reinstall them into new devices. Additionally, chips that customs agents cannot verify as authentic eventually find their way to the grey market of unauthorized resellers. Similar to counterfeit clothing, jewelry, and pharmaceuticals, these chips are targeted towards those people seeking name-brand end devices at a discounted price. Current estimates place the sale of all counterfeit products at 7 percent of total sales. With annual sales of semiconductor chips exceeding $300 billion, 7 percent is more than $20 billion, representing a substantial number of dangerous parts.[84]

Additionally, unfriendly countries can intentionally target the U.S. by purposely manufacturing chips containing malicious logic. These chips could target military or industrial applications and can act as "Trojan Horses" by waiting on specific conditions or commands before activating the malicious logic. Depending on the end-state application, the logic contained on the chip can either actively cause a malfunction or passively collect data for transmission back to the originating manufacturer. End state applications can include purpose built chips for military hardware, SCADA control systems, medical devices, and industrial systems.[85] Given the potential catastrophic impact posed by counterfeit chips in these types of applications, it is imperative that U.S. government policies support chip and end-device manufacturers in their efforts to combat counterfeit products.

Unfortunately, the widespread use of semiconductor chips does not lend itself to a comprehensive policy easily expressed in one document. Perhaps the best-known policy regarding the trusted supply chain in electronics is the Trusted Access Program Office[86], which helps companies comply with the requirements in Department of Defense Instruction (DoDI) 5200.44, Protection of Mission Critical Functions to Achieve Trusted Systems and Networks (TSN).[87] Managed by the Defense Microelectronics Activity (DMEA), TAPO provides a means for companies to ensure the integrity and confidentiality of integrated circuits intended for defense applications.[88] However, the recent IBM foundry, a primary supplier in the Trusted Foundry program, sale to GlobalFoundries raises questions of DoD's continued access.[89] Since GlobalFoundries' ownership is based in Abu Dhabi, the U.S. government must thoroughly review of the company's participation in the Trusted Foundry Program.

Additionally, different policies contain elements supporting anti-counterfeiting efforts. For example, the National Defense Authorization Act for fiscal year 2012 required defense contractors to detect and avoid counterfeit components or face financial and criminal penalties.[90] Additionally, the Department of Defense and the General Services Administrations (GSA) published a report titled "Improving Cybersecurity and Resilience through Acquisition" in November 2013 in response to Executive Order 13636. The report provides a recommendation to require government contractors to purchase electronic components from the original equipment manufacturers (OEM), authorized resellers, or other trusted sources.[91] While the reports focused on this as a means to address risk in the cyber domain, the principle applies within the broader context of counterfeit materials and products. Within the Department of Defense, anti-counterfeit prevention policy is contained in several documents including DoD Instruction 4140.67 (DoD Counterfeit Prevention Policy)[92]; and DoDI 5200.39 (Critical Program Information (CPI) Protection Within the Department of Defense)[93]. Each of these documents provides DoD-level policy on enhancing the security and safety of major weapons systems by requiring the use of a trusted supply chain, protecting against counterfeit products, and using risk management to protect critical defense systems and programs. However, anti-counterfeiting measures can, at times, be counter-productive, as was the case with security measures taken by the U.S. Department of Homeland Security (DHS) in 2008. The measures, developed as a means of protecting importers, actually helped unverifiable semiconductors to make their way back into the grey market.[94] Given the risk to military personnel and the risk to the defense industrial base posed by counterfeit products, it is important that national level policy makers continue to review the effectiveness of their policies and adjust accordingly. [95]

U.S. Government Role in R&D, TRP AND SBIR: Research and development comprises three stages: basic, applied, and development. Basic research is "any original investigation for the advancement of scientific knowledge not having a specific commercial objective," and has long time-horizons.[96] Applied research has a shorter timeline of 5-6 years, "designed to link scientific knowledge to some practical purpose, ultimately leading to the development of a marketable product or service."[97] Development research is the improvement of products and services with imminent prospects of successful commercial implementation to achieve an economic payoff.[98] Applied and development research is costly and time consuming, from $10 to $100 million and around five years.

As expected, universities and scientific non-profits typically occupy the basic R&D stage, while small business start-ups, and larger companies are in the applied and development stages. Today the USG remains the largest contributor to Basic research, almost 3-times more than industry. However, where the USG use to dominate, private industry now accounts for over 2/3 of all development stage funding, and over half of the applied research funding. [99] Recognizing this dynamic, a renewed technology development program can follow two approaches: raise the level of funding and grants in the applied and development stages in an attempt to compete with private industry for influence or reside where private industry is unlikely to invest, such as in basic research or training and education.

R&D time horizons and industry investment segments are important considerations for the USG and DoD to consider when investing in R&D. Federal R&D budgets are still substantial, and a renewed technology development program should focus effort in shaping the R&D and technology environment where the relative value of government dollars is greatest. Early influence in R&D may help ensure military and national security considerations are passed onto development and commercial stages, while training and education investment can grow a pool of labor expertise. R&D is only beneficial if industry is able to commercialize these discoveries, and even when properly linked, closing the gap to successful commercialization is difficult. Acknowledging this shift the USG introduced two technology-development focused initiatives, TRP and SBIR to help ensure military and national security technology needs would be met.

Technology Reinvestment Project (TRP). Created in 1993, TRP was a $19B program, awarding federal grants in the areas of technology development, technology deployment, and education and training. Funded from the DoD, an interagency council led by DARPA that included DOE, NSF, and NASA, the awards provided awards intended to "bring more benefits of civilian technology to the military," and to "broaden the base of companies in defense production." [100] Up to half of their R&D funding (with caps) could come from TRP as "seed money to cultivate new dual-use technologies…to the civilian market, the military sector, or both…for example, foster research into special materials for high-speed computer chips." In 1993 TRP provided a grant to a consortium that included IBM, Texas Instruments, Micron Technology, and North Carolina State University to develop advanced DRAM (dynamic random access memory) chips.[101] TRP was stopped in 1996.

Small Business Innovation Research program (SBIR). Created in 1982, the SBIR grew out of the 1958 Small Business Act "to support scientific excellence and technological innovation" in order to promote commercializing R&D.[102] Applicable for companies with 500 or less employees, the SBIR was designed to facilitate "the creation of startup companies to develop promising and targeted technologies," and to pursue R&D efforts that major corporations have shed "to focus on current production concerns."[103] SBIR has three phases: Phases I and II provided a maximum of $150,000 for 6-months, and $1M for two-years, respectively; Phase III provides no funding, releasing firms to pursue commercialization. Notable SBIR successes were "Amgen and Genzyme in biotechnology and Qualcomm in communications."[104] SBIR remains in effect, and since FY09, $26.9B has been awarded for 112,500 grants.[105]

Federal R&D budgets are still substantial, so a renewed technology development program focused on shaping the R&D and technology environment where the relative value of government dollars is greatest may help ensure military and national security considerations are passed onto development and commercial stages. Universities and scientific non-profits typically occupy the basic R&D stage, while start-ups and established firms look for commercialization opportunities in the applied and development stages. TRP and SBIR were centered on applied and development research, but were not well suited to support basic stage R&D. A renewed technology development program can follow two approaches: raise the level of funding and grants in the applied and development stages in attempt to compete with private industry for influence or reside where private industry is unlikely to invest, such as in basic research or training and education. Regardless, the Federal government must incentivize R&D and tax reform is a good first step.

Tax Reform: In order to help academia conduct basic R&D and further incentivize private industry to commercialize innovation, certain research tax and corporate tax credits were established. The following presents some research tax and corporate tax policy reforms. Recognizing that academia, start-ups, and established companies typically occupy particular tax regimes, these reforms are intended to be complimentary, supporting R&D stages and follow-on commercialization.

Tax credits: The two types of research tax credits are basic research and regular research credits. Historically about $7 billion in research credit has been paid each year.[106] Universities and non-profit scientific research organizations normally populate the basic research regime, while start-ups and established firms occupy the applied and development stages because of the nearer-term prospects for commercialization. The basic research tax credit is 20 percent on what is spent over a base amount calculated from a 3-year average. Commercial "firms conducting their own basic research may not claim [this specific] credit for their expenditures.[107] Regular research credit rates are the same, but use a different multi-year base calculation, and the non-refundable credit can be carried for 20-years.

Basic and regular research tax structures are ill-suited to support R&D. The base amount calculation assumes an entity has a reliable 3-year funding stream. A 20 percent credit is small, therefore spending elsewhere is potentially more attractive. Particularly for basic R&D with long time horizons, the annual tax credit application introduces additional uncertainty over the life of the project, and may negatively influence the overall investment decisions and "deter…pursing some of the R&D projects…if the credit were permanent."[108] The number of renewals and modifications regarding regular research has resulted in disputes with the IRS on what defines regular research, and "has created uncertainty for companies trying to make long-term investment decisions…and potentially chilled spending on innovation."[109] The list of excludable items which "account for 27 percent to 50 percent of business R&D spending," and the non-refundable aspect are deterrents for large firms from making large R&D investments, while small companies and start-ups would benefit more by receiving full credit earlier to enhance their "prospects of survival and growth." [110] Resolving these research tax deficiencies could provide a boost to company level R&D. What has the potential to infuse even more capital in industry to help the R&D-commercialization process is corporate tax reform.

Corporate tax reform: At 39.1 percent, the U.S. corporate tax rate is among the highest in the world. Although reducing the overall U.S. corporate rate helps the entire high-tech industry and broader economy, three reforms are desired in the semiconductor industry: (1) changes to the policies on depreciation, the (2) U.S. international taxation system, and (3) capital repatriation. For example, changes to the depreciation rules would help foundry investors defray the upfront costs of a multi-billion dollar construction project and material outfitting. A favorable U.S. international tax and repatriation policy with conditions requiring technology-related investment, for example, could allow fabless design and IP to hire more technical employees and pay them higher wages. Supporting segments such as EDA, wafer, and test equipment manufacturers will also benefit from tax reforms, as well as from overall industry expansion. Overall, tax reform will increase U.S. competitiveness by bring U.S. dollars back to the U.S. for R&D.

ESSAY 2: Innovation through Research and Development

Introduction: The United States has identified and exemplified itself as an innovative society since the 19th century. From Edison's invention of the light bulb to Alexander Graham Bell's telephone to the first manned-powered flight by the Wright brothers at Kitty Hawk, North Carolina, the U.S. has led many of the inventions and innovations in modern times. Innovation has long been determined to be a driver of U.S. global competitiveness and accounted for a good portion of wage and job growth. The U.S. comprises about 5 percent of the world's population, but makes up between 20-25 percent of the world's economy.[111] This disproportionate effect on the world economy is largely believed to be because of innovation. The U.S. economy continues to be heavily driven by innovation. Innovation in semiconductors, particularly from companies such as Intel, Qualcomm, Texas Instruments, and Micron, has led to rapid growth in the electronics industry and has allowed the U.S. a competitive edge.

Unfortunately there is evidence the U.S. lead in innovation may be coming to an end as companies in the Asia-Pacific continue to close the gap.

Measuring innovation is particularly difficult. There is no innovation metric that can be pulled from U.S. Department of Commerce reports or read in a company's Securities and Exchange Commission 10K filing, but there are a few key metrics that are used to measure the capacity of a country to be technologically innovative. One of those common indicators is the amount of capital invested in research and development (R&D). Countries with high levels of R&D investment reflect a business culture that is postured to take advantage of the opportunities inherent in "the next big thing" that will come out of a commitment to pushing the envelope of new science and technology. The U.S. led the world in 2014 by spending $465 billion collectively on R&D – an amount that is equal to 2.8 percent of its gross domestic product.[112] U.S. spending along with the next three nations and regions (China, Japan, and Europe collectively) accounts for 78 percent of the world's investment in R&D and is a key indicator of the concentration of global innovation investment.[113]

Intel continues to be the worldwide leader and its investment of approximately $10.6 billion was more than three times of what Qualcomm, number 2, invested in R&D and Intel alone accounts for 19 percent of all R&D investment in the semiconductor industry.[114] Broadcom's R&D to sales ratio recorded the highest percentage of R&D investment to revenue of any of the companies included in the top 10. "Broadcom's R&D-to-sales ratios varied widely during its formative years, including a couple years (2001 and 2002) when it spent all of its sales on R&D, but since 2006 the company's R&D budgets have grown at the same 12 percent annual rate as its sales, keeping its R&D-to-sales ratios at an average of 31 percent!"[115]

Despite the U.S. dominance in semiconductors, R&D, design and innovation, the U.S. will eventually be outpaced by China by 2020, according to Battelle's 2014 Global R&D Fund Forecast, which analyzes expected R&D investments across several industries. By 2022, it is anticipated that China's investment will surpass the U.S. reflecting their government's desire to transition from a manufacturing nation to an "innovation driven" economy. "China has increased its R&D investments by 12 percent to 20 percent annually for each of the past 20 years; while at the same time, U.S. R&D spending increased at less than half those rates."[116] The globalization of R&D and increased competition in innovation from rising economies will clearly have an effect on the future of R&D for the U.S. and the industry.

Secondary to globalization's effect on U.S. dominance in semiconductor innovation is the struggle of companies to balance investment between the pursuit of Moore's Law and the immediate market forces that call for low-powered, multi-functional chips for mobile computing or the Internet-of-Things (IoT). Since 1965, the mantra of the industry has been to double the number of transistors on an integrated circuit every 12-18 months. There is ample evidence that the end of this trajectory will be reached in the next 15-20 years. Market forces simultaneously have increased the pressure on the industry to reduce energy consumption and add scaled features that provide more capability on-die such as digital radio.[117] The split in technology between high speed microprocessors, pushing the edge of silicon technology capabilities, and small simple semiconductors that focus on lower power, lower processing capability, integrated memory, and unique packaging requirements may be forcing a split in the semiconductor industry. Companies increasingly have to decide if there is cost benefit to keeping up with Moore's Law or focusing R&D efforts on emerging markets such as Automotive and IoT.

Emerging R&D Focus Areas: Despite the possible market split, pushing the boundaries of silicon and Moore's Law continue to be a major focus of R&D efforts. The major areas of research that are trying to breach the impending Moore's Law "wall" include using existing silicon technologies in novel ways such as stacking, using alternates to silicon such as carbon nanotubes, and fundamentally changing the basic architecture of computing to maximize efficiency.

Existing Silicon Technologies: There is a significant amount of R&D that is going into connecting existing chips through packaging that allows for greater power management and pushes computing power beyond the scaling of transistors demanded by Moore's Law. Stacking is a leading research area, which could begin production within the next 3-5 years. Stacking chips, bonding them together on the Z-axis, increases the speed at which both functions can operate and dramatically reduces the distance that has to be covered and the amount of energy required.[118] Alternatives include stacking multiple logic chips together and having them run in parallel in order to multiply the computing power. IBM has worked with 3M on a heat-dissipating adhesive that would facilitate this process.[119] The technical hurdles with this type of process involve incorporating the right type of heat sinks into the design to prevent overheating, figuring out how to efficiently solder the wafers together consistently, and developing the right type of material to use as the solder.[120]

Another emerging technology that will facilitate stacking logic and memory is the development of a whole new class of flash memory called resistive random access memory (RRAM). RRAM behaves like flash memory by storing data without the requirement for constant power, however, it uses resistance rather than transistors which gives engineers the ability to pack much more memory into a tighter space using less power and producing less heat.[121] Some prototypes have produced a terabyte's worth of memory packed into the size of a postage stamp.[122] RRAM uses only two connections, rather than traditional flash memory's three, which makes it much easier to stack.[123] Using RRAM in conjunction with logic chips creates a stack that can multiply the functions of each of the chips together using less energy and at a size that will fit into mobile devices.

Alternatives to Silicon: As semiconductors approach ten nanometers and below, scaling is becoming increasingly difficult and produces challenges that indicate a new material may be required. A leading material technology for replacement of silicon in semiconductors is carbon nanotubes. These tubes are excellent at conducting electricity and can greatly reduce the amount of energy wasted through heat that is inherent in silicon-based chips. A number of research facilities have made transistors out of nanotubes, but there are two major issues. The first issue is that the tubes must be perfectly aligned to properly work as a transistor – scientists have only been able to align them up to 99.5 percent so far which, because of the millions of tubes required to make the technology work, introduces too much error to be practical. The second issue is that when large amounts of nanotubes are produced, some of the tubes take on conducting characteristics that make them function like wires and short-circuit the system. Recently, engineers at Stanford University were able to overcome both of these barriers through some clever processes that produced a functional computer with 178 transistors.[124] The number of transistors was only limited by the capabilities of the fab located on campus. Even with this break-through most believe that a truly functional and marketable chip is at least 15 to 20 years away.

R&D efforts by University of Manchester scientists have proven graphene as a possible and viable replacement to silicon chips. Graphene has been deemed a "'miracle material', which could revolutionize materials science because of its unique properties."[125] Graphene, a two-dimensional substance, is also the thinnest, strongest, most flexible and conductive material on earth. Many in the electronic industry are excited about the possibility of graphene and its potential to revolutionize the realm of the possible. If its potential can be harnessed, it is likely that the world will see bendable phones, wearable and foldable computers.[126]

Scientist have also discovered and proven molybdenite to be a smaller, low energy alternative to silicon. Experiments with this substance have proven it to be energy efficient, highly conductive, and a flexible transistor. While many of molybdenite properties are similar to graphene there is one distinguishing characteristic: molybdenite can conduct electronic signals at room temperature while graphene must be cooled to 70 Kelvin to operate efficiently. It is estimated that molybdenite is 10 to15 years away from commercial use.[127]

Reimagining Computer Architecture: All of the technologies discussed so far still operate under the traditional computing logic that is based on 1's and 0's. The final area to explore considers moving into a whole new area called quantum computing in which qubits substitute bits and operate in alternative states at the same time.[128] This type of computing theoretically allows for an astounding number of calculations to occur simultaneously. Applications range from extremely sophisticated cryptology to stock market evaluations that are currently impossible. A company called D-Wave in Canada currently manufactures a quantum computer called the D-Wave Two and has sold 10 of them to the likes of Google, NASA, and others.[129] There is some speculation whether these computers, which require a very complex environment to operate in, are actually performing quantum calculations. If the technology does mature as promised and can be manufactured to function in a less specialized environment, it could revolutionize computing.

ESSAY 3: Workforce and Human Capital Resources

Introduction: Producing microchips at the molecular level is an enormous technological achievement. Talented human capital is the most valuable resource for the U.S. semiconductor industry.[130] To obtain and retain the requisite levels of human capital for the semiconductor industry, there must be a concerted effort focused on STEM education – including education reform, immigration reform, and diversity. These steps will ensure the U.S. semiconductor industry maintains its competitive advantage.[131]

STEM Education: The semiconductor industry requires employees with advanced specialist degrees in electrical engineering and computer science. A major issue confronting the industry is a perceived lack of trained personnel with science, technology, engineering or math (STEM) degrees.

The focus put on STEM education over the last decade is a positive trend. Neither the government nor the semiconductor industry will solve the disagreement on whether or not a STEM shortage actually exits; the important aspect is the focus on STEM education as an avenue to keep the U.S. semiconductor industry healthy.

The crux of the STEM shortage disagreement is a traditional supply and demand equation; except in this case the semiconductor industry's desire to keep innovating magnifies the situation as they have decided young workers are necessary for innovation.[132] The major downside to this line of thinking is the lack of emphasis on company commitment and workforce loyalty, which leads companies away from retraining efforts.

As with most industries lately, the path to prosperity is not through a lifetime of commitment to one company.[133] Making matters worse is the reality that companies pay younger workers less than experienced, older employees. For this reason, if youth equals innovation, and you must innovate to remain competitive, it only makes sense that companies see this as a definite win for themselves. Getting more STEM workers into the workforce involves an education system that produces more STEM graduates.

Education Reform: Education reform is essential for ensuring firms recruit and retain the right human capital with the requisite skills and knowledge to contribute to a culture of innovation. Bart Gordon, former congressman and current fellow to the Council on Competitiveness, believes a first step is boosting teacher expertise.[134] Gordon links student performance to teacher proficiency. He noted, "The urgency of this problem is evident. For example, 69 percent of middle-school students are taught by math teachers with neither a college major in math nor a certificate to teach math…Likewise, 67 percent of high-school physics students are taught by similarly unqualified teachers."[135] Gordon's answer to this problem was

House resolution 362, which incentivizes math and science major to pursue teaching careers. One resultant program is UTEACH.[136] Although this program is making great strides in bringing fully qualified math and science majors into the classroom, there is still significant expansion opportunity to generate nationwide impact. More support at the national level is required to make H.R 362 a complete element of a national strategy for innovation. Specifically a financial incentive mechanism may be required to address the income gap between the science major who works semiconductor manufacturing research versus a science major who teaches an 8th grade science class.

The United States should also expand government grants to promote Science, Technology, Engineering, and Math (STEM) programs. Part of the long-term sustainment strategy must include a strong, steady pipeline of highly capable students who foster the next generation of innovations. These STEM programs should be accompanied with strong partnerships between the education sector and the high-tech business sector. Micron is an example of a company with strong ties to local universities.[137] With that relationship, Micron has developed a strong internship program, which supports their ability to effectively recruit local talent.

STEM programs, UTEACH, and internships are long-term, sustainment initiatives. They are critical to ensuring the semiconductor industry maintains a healthy supply of the brightest minds capable of the sustaining the pace of innovation that has become the hallmark of the semiconductor industry.

Immigration reform: America must also recruit and retain a ready workforce of engineers and technicians capable of driving innovation in the near term. This is precisely where immigration programs such as the H-1B Visa program become important. The H-1B visa is granted to companies to hire a specific foreigner temporarily (not to exceed six years) for a job that requires specialized knowledge and at least a bachelor's degree.[138] The current annual limit on H-1B visas is capped at 85,000.[139] One indication the cap on H-1B visas should be raised is the fact that in 2014, the U.S. Citizenship and Immigration Service received 172,500 H-1B petitions, over twice the cap limit, in the first five days of the filing period and had to stop accepting applications.[140] The key takeaway is that immigration continues to play a role in the semiconductor industry and the H-1B visa program is an important avenue for some companies to use as they search for talent. U.S. policymakers have the ability to improve the situation dramatically.[141] Steps have already been taken to increase the H-1B visa cap to 195,000 per year.[142] This is a critical first step towards meeting the near-term talent needs of the American semiconductor industry.

Diversity: The *Semiconductor International* Journal made some insightful observations in 1997, before diversity was a common buzzword. The journal defined diversity 18 years ago as: "Diversity means variety. It means change through differences, a mixing of techniques, methods and ideas. Out of these ideas come growth, stimulation and most importantly, innovation."[143] As the world economy becomes more global, diversity will continue to matter even more – particularly in the global semiconductor industry.

It is important to point out a few companies that value diversity and demonstrate examples of why diversity matters to the companies. Applied Materials, a major player in semiconductor industry and abundant fabrication supplier, defines on the Applied Materials website the core values that represent the company and two concepts that help shape a corporate culture that regards diversity as a competitive advantage. "The first concept is *Respect for the Individual*, mutual trust and respect are shared by all. The second concept is *Global Awareness*, embracing different perspectives leads to a wealth of opportunities."[144] The vision statement is "It is our goal to actively promote a work environment where differences are valued and respected, capabilities are leveraged and employees are fully engaged."[145] Applied Materials also takes pride in recruiting from minority associations and academic institutions and has a deliberate plan to seek out minorities from these organizations.

In other positive diversity news, Intel recently announced that it was spending $300 million to improve their diversity in gender and racial workforce makeup. Intel states that the current statistics revealing 20 percent of the workforce in Silicon Valley is female, and a much lower percentage is made up of Hispanics and African Americans, is to low. Intel plans on using the money towards their new Diversity in Technology initiative and other initiatives to improve on overall diversity.

Not all the news regarding diversity is trending positive. Much has been written on the lack of diversity in Silicon Valley. Until recently, many of the companies refused to release statistics to demonstrate diversity. As such, 2014 is the first year the government required companies to release their diversity data; however, not all companies define categories in a consistent manner, so the statistics are still not always easily comparable.

Wall Street Journal recently published a report on technology companies based on the reported demographics. Hewlett Packard (HP) has a company of 302,000 employees with 20 percent of the leadership positions filled by women. Additionally, 83 percent of the leadership in HP is white and 11 percent of the leaders are Asian. Intel employs 107,600 people with 16 percent of their leadership were female, 83 percent white, and 12 percent Asian.[146] As a general observation, SMIC does not have any females in any executive positions. TSMC has 1 female Senior Vice Present and 4 of 13 Vice Presidents are female, demonstrating more gender diversity then SMIC. Just one in 14 technical employees in Silicon Valley are black or Hispanic. Nationally, blacks make up 12 percent of the U.S. workforce and Hispanics 14 percent."[147] "By 2040, the U.S. will be a minority majority, with 42 percent of the country black or Hispanic. I bet we'll be able to do some really interesting business case studies in 10 years and see what companies did and didn't make it, and who had the most diverse teams from top to bottom."[148]

Companies looking for the extra competitive edge may want to consider a more deliberate approach to creating diverse teams. Pinterest created a value statement on why diversity matters.[149] Jason Young, co-founder and CEO of Mindblown Labs, states: "Your desire to like and be liked by others may be inadvertently affecting your ability to recruit (and maintain) a diverse workforce".[150]

Lastly, retaining diverse employees is also a challenge. The New Yorker provides a recommendation on how companies can take to keep female and minority employees from leaving. "Companies have seen success when they hire enough people from diverse backgrounds that they can form friendships and not feel isolated, and help them find those social connections, rather than hiring small numbers of "token" minorities for the sake of demonstrating an attempt at becoming more diverse. It also helps to spell out clear performance standards, so that employees are judged based on how well they are meeting those standards, rather than on subjective, and potentially biased factors."[151]

The article makes the point that the industry has a long way to go in relation to hiring of African Americans and women in the sector, and this is needed to achieve the level innovation required to create the competitive advantage.

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