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Industry Study

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Electronics Industry

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ELECTRONICS 2007

ABSTRACT: This paper analyzes a critical U.S. sector by the Electronics Industry Seminar at the Industrial College of the Armed Forces (ICAF), Class of 2007. This report is the culmination of a focused series of classroom seminar sessions and meetings with industry, government, and academic leaders through field studies in the metropolitan Washington, D.C. area, New York State, Silicon Valley (California), Taiwan, and China. This approach provides a wide range of perspectives from which to examine the selected industry's current condition, outlook, and challenges. The electronics industry, fueled largely by semiconductors, is one of the largest and fastest growing industries in the world. Advances in this industry increased productivity and led to numerous innovations in science, education, healthcare and other industries across all sectors of the U.S. economy. U.S. leadership in the industry propelled economic growth and enabled the country to lead the world in innovation and advanced military technologies. In recent years, however, an increasing number of global semiconductor activities have shifted to Asia. This change is beginning to threaten U.S. defense supplies and technological advantages, and weaken the country's economic strength in technology-based industries. The report recommends policies to counter or mitigate this trend and achieve goals related to national security, industry competitiveness, or both. In general terms, the government needs to protect key technologies, enforce fair trade agreements, stimulate innovative capacity, and enhance the business environment for semiconductor companies in America.

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FIELD STUDIES

Local Area

Virginia Semiconductor (Fredericksburg, VA)
Micron (Manassas, VA)
Argon, ST (Fairfax, VA)
International Business Machines (Washington, DC)
Capitol Hill (Washington, DC)
Northrop-Grumman (Baltimore, MD)
Defense Supply Center Brief (ICAF, Seminar Classroom)
Department of State Brief (ICAF, Baruch Auditorium)
Department of Commerce (ICAF, Seminar Classroom)
Department of Defense (ICAF, Seminar Classroom)
Semiconductor Industry Association (ICAF Seminar Classroom)
Semiconductor Research Corporation (Washington, D.C. meeting)
National Research Council (ICAF Seminar Classroom)

Domestic: New York State

International Business Machines
- Yorktown Heights – Watson Research Center
- Fishkill - 300mm Fabrication Plant
- Poughkeepsie – Customer Solution Center

Domestic: California

INTEL (Sunnyvale)
Electronic Design Automation Consortium (Sunnyvale)
- Cadence
- Mentor Graphics
- Synopsys

Tessera (Sunnyvale)
Applied Materials (Sunnyvale)
Defense Micro Electronics Activity (Meeting at Moffett Field)
Advanced Micro Devices (Sunnyvale)
Stanford University (Palo Alto)

International: Taiwan

ETRON (Hsinchu Industrial Park)
United Microelectronics Corporation (Hsinchu Industrial Park)
MACRONIX International (Hsinchu Industrial Park)
American Institute in Taiwan (Taipei)
Industrial Technology Research Institute (Hsinchu Industrial Park)
Nanya Technology Company (Hsinchu Industrial Park)
Advanced Semiconductor Equipment Engineering (Hsinchu Industrial Park)

International: People's Republic of China

United States Consulate Annex (Shanghai)
SEMI (Shanghai)
SMIC (Beijing)
International Business Machines Innovation Center (Beijing)
China Semiconductor Industry Association co-located with Ministry of Information Industry (Beijing)
United States Information Technology Office (Beijing)
Semiconductor Industry Association, China Manager (Beijing)

Introduction

This paper analyzes a critical U.S. sector by the Electronics Industry Seminar at the Industrial College of the Armed Forces (ICAF), Class of 2007. This report is the culmination of a focused series of classroom seminar sessions and meetings with industry, government, and academic leaders through field studies in the metropolitan Washington, D.C. area, New York State, Silicon Valley (California), Taiwan, and China. This approach provides a wide range of perspectives from which to examine the selected industry's current condition, outlook, and challenges; and an opportunity for seminar fellows to recommend policies that address key issues impacting U.S. national economic and security interests.

Over the course of America's history, our ability to innovate and create new technology has been the foundation of economic growth, high-paying jobs for American workers, and ultimately, national security for our nation. (SIA, 2007a). The U.S. electronics industry provides a shining model for the prosperity and growth that can be achieved through American innovation and the practical application of scientific discovery to create productivity and advantage in everyday life—as well as critical capabilities for national defense. The electronics sector promotes economic welfare and serves national strategic needs.

At the heart of the electronics industry is the semiconductor, which drives the growth and technology enabling the entire electronics value chain. Because of its importance to electronics applications and end products, the semiconductor industry is the focus of this report. The U.S. semiconductor industry provides high-paying jobs for hundreds of thousands of skilled workers, as well as the enabling technology for thousands of products and services Americans use daily, such as personal computers, cell phones, digital music players, remote-controlled automobile door locks, the internet, on-line banking, digital cameras, and more. The National Research Council (NRC) found that national policies should focus on the semiconductor industry as one that "has had a distinctive positive impact on the economy" because it is—

- **An enabling industry** that contributes to productivity gains across all sectors of the economy;
- **A key contributor to enhanced economic growth** and a driver of the high-technology revolution;
- **A source of high-wage job creation** across knowledge-based industries;
- **A source of competitive advantage** and rapid advances in information technology; and,
- **A key element in national defense** against old and new threats (NRC, 2003, p. 18).

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

Industry Defined

The genesis of the semiconductor industry dates back to 1958, when the integrated circuit (IC) was invented to handle increasingly complex electronic designs. An IC is a piece of silicon (or other semiconductor material) that contains a network of interconnected miniature electronic components (Newton, 1999, p. 423). The *value chain* for IC development involves five primary activities: design, mask generation, fabrication, packaging and testing (Howe, 2006; Brown & Linden, 2005, p. 2).

The design of circuit diagrams is skill dependent and relies on sophisticated electronic design automation (EDA) software (Brown & Linden, 2005, p. 2). Mask generation transfers designs to glass reticules—also highly skill dependent and one of the more costly activities in the value chain. Masks for some advanced circuits can cost over $1 million and in some cases up to 40 masks may be needed to create an IC. During fabrication, the designs are "etched" onto silicon wafers layer-by-layer using the masks and a process known as photolithography (Mathews & Cho, 2000, p. 37). This process is capital intensive with state-of-the-art, 300mm wafer fabrication plants, or "fabs," costing roughly $3 billion (B) (Howell, 2005, p. 2). Assembly and testing involves cutting wafers into "chips" of completed ICs, packaging them into substrates and validating performance. These final steps require smaller capital investments and less skilled labor (Brown & Linden, 2005, p. 3). Primary and supporting activities in the semiconductor value chain are depicted in Figure 1 (Howe, 2006).

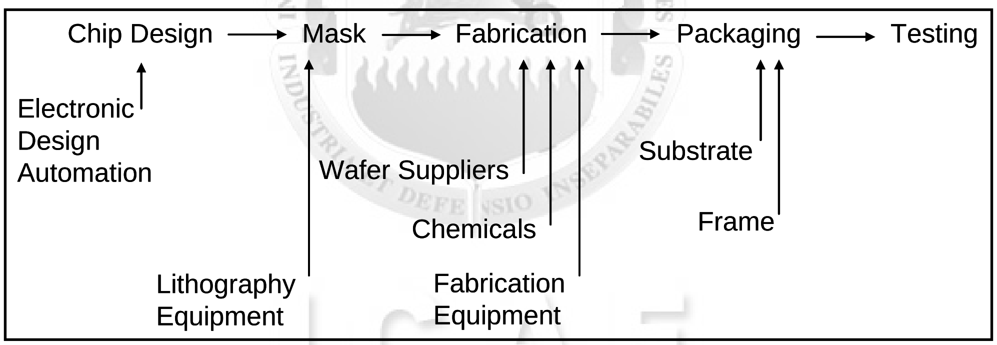

Figure 1: Semiconductor Industry Value Chain

The semiconductor industry is included in North American Industry Classification System (NAICS) code number 334400: Semiconductor and Other Electronic Component Manufacturing. There are two-hundred Standard Occupational Classification codes working in semiconductor companies, including unskilled material handlers, all administrative and business positions, skilled equipment operators, highly educated and specialized electrical engineers, managers and senior company executives (Bureau of Labor and Statistics, 2007).

The semiconductor industry is at the center of an economic competition among more than ten nations in three major regions: United States, Europe and Asia. Companies based in industrial countries (such as the United States, Germany and Japan) compete with each other and with countries in developing market nations in Asia (such as Korea, Taiwan, Singapore, Malaysia, China and Vietnam). The competition for the knowledge, economic and military advantages offered by having high tech electronic businesses within national and regional boundaries is fierce among countries, and has profound implications for U.S. defense and industrial base interests.

Current Conditions

The Semiconductor Industry Association (SIA) estimates worldwide sales of semiconductors were $248B in 2006. Due to advancements in chip technologies and the demand for personal computers, digital consumer products, and wireless communication devices, the semiconductor industry is predicted to grow by 11 percent in 2007 and 12.8 percent in 2008 (Smith & Kawaguchi, 2007, p. 1). The 2006 Standard & Poor's Industry Survey on Semiconductors places the Asia-Pacific region (excluding Japan) at the forefront of the industry with over $103B in revenues in 2005. This represents 45 percent of the global market followed by Japan at 19.2 percent, the Americas at 17.8 percent, and Europe at 17.1 percent (Ibid., p. 9).

United States

The semiconductor industry represents the largest segment of the U.S. manufacturing sector and its leading export industry. "With more than $43 billion in exports in 2005, the semiconductor industry is the leading U.S. exporter. More than 75 percent of U.S. chip industry sales are outside the United States" (SIA, 2007b, p. 20). The semiconductor industry has long been a growth industry that generates a significant amount of job opportunities within the United States. Three U.S. companies are currently listed within the top ten companies in revenues in the world: Intel, Texas Instruments, and Freescale; and the industry generates over 234,000 highly skilled jobs across the United States (Ibid.).

"In 2000, the U.S. accounted for around 49.9% of total world market share for the semiconductor manufacturing industry. This had decreased only slightly to 48.3% by 2005" (IBIS*World*, 2006, p. 19). While this market share indicates the U.S.'s continued role as a leader in the industry, it does not reflect the transfer of U.S. based firms' manufacturing to overseas locations. "According to the Semiconductor Industry Association (SIA), SIA member companies have just over 50% of their fabrication facilities in the U.S." (Ibid., p. 19). Further, U.S. semiconductor exports continue to decline. "Since 2000, U.S. exports have declined by an average rate of 8.9% per annum. Exports as a share of industry revenue decreased from 38.3% in 2000 to 35.2% in 2005" (Ibid., p. 12).

The Government Accountability Office (GAO) reports that these exports consist primarily of chips and wafers used to produce finished integrated circuits in other countries. At the same time "U.S. imports of semiconductors and semiconductor components have also declined, but the U.S. has still maintained an overall trade surplus" (GAO, 2006, p. 15). This trade surplus actually reflects that more electronics end items are being produced overseas. "In 2005, only 13% of imports were chips and wafers whereas 71% of U.S. exports were chips and wafers" (Ibid., p. 15).

The "crown jewels" of the U.S. semiconductor industry are the research and development (R&D) programs and semiconductor design needed to retain technological leadership. Currently, about 80% of semiconductor R&D is taking place in the U.S. (Gorecki, 2006, p. 1). In 2005, the semiconductor industry invested 14% of its sales into R&D (IBIS*World*, 2006, p. 11).

Europe

Companies in Europe failed to generate momentum in the development of emerging semiconductor technologies in the mid twentieth century, allowing the U.S. and Japan to gain overwhelming competitive advantage within the developing industry (Peters, 2006, p. 90). Although

Europe has since taken strides to overcome a late entrance in the global semiconductor market, this region still remains the least competitive region in the industry. Today, Europe continues to trail both Asia and the United States in terms of total revenue generated from semiconductor sales. In 2006, Asia significantly outpaced both the U.S. and Europe by generating $143B in total revenue compared to $50B by the U.S. and $39B by Europe (Datamonitor, 2006e, p. 8). Market segmentation within the industry proportionally corresponds to the total revenue by region. In this regard, Asia dominates the market with 60.5% of the semiconductor market share followed by the U.S with 19%, Europe at nearly 17% and the rest of the world at 3.8% (Ibid., p.11).

Germany, the United Kingdom (UK), and France are the primary countries in the European semiconductor industry. Germany currently is Europe's industry leader, generating $9.7B in total revenues during 2006 with a market segmentation of 24.6% (Datamonitor, 2006c, pp. 8 & 11). The UK's semiconductor industry trails Germany with $7B in total revenues and 19.6% of Europe's semiconductor market share (Datamonitor, 2006d, pp. 8 & 11). The French semiconductor industry places third, generating $4.6B in total revenue with 11.8% of Europe's overall semiconductor market share (Datamonitor, 2006b, pp. 8 & 11).

The European Semiconductor Industry Association (ESIA) reports that over ten major companies actively compete in the European market, including Intel, Infineon Technologies, STMicroelectronics, Samsung Electronics, Texas Instruments, AMD Spansion, Philips Semiconductor, Freescale Semiconductor, Renesas Technology and Micron Technology. Of these ten, Infineon Technologies (Germany), STMicroelectronics (France) and Philips Semiconductor (Germany and UK) are European headquartered companies and are listed among the top ten semiconductors companies in the world (ESIA, 2005, p.26).

Asia

Today, Asia dominates the world's semiconductor industry in many aspects. Of the $248B generated in the industry in 2006, Asia (including Japan) accounted for over 60% of all sales (S&P, 2006, p. 9). This region currently has 65% of all IC sales, 64% of all equipment sales, and 76% of all material sales (SEMI, 2007). This region also is the fastest growing in the world, with a 12.8% compound annual growth rate (CAGR) in sales over the last five years (2002-2006) as compared to 8.5% and 4.2% for the United States and Europe, respectively (Datamonitor, 2006a, p. 8). This growth appears to be well correlated with overall chip demand. In 2006, over 60% of all chips made were consumed by the electronics industry in this region (S&P, 2006, p. 9). The largest end use markets were personal computers (44%), consumer electronics (17%) and cell phones (17%), all of which are increasingly manufactured in Asia, especially China (Ibid., p. 2).

Of the top ten semiconductor companies in terms of 2006 sales, half are from Asia: #2 Samsung ($19.7B), #5 Toshiba ($9.8B), #6 TSMC ($9.7B), #7 Hynix ($8.0B) and #8 Renesas ($7.9B) (McGrath, 2007, p. 3). Samsung, headquartered in Seoul, South Korea, is well known for its consumer electronics and computers. It is currently the number one producer of three popular memory chips: dynamic and static random access memory (DRAM, SRAM) and NAND flash memory (S&P, 2006, p. 11). The Japanese firm Toshiba (headquartered in Tokyo) is one of the world's largest diversified electronic manufacturers and the inventor of NAND (Ibid., p. 12). Headquartered in Taiwan, TSMC is the largest chip foundry in the world (Ibid., p. 13). Hynix is another Korean firm headquartered in Seoul which specializes in producing memory chips. Finally, Tokyo-based Renesas is jointly owned by Hitachi (55%) and Mitsubishi (45%). It is currently the top producer of microcontrollers used in a variety of markets such as autos (Ibid., p. 12).

Globalization

The dynamic forces of globalization are changing the way the semiconductor industry competes—both domestically and internationally. Increasingly, success in the semiconductor industry depends on the capacity to orchestrate “vertical specialization” of a complex international resource network which integrates suppliers with the industry’s strategic and operation planning (Hummels, Rapoport, & Yi, 1998, p. 81). Traditionally, companies organized vertically and performed all aspects of work along the value chain. Such integrated device manufacturers (IDMs) include Intel, AMD, and IBM. However, a number of companies in the industry configured themselves along three different business models: fabless, fab-lite, and foundries. The “fabless” companies strictly focus on producing semiconductor designs, outsourcing wafer manufacturing to a foundry, or dedicated “fab”. Semiconductor companies that follow a “fab lite” business model maintain in-house wafer fabrication facilities, but also outsource a significant amount of production to chip foundries.

In turn, globalization and vertical specialization facilitates the concentration of semiconductor production in countries such as Singapore, Malaysia and China. These countries (and others) used lower wage structures and public policy to attract foreign businesses and to stimulate their own domestic industries, developing integrated technology parks with modern electronic facilities and manufacturing technology that employ thousands of people. As they shift more of their manufacturing capacity offshore, countries such as the U.S. and Japan increasingly orient their semiconductor industries along a knowledge-based approach based on networks of specialized, fabless, and innovation-leading companies. The result is segregation of high-value “service sectors” in developed nations matched by an increasing horizontal integration of lower-value activities in the semiconductor value chain located in emerging regions (Smith, Sonnenfeld, & Pellow, 2006, p. 29). Of concern, however, is that as this trend continues an increasing amount of engineering work and design inevitably follows the manufacturing operations overseas.

Outlook

United States

While analysts forecast growth in the U.S. semiconductor market value, current projections reflect that this growth will slow over the course of the next five years. Overall, the market value forecast for the U.S. semiconductor industry will increase by 21.7% from $44.9B in 2006 to $54.6B in 2011. The average growth of the CAGR for the U.S. from 2006-2011 is 4%; however, the negative trend in future growth will see a decrease from 4.6% in 2006 to 3.8% in 2011 (Datamonitor, 2006e, p. 16).

Continuing trends in the industry threatens U.S. leadership in the global semiconductor industry. Several foreign countries currently provide substantial incentives encouraging semiconductor companies to establish state of the art facilities in their countries as part of a concerted effort to grow their own domestic industries, increase their technology knowledge base, and develop a skilled workforce capable of performing more complex operations in the semiconductor value chain. One major concern is that as U.S. firms send more complex manufacturing overseas, R&D and design activities eventually will follow. Already there is an increasing trend of U.S. companies making significant investments in offshore R&D programs.

Continued vigilance and investment is required to maintain U.S. technology leadership and innovative capacity. Wise R&D investments increase competitive advantage, innovative capacity, and advances in manufacturing productivity. However, some analysts predict loss of some of these benefits due to a "looming R&D funding gap" because "increasing consumer market pressures coupled with slower industry growth rates are constraining the availability of R&D funds" (Leckie, 2005, p. 2). Further, although the U.S. has the largest semiconductor industry in the world, the country only has 15% of the world's leading edge capacity—down from 35% of the total share five years ago (Gorecki, 2006, p. 1).

Europe

Industry analysts project that the European semiconductor market value will increase to an estimated value of $27.3B by 2011 (Datamonitor, 2006b/c/d, p. 3). While this forecast is favorable for Europe's industry, this growth is unlikely to change their relative position within the global industry as the market value in other key regions is expected to grow during this same timeframe. For example, U.S. market value is expected to reach an estimated $54.6B in 2011, an increase of nearly 22% from 2006 (Datamonitor, 2006e, p.3).

Europe is pursuing technology advances through intense R&D efforts. While European companies have historically reinvested about 15% of their income in R&D, their total expenditures have fallen short of other countries such as the U.S. and Japan (ESIA, 2006, pgs. 33-34). However, recent surveys within the industry indicate that Europe is poised to increase investments in R&D by as much as 5% per year through 2008 or 2009 (Clarke, 2006, p.1). Additionally, Europe has successfully leveraged the power of partnerships and alliances among regional semiconductor companies, academic institutions, and regional governments to promote innovation, mitigate risk and facilitate cost sharing (ESIA, 2006, p.36; NRC, 2003, p. 238). The Crolles 2 Alliance and the Microelectronics Development for European Applications (MEDEA) Plus are two examples of successful R&D alliances and partnerships worthy of further discussion (Ibid., pp. 37-38).

Asia

Growth in the Asian semiconductor industry is expected to decrease slightly over the next five years but remain relatively strong due to regional chip demand and favorable business environments. The CAGR of sales is predicted to be 10.9% for the region from 2006-2011 (Datamonitor, 2006a, p. 8). Fab capacity will continue to expand rapidly, especially in China, to meet chip demand. This demand is expected to increase due to a growing Asian middle class and an expanding electronics industry responding to global demand. In China alone local IC supply, currently at 6.5% of that country's demand, will only be able to meet 11% of demand by 2010 (SEMI, 2007). Asia currently has over forty 300mm wafer fabs with an additional forty more planned or under construction—more than three times the number of similar investments in North America (Ibid.). Government policies and tax structures also are supporting growth in Asia. A new fab in Asia currently costs about $1B less to operate over a decade than in the United States, primarily due to lower tax rates (Lyne, 2006, p. 6; Morrison, 2005, p. 3).

One global industry trend that may spur additional growth in Asia is in rapidly rising costs of R&D. Moore's Law, which observes that the number of transistors on an IC typically double every 18 months, may not hold true much longer (S&P, 2006, p. 22). As companies attempt to make smaller, more powerful and less expensive chips, they face more daunting technical challenges and escalating R&D costs. The current scaling approach to increasing the number of transistors on an IC is expected to be ineffective by 2020, at which point a fundamentally different chip architecture may be required (Ibid., p. 22). Experts believe there is at least a $15B gap between what the industry can afford and what it needs to stay on Moore's Law (SEMI, 2007). Higher R&D costs may favor additional growth in Asia—where there are larger government subsidies and lower overall operating costs. On the negative side, however, parts of Asia, especially China, still lag behind the United States and Europe in terms of intellectual property rights protection and quality university research (Normile, 2005, p. 4).

Another broad industry trend that will affect Asia is continuing specialization and outsourcing. Although integrated device manufacturers—companies that conduct all semiconductor value chain activities—still dominate the industry, the number of dedicated foundries (fab) and design (fabless) firms is on the rise (Howell, 2005, p. 2). The rising cost of fab construction and operation is a significant driver. Of the hundreds of firms in the semiconductor industry worldwide, only an estimated 20 have sufficient revenues to afford their own 300mm wafer fab (SEMI, 2007). The dedicated foundry business is expected to experience double-digit growth over the next few years, centered on existing players (Jelinek, 2006, p. 2). Since the first 9 of the top 10 dedicated foundries are all in Asia, this likely will mean more growth for the region (IC Insights, 2006, p. 2). Companies also are increasingly outsourcing (and off shoring) design activities, especially to areas with abundant lower cost engineering talent such as India (Davis, 2006, p. 2).

Challenges

The semiconductor industry faces a number of challenges. Not surprisingly, many of these challenges are inter-related, so there is no clear scheme for categorizing them. While not a comprehensive list, some of the notable challenges identified during the course of this industry study are described in brief synopses in this section. Others that represent major issues are described in more depth in the section that follows.

Technology Barriers: More Moore's Law

In 1965, Gordon Moore, co-founder of Intel Corporation, noted that the semiconductor industry was driving technology by doubling the transistor's density on integrated circuits every 18-24 months (SEMI, 2005, p. 2). This observation, commonly known as "Moore's Law", is the phenomenon that, consistently and predictably, has driven down semiconductor costs while vastly improving performance. To date this concurrent achievement of lower costs and higher performance has been achieved primarily though scaling of feature sizes to smaller sizes—approaching the atomic level. However, many engineers feel that Moore's Law can not hold true beyond certain physical limits that will be reached within the next decade. Nanotechnology has become a metaphor within the semiconductor community for solution to escaping the impending cul-de-sac in the continuing march of Moore's law (Burton, 2007). The cul-de-sac will occur as the distance between transistors placed on a semiconductor chip approaches 10 nanometers (nm). At 10 nm the chip will literally disintegrate due to the heat generated (Scalise, 2007; Shelley, 2006, p.11). The best and brightest researchers are exploring technologies that may overcome the barrier. The important question is: Who will get there first? "The first firm, or geographically concentrated group of firms, that resolves the technical challenges facing the industry could develop a position of leadership in semiconductor design and production in the years ahead" (NRC, 2003, pp. 12-13).

Capital Intensive Industry: Show Me the Money

Pursuing Moore's Law requires significant R&D investments, which some analysts estimate will reach $16.2B by 2010. As the sophistication of technology has grown over the years, the costs associated with manufacturing facilities have grown exponentially, as well. Currently, building a fab costs approximately $3B. Given the fast pace of technological change, the average plant life in the semiconductor industry is between 3 to 5 years before the technology becomes outdated and the facility needs to be upgraded (IBIS*World*, 2006). The capital stakes within the semiconductor industry are high, and many corporations are taking a hard look at the strategies for competing in the 21st century. In some cases this has led to new business models (vertical specialization) and the migration of fabrication offshore—particularly to countries that directly subsidize building or modernizing plants within their borders.

A Skilled Workforce: Help Wanted

A crucial element of the U.S. semiconductor industry is a highly skilled technical workforce that designs and manufactures semiconductor products, and researches innovative improvements to keep America on the leading edge of the global electronics marketplace. The advancement of technology and development of the next generation of electronics drives intense competition for skilled labor, engineers, and research scientists. As the number of American-born engineering and science graduates declines, companies actively seek out foreign students—particularly those educated in U.S. universities. However, post-9/11 immigration policies make it harder for foreign students to remain in this country to work after they graduate. Not so tongue-in-cheek, many companies advocate that foreign engineering and science majors receive their diploma with a work visa attached. However, the regulated influx of highly skilled graduates who seek the legal right to work in this country currently is bundled with (and sidetracked by) the more contentious issue of unconstrained flow of illegal aliens and undocumented workers across our borders. In the interim, while the fast-paced evolution and continued growth of the semiconductor industry in the U.S. demands increasing numbers of talented and highly-trained workers, the supply pipeline increasingly is becoming insufficient to meet the need.

Export Controls: Security versus Sales

The United States controls the export of certain technology and services, including semiconductor technology and services, to selected countries for national security or foreign policy reasons. Export policies strive to balance the need to protect U.S. national security and foreign policy interests with the objective to promote U.S. trade and competitiveness. However, critics charge that these export controls are cumbersome and generally ineffective in achieving the stated goals of preserving national security and are, instead, cumbersome barriers to U.S. competitiveness. Export control reforms are constantly sought after by industry and sponsored by politicians, but not enough focus is placed on updating policy to keep pace with major trends in globalization and advances in semiconductor technology. A common theme heard during site visits and briefs from industry leaders during this study was the need to decrease timelines for reviewing and adjudicating requests for export licenses by improving efficiency.

Environment: Don't Mess With Texas…or Asia

Many environmental issues in the semiconductor industry require a shared vision and commitment from the industry as a whole. Organizations such as the World Semiconductor Council (WSC) and the Semiconductor Industry Association (SIA) have considerable influence on the industry and should continue to lead initiatives for environmental compliance. The common thread in the industry is its ability to improve technology and its manufacturing capability while at the same time improving its global impact on the world's environment. By working together, the industry must continue to seek the elimination of toxic chemicals and substances that produce harmful emissions and hazardous byproducts of production.

Effective Lobbying: One Voice for Many

Lobbyists represent their clients' or organizations' interests with policy makers, particularly in the U. S. Congress. While recent highly-publicized scandals cast a shadow of skepticism over the entire lobbying industry, lobbyists play an important role. Professional associations such as the Semiconductor Industry Association (SIA) and Semiconductor Equipment and Materials Industry Association (SEMI) lobby on behalf of the United States semiconductor industry and advance education causes that benefit the nation's high-technology sector. Their work contributes significantly to the awareness and technical insight of many of our elected officials in Congress; and it is vital that their work continues unhindered by the unscrupulous acts of some lobbyists.

Major Issues

How Can Something This Small be a Threat to National Security?

The United States relies on specialized integrated circuits (ICs) for critical Aerospace, Communications, Defense, and National Security applications. The security of the United States is contingent upon continued leadership in the research, development, and manufacture of semiconductors, chips, and integrated circuits, as well as assured access to trusted sources of supply. In the last decade, the design, production, and integration of IC technology has moved offshore to Malaysia, Japan, Singapore, Taiwan, and the Peoples Republic of China. Competitors, adversaries and potential enemies of the United States have recognized the dependence of U.S. military and commercial advantages on the underlying IC technologies that enable them.

While some elements of the United States Government recognize the risk of diminishing sources of trusted chips, Congress has been slow to address the issue. The Department of Defense and the National Security Agency instituted a stop-gap measure by establishing the Trusted Foundry Initiative with International Business Machines (IBM), ensuring that the United States Government has an assured supply of integrated circuits and chips for critical needs in the near term. However, longer term measures need to be explored, as well. To protect U.S. national security interests, policymakers must understand where the Asian semiconductor industry is headed, the implications changes may have on U.S. security, and what protective measures can be taken via policy.

As manufacturing capabilities and knowledge continue to flow offshore, the defense industrial base weakens and the U.S. becomes more dependent on non-U.S. suppliers for critical technologies and semiconductor products (chips and integrated circuits) that are manufactured outside of the United States. “More than 56 percent of the electron tubes used in the United States are imported, as are nearly 69 percent of the resistors, nearly half of the electric coils, transformers, and inductors, nearly 99 percent … of the capacitors and parts, and nearly 61 percent of a broad catch-all electronic components category” (Tonelson, 2006, p 2). Already, there are strong indicators that the United States is losing its leadership position, as design and production facilities move offshore (SIA, 2006, p 1). The Department of Defense noted that there are risks associated with foreign dependence on sources of supply, such as counterfeits, compromise, geo-political influences, and natural disasters (Defense Science Board, 2005, p 24).

The shifting of high-value semiconductor activities (and high paying engineering jobs) to Asia also may have long term consequences on U.S. economic strength, which is critical to national security. The semiconductor is a vital foundation of the broader electronics industry, one of the largest and fastest growing industries in the world. This industry, which had estimated sales of $1,504B in 2006, is expected to grow at 8.25% over the next three years, or nearly double the rate of the world Gross Domestic Product (SEMI, 2007; Central Intelligence Agency [CIA], 2007). If the United States loses its design lead in semiconductors, it may also lose market share in the overall electronics industry which could hurt its future economic strength in a technology driven world.

Intellectual Property Protection in the Semiconductor Industry

Most of the value of a new and specialized high technology product (such as an IC) lies in the costs of innovation—the research, design and testing involved in its creation. The protection of intellectual property (IP) is vital to continued technological advancement and survival of the U.S. semiconductor industry. This industry is highly knowledge-intensive, and requires companies to invest approximately 15-20 percent of revenues into R&D annually in order to remain innovation leaders and competitors (SEMI, 2006). Loss of revenue caused by IP theft ultimately limits future R&D, which slows innovation and compromises the competitive advantage of American corporations. The National Research Council (NRC) finds that “the strong performance and development of the U.S. economy in recent years is rooted in the investment in and subsequent application of information technologies ultimately driven by modern semiconductor technology” (NRC, 2003, p.1). The gradual shift of American semiconductor activities overseas—particularly to near-peer competitor countries with poor track records in protecting IP—potentially has economic and security implications.

The fierce competition within free and open markets around the globe—coupled with the rapid, free flow of information—makes it easier and more enticing for competitors to forgo expensive R&D projects by violating IP rights. Such violations occur in the form of stolen patents, trademarks, copyrights, and trade secrets, as well as the manufacture and sale of counterfeit products. All such violations rob corporations of the value of their hard earned IP in the market place.

The United States Commerce Department defines IP as creations of the mind—creative works or ideas embodied in a form that can be shared, or can enable others to recreate, emulate, or manufacture them (Department of Commerce, 2005). According to the United States Patent and Trademark Office, "the intangible nature of intellectual property and the worldwide inconsistency of standard practices create challenges for U.S. businesses wishing to protect their inventions, brands, and business methods in foreign markets"(Export.gov, 2007). Ensuring international adherence to established IP rights is a growing challenge across a number of industries to include electronics, software, clothing, pharmaceuticals, and automobile parts, with counterfeits accounting for approximately 5 to 7 percent of global trade (Department of Commerce, 2005). Within the semiconductor industry, organizations such as the Semiconductor Equipment and Materials International (SEMI) and the Semiconductor Industry Association (SIA) lobby on behalf of their member companies to ensure strong and effective international intellectual property protection programs are in place to protect investments in R&D and ensure continued industry growth and innovation.

Developing complex ICs demands close contact and feedback between the designer and fabricator, nudging the critical design process to move overseas as well. The continuing shift to foreign manufacturing sources and the steps foreign governments are taking to secure increasingly greater portions of the semiconductor industry only heightens the importance of IP protection. Along with chip design and manufacturing processes, it is critical that IP protection also cover manufacturing equipment designs, materials, spare parts, components, subsystems, software, technology, process recipes, and best-known methods (SEMI, 2006).

The U.S. Congress takes an active role in providing adequate protections for both foreign and domestic owners of IP conducting business within the U.S. In addition to protecting American manufacturers, the U.S. actively protects the rights of foreign IP holders from infringement in the U.S. The U.S. is a member of both the World Intellectual Property Organization (WIPO) and the World Trade Organization (WTO). In one of its early efforts to protect the semiconductor industry from aggressive Japanese competitors, Congress enacted the Semiconductor Chip Protection Act (SCPA) of 1984 to protect the designs of computer chip faces from unauthorized copying. Passage of this law marked the first time Congress enacted a specialized, explicit, copyright-like provision to protect an item with largely utilitarian functions (Magdo, 2000, p.2).

The WTO Agreement on Trade Related Aspects of Intellectual Property Rights (TRIPS), which came into effect 1 January 1995, introduced intellectual property rules into the multilateral trading system for the first time. It is the most comprehensive agreement to date, and the first to include enforcement provisions (WTO, 2007). However, even with the TRIPS agreement in place, violations of IP rights continue to occur in the semiconductor industry, primarily in less developed countries. Differences in how countries grant patents, and cultural and philosophical differences in weighing IP rights versus the public good, can lead to complicated legal entanglements. The safeguards of intellectual property are territorial and consist of a patchwork of different protection levels and enforcement mechanisms (Mikhail, Gallagher & Hsue, 2006, p. 86).

Even within the WTO, resolution of IP violation disputes can be lengthy, and the disputed IP can lose its value in the marketplace before the issue is resolved. For U.S. semiconductor manufacturers, the lure of potentially lucrative markets in China and other developing nations is great; however, company executives should closely weigh the true costs of entry, and force such countries to play fair where IP rights are concerned. Failure to bring emerging powers such as China into full compliance with all aspects of the TRIPS agreement ultimately could lead to a collapse of many recognized IP protections. In turn such loss of protection could result in a semiconductor market downturn for US manufacturers—one that could eclipse by many times the downturn of the 1980's at the hands of Japanese competitors.

The U.S. government must be active bilaterally and through globally established bodies in protecting the hard-earned IP of American companies competing in the world market. It should actively demand compliance and enforcement of IP protection agreements; and it should pursue appropriate penalties if enforcement is lacking. Without vigorous U.S. government intervention through the WTO, the continued shift of semiconductor design and fabrication to China and other developing nations with lax IP protection policies could result in the loss of valuable IP and revenue. Lost revenues reduce the funding available for R&D, and ultimately, stifle innovation. Recognizing that emerging nations may put their national ambitions ahead of international commitments to protect IP, U.S. manufactures must make hard choices between entry into these markets and risks to their very survival. The choices they make, right or wrong, will determine future standards for internationally recognized IP rights and protection, and the future of the U.S. semiconductor industry.

Educating a High-Tech Workforce for the 21st Century

Recent reports indicate that the next generation of American youth is lacking in math and science skills; and there are not enough U.S. students getting degrees in fields such as mathematics, engineering, science, and computer science to feed the increasing demand for needed skills in an American economy driven by technical innovation and technology pre-eminence. Between 1990 and 2002, high-tech industry employment grew by 50%, while the number of engineering bachelor degrees awarded in the U.S. during the same period fell by 6% (AEA, 2005, pg. 19). The limited availability of American-born technicians, scientists, and engineers has placed a strain on the semiconductor industry, and has prompted companies to seek foreign-born (but American-educated) talent to fill their needs. Industry and government have taken steps to improve high-tech skills, quality of education, and immigration laws for students and workers. The U.S. must address this challenge to remain competitive over the long-term.

Many trace the short-fall of American students entering engineering fields to low mathematics and science achievement by students in grades K-12. The National Science Board reports that "among Organization for Economic Cooperation and Development (OECD) nations participating in a recent assessment of how well 15-year-old students can use mathematics and science knowledge, U.S. students were at or near the bottom of the 29 OECD members participating (NSB, 2006b, pg. 1)." The 1999 Third International Mathematics and Science Study reported that U.S. 8th graders ranked 19th and high school seniors ranked 17th among developed nations in mathematics, behind Slovenia. In science, U.S. 8th graders are 18th and seniors rank 15th (Harbert, 2004). In 2000, the National Assessment of Education Progress (NAEP) reported a decline in math and science scores for 12th graders: in 1996, 21% of the students were proficient in science while only 18% tested proficient in 2000 (AEA, 2005, pg. 18). The importance of K-12 in the education of America's future high-tech workforce cannot be overemphasized. Without science and mathematics achievement in K-12, American students will have trouble earning technology degrees, and ultimately, technology jobs (Ibid., pg. 18). Without bachelor's, master's, and doctorate-level technology degrees, the next generation of American workers will not be poised and ready to participate in and sustain an economy based on scientific innovation and technological pre-eminence.

Federal/state/local governments, the U.S. public education system, and the parents of the children in that system share responsibility for the lackluster performance of American students in grades K-12. Several policy initiatives such as the No Child Left Behind (NCLB) Act of 2002 have been aimed at improving the performance of public schools in student achievement through increased accountability, providing incentives for school reform, and increasing the availability of qualified teachers in the classroom. Unfortunately, NCLB has had minimal success. One problem is that although it made accountability for student achievement a national imperative, it allowed individual states and even individual school districts to decide their own assessment procedures. One of the root causes of low-quality math and science education is the under-qualification of math and science teachers teaching these subjects in American public schools. For example, two of three middle school match and science teachers in the U.S. do not have degrees or teaching certifications in the subjects they teach. (Mutschler, 2006; NSB, 2006). At the high school level, the National Science Board reports "nationally, between 17 percent and 28 percent of public high school science teachers….and 20 percent of mathematics teachers lacked full certification in their teaching field in 2002" (NSB, 2006, p. 3).

While struggling to persuade sufficient numbers of its own citizens to pursue careers in science and engineering, the U.S. has overcome these deficiencies by welcoming the best and brightest foreign talent to study, work, and conduct research in the United States. (Mutschler, 2006). American universities are increasingly admitting highly qualified foreign-born baccalaureate and graduate students to fill their classrooms in engineering, science, and mathematics. The U.S. Department of Education reports that foreign nationals received over 50% of doctoral engineering and math degrees awarded in 2002 (AEA, 2005, pg. 19). Based on 2003 and unpublished 2005 data, Michael Finn of the Oak Ridge Institute for Science and Education reports that between 4,500 and 5,000 of foreign students remain to work in the U.S. following graduation, from each annual cohort of new science and engineering doctorates (NSB, 2006, pg. 3-36). One out of very five scientists and engineers in the U.S. is foreign-born, accounting for over 1 million workers who contribute a tremendous amount of knowledge, talent, and innovation to the U.S. economy (AEA, 2005, pg. 19).

The policy that allows talented foreign-born students to study and then work in the U.S. is sorely in need of revision. Many American companies aggressively seek to hire newly minted doctoral degreed graduates, especially the ones who may have already established relationships with the companies during participation in internships and research projects. However, U.S. immigration policy continues to set rigid barriers on companies' access to this talent, due to mandated constraints placed on H-1B visa limits. In recent years, following the 9/11 terrorist attacks, the U.S. has raised the restrictions—even on highly skilled workers desiring to enter the country. For workers with specialized skills, the number of accepted visa applications dropped 27% from 225,000 in 2001 to 165,000 in 2003 (AEA, 2006, pg. 20-21). The H-1B visa cap for FY07 was reached four months before the fiscal year even began, the third year in a row that it has been reached on or before the start of the fiscal year (CompeteAmerica, 2007).

Declining interest and lackluster academic performance in mathematics and science in U.S. public schools is increasingly hobbling the next generation of American worker in its ability to maintain America's global competitiveness in this key industry. At the same time, immigration policy severely limits opportunities for highly skilled students and workers to seek employment in this country.

Semiconductors are vital to America's economic prosperity and growth. This industry breeds innovation, new jobs, and new technologies that are applicable across a broad range of industries and scientific disciplines; and it produces the essential electronic devices and high-end computing Americans rely on in an increasingly networked and knowledge-based world. There are no easy answers to the challenges of K-12 education in the U.S. No amount of accessibility to foreign-born talent will relieve this country of the imperative to ensure that its own citizens possess the science, mathematics, and engineering skills to participate in our technology pre-eminent society. A strong commitment from the entire educational ecosystem of national leaders and policymakers, school administrators and teachers, industry, parents, and the community is required—all must work together in an integrated fashion to mentor and educate America's 21st century workforce.

Investing in the Future: Research and Development (R&D)

Throughout the history of the world's industrialized countries major economic advances resulted from complementary public and private R&D investments leading to expansion of scientific knowledge, technological development, and—perhaps most important—innovative capacity. In this country continuing R&D investments are vital in developing knowledge and technologies that advance society in the future—and help U.S. citizens sustain and improve the standard of living they enjoy today. As the semiconductor industry continues to invest in *applied* research for new products, many analysts are concerned that the federal government is reducing its investments in *basic* research. These reductions in U.S. government-funded basic research are contrary to global trends; in contrast, "governments abroad are active in supporting their respective industries, notably semiconductors." This has a direct impact on America's innovative capacity and ability to compete. Additionally, reducing support for R&D "may compromise the U.S. government's ability to achieve other societal goals over the long term" (National Research Council, 2003, p. 36). In a constrained budgetary environment, policy makers must determine the level of public R&D investments that stimulate—and complement—private investments in order to achieve national objectives.

Government R&D investments made years ago sowed the seeds for the military, technological, and economic preeminence this country enjoys today—as well as the steadily increasing standard of living enjoyed by most Americans from one generation to the next. Support for basic research is an inherently governmental responsibility for the public good. "Government investment in basic research funding is imperative for the continuation of America's innovation leadership, competitiveness, and national security" (SIA, 2007c, pp. 1-2). Basic research conducted in universities expands opportunities for students to learn and discover—in preparation for their roles as innovators in the future. The country that loses or falters in its ability to innovate eventually will lose ground to countries that invest in their own innovative capacity. Yet, U.S. federal government support for basic research has declined "37% as a percentage of GDP [Gross Domestic Product] over the past 30 years" (Panchak, 2005, p. 2).

Why is basic research so important? And why is it important that the federal government support it? By definition such research pursues the expansion of knowledge through deeper understandings of *basic* physical, chemical, and biological phenomena. Basic research strengthens the innovative capacity of the nation—as made up of individuals, companies, and industries—because it increases the capability of these same constituent entities to understand and absorb scientific and technical knowledge. This knowledge is applicable across multiple industries and domains; therefore investment in basic research does not entail picking winners and losers in the economy. However, while "basic research plays an important role in building the foundation of technological advancement," since it is not referenced to application "it does not always lead directly to the creation of new products and services" (Kazmierczak & James, 2005, p. 15). Ergo, basic research is "generally inconsistent with the objectives of profit-making industry" (Industry Retakes Leadership Role, 2007, p. 5).

However, there also is a role for government to encourage industry executives to make complementary R&D investments by making the federal R&D tax credit permanent. Typically industry pursues applied research to develop the "next product" or perhaps the next technology node. Applied research provides specific subject matter expertise—the basis for competition against emerging peers. Private sector investment in R&D enables the translation of science and technology into the production of useful and marketable products that provide high paying jobs and enhanced productivity for American workers.

The current administration has shown its support for increased investments in R&D funding, reallocation of funding from life sciences to broader technology fields that support multiple sectors of the economy, and R&D tax credits for industry. Time will tell if public and private investments in R&D help the U.S. retain its technological leadership against increasing offshore competition and result in new products, high wages, and improved standards of living for the American people.

Government Goals and Roles

In addition to preserving their individual rights and freedoms, American citizens depend on government to safeguard national security, to provide a regulatory environment in which businesses can thrive, and to facilitate a robust economy. To varying degrees many citizens and politicians oppose economic intervention by the state beyond what is needed to maintain peace, security, and property. When considering intervention, policy makers strive to balance and harmonize competing interests for the greater good.

The objectives of this study were to evaluate the performance of the semiconductor industry in terms of serving national strategic needs and promoting economic welfare, and to recommend government policy that would improve the industry's performance from one or both perspectives. Not surprisingly, seminar members found instances where interests compete, such as export controls imposed in the interest of national security hampering the domestic industry's ability to compete in the global market. What was surprising, however, was the degree to which national security and economic interests aligned with respect to the increasing migration of what were once domestic semiconductor activities to offshore locations. While that trend can not be reversed, we feel that steps taken to make the industry more competitive also serve national security interests. This section summarizes the seminar's findings with respect to national security and economic implications, and recommends some broad policy considerations.

Industry Implications to U.S. National Security

One concern the U.S. Department of Defense (DoD) has with the rising strength of the Asian semiconductor industry is the loss of IC manufacturing capability in the United States. Today, IBM, Intel and Micron are the only U.S. companies which operate 300mm fabs in America (Vacca, 2007). The U.S. DoD and intelligence agencies have stressed that the country can not rely on foreign producers such as China, Taiwan and Singapore to manufacture the advanced ICs needed for critical defense capabilities. Given the increasing dependence of the country's "network centric" military force on advanced ICs, the erosion of the indigenous manufacturing base is significant (Lieberman, 2003, p. 3). If current trends continue, defense experts worry that the country may lose access to secure fabs, which take 1-2 years to build in today's environment (Lorick, 2003, p. 1). To preserve some secure advanced chip making capability, the DoD and the National Security Agency signed a 10 year, $600 million dollar deal with IBM in 2004 to use its Vermont fab as a "trusted foundry" for defense needs (McCormack, 2004, p.1).

Another significant U.S. defense concern related to the Asian semiconductor industry is the increasing movement of IC design activities to this region. As of June 2005, 13 of the top 15 U.S. semiconductor companies in the U.S. have opened research centers in India, and 5 have done the same in China (Brown & Linden, 2005, p. 24). While China's IC design capabilities are still meager, the country's growing chip manufacturing base and its efforts to attract top engineering talent will likely lead to significant improvement. Since semiconductor designers tend to interact closely with manufacturers, many experts believe that design activities will continue to migrate to China and other Asian nations over time. As IC design talent moves abroad, however, other nations may be able to develop more sophisticated military hardware, especially if knowledge transfer continues to expand to countries beyond the point of manufacture. This trend could significantly reduce the technological superiority advantage the U.S. military currently holds over potential adversaries.

Industry Implications to the National Economy

The electronics sector and the semiconductor industry have played an important part in driving the growth of the global economy. Through continuous performance improvements and decreasing costs, ICs embedded in electronics devices, computers, routers, servers and telecommunications equipment make it possible to link the world in ways never before possible. This fosters the worldwide flow of information, making it possible to conduct business virtually anywhere on the globe instantaneously. According to the National Research Council (NRC), "the strong performance and development of the U.S. economy in recent years is rooted in the investment in, and subsequent application of, information technologies ultimately driven by modern semiconductor technology" (NRC, 2003, p.1). The electronics industry also provides innovations, efficiencies and advanced technologies that improve the productivity of individual workers and organizations, grow the economy, and provide our military with unprecedented advantages in all forms of warfare. With that in mind, one must seriously consider the potential economic and security impact caused by the migration of fabrication capabilities to offshore locations, and the gradual shift of domestic semiconductor design and R&D that may follow. Companies must be vigilant against the transfer of technologies and knowledge to potential peer competitors, particularly in countries that ignore international agreements to protect intellectual property (IP).

The shifting of semiconductor activities to Asia also may have long term consequences on U.S. economic strength, which is critical to national security. According to the Semiconductor Industry Association (SIA), the U.S. industry currently employs approximately 232,000 people—down from over 260,000 in 1998 (SIA, 2007b). As value chain activities move offshore, this number may continue to fall. The economic impact of higher end value chain activities, such as design, moving offshore is even greater as this change results in the loss of high paying engineering jobs and associated design expertise. The semiconductor industry is a vital foundation of the broader electronics industry, one of the largest and fastest growing industries in the world. This industry, which had estimated sales of $1,504B in 2006, is expected to grow at 8.25% over the next three years, or nearly double the rate of the world Gross Domestic Product (SEMI, 2007; Central Intelligence Agency [CIA], 2007). If the United States loses its design lead in semiconductors, it also may lose market share in the overall electronics industry which could hurt its future economic strength in a technology driven world. While activities in other regions of the world must be monitored, the Asia-Pacific region is of particular concern due to its rapid growth, strategic intent in attracting foreign investment and technology, direct and indirect barriers to free trade in the past, and IP infringement.

Recommended U.S. Policy Actions

In considering possible policy recommendations, the seminar members reviewed those obtained from government and industry officials we met with during field studies, and from past personal experience with state and local government-industry partnerships. Additionally we reviewed recommendations from other study reports and industry associations, including reports issued by the National Academies, the President's Council of Advisors on Science and Technology, the National Innovation Initiative, the Defense Science Board, the Business Roundtable, SIA and SEMI. Recommendations are intended to achieve goals that serve national security needs, promote economic welfare, or both. Policies related to economic welfare are those that remove barriers and allow the U.S. domestic semiconductor industry to remain competitive in the global market. In general terms, the government must protect key technologies and intellectual property, enforce fair trade agreements, stimulate innovative capacity, and enhance the business environment for semiconductor companies in America.

The policy recommendations are grouped in terms of near-term, mid-term, and long-term effects. One up-front recommendation would be to establish a standing advisory panel representing key government agencies and leaders from industry and academia that would develop a coherent strategy to improve the competitiveness of all key technology industries, such as: semiconductors, electronics, information, communications, and biotechnology.

Near-Term. One of the first semiconductor-related national security issues the U.S. Government needs to address is the loss of IC manufacturing capability to Asia. While the Trusted Foundry Program is a step in the right direction, it relies on the strength of only one company (IBM). The U.S. Government should explore expanding the Trusted Foundry Program, perhaps through cooperation with trusted coalition partners such as Britain, Canada and Australia. Policymakers also need to remove or counter indirect barriers to trade and competition, and improve the business environment for fabs in America. One way to counter government subsidization of foreign industries through income tax incentives and tax holidays without directly subsidizing our domestic industry is by restructuring allowed depreciation to reflect the rapid pace of modernization needed to keep pace with manufacturing technology. (McCormack, 2005, p. 3). Any steps that streamline or reduce administrative overhead to comply with needed regulations can improve the business environment for semiconductor operations within our boundaries. Additionally, the U.S. government should sponsor research to improve IC manufacturing flexibility and test processes. Flexible manufacturing is needed to efficiently handle smaller DoD chip orders, while better test processes will ensure that defense chips obtained from foreign sources are free of malicious logic. The Department of Defense should continue funding the joint government/industry/university Focus

Center Research Program, which performs research to address the most difficult problems limiting the advancement of Moore's Law.

Mid-Term. To retain semiconductor design preeminence, the federal, state, and local government authorities must find ways to maintain and grow semiconductor ecosystems in the world, such as are found in "Silicon Valley," Austin (TX), and upstate New York in order to grow and retain the top IC design talent in the world. State governments can benefit their local economies by providing a business-friendly environment, by encouraging local partnerships of industry, government and academia engaged in technology initiatives. Federal labs, R&D centers and systems commands can partner with industry for the commercialization of government-developed patents. U.S. policymakers can attract talented science and engineering students and stimulate technology development through focused university research grants and industry tax incentives for R&D and modernization. Further, Congress should make the Research and Exploration (R&E) tax credit permanent so that companies can plan and program future investments. To maintain a skilled workforce, Congress should sponsor efforts to benchmark U.S. education in all grades against the top performing nations in the world, particularly in math and science, and fund programs to close any gaps. Policymakers also should revise visa requirements to make it easier for foreign-born students to stay in the United States after completing advanced technical degrees in the country's top universities; and provide tax incentives for American workers to pursue advanced degrees and life-long learning in areas that provide a skilled high-tech workforce. Congress is reviewing several innovation and competitiveness bills to address these issues; however, none have been passed into law (Gordon, 2007, p. 1).

Long-Term. The U.S. government should continue to pursue long-term strategies to protect U.S. military technological advantages and the country's ability to compete in the semiconductor (and greater electronics) industry. Smart domestic and international export controls are needed which can keep advanced military-use semiconductor technologies from potential adversaries without interfering with non-military commercial trade. These controls must clearly delineate prohibited nations and export technologies, and keep pace with rapid technological advancements. Critics argue that many current restrictions, such as radiation hardening provisions in existing International Traffic in Arms Regulations, have not kept pace with technology changes (SIA, 2007b). As a result, many commercial video games, cell phones and computers may soon be classified as prohibited munitions (Ibid.). The U.S. government also needs to continue to work with other nations and the World Trade Organization to guard against discriminatory practices, such as China's value-added tax laws prior to April 2005, which charged 14% more to non-Chinese semiconductor firms (Manufacturing & Technology News, 2003, p. 1; Lyne, 2004, p. 6). Finally, the U.S. government and industry associations should work with their counterparts in emerging nations to develop agreements for the protection of IP and the environment.

Conclusion

The electronics industry, fueled largely by semiconductors, has become one of the largest and fastest growing industries in the world. Advances in this industry have increased worker productivity and led to numerous innovations in science, education, healthcare and other industries across all sectors of the U.S. economy. U.S. leadership in this industry has propelled U.S. economic growth and enabled the country to lead the world in innovation and advanced military technologies. In recent years, however, an increasing number of global semiconductor activities have shifted to Asia. This change is beginning to threaten U.S. defense supplies and technological advantages, and weaken the country's economic strength in technology-based industries. The report recommends policies to counter or mitigate this trend and achieve goals related to national security, industry competitiveness, or both. In general terms, the government must protect key technologies and intellectual property, enforce fair trade agreements, stimulate innovative capacity, and enhance the business environment for semiconductor companies in America. Table 1 summarizes the challenges and major issues faced by the semiconductor industry, and the top-level goals of the U.S. government.

Table 1. Analysis Summary

Industry Challenges	**Major Issues**	**National Goals**
Technology Barriers	National Security	National Security
Capital-Intensive	Intellectual Property Protection	Promote Economic Welfare:
Skilled Workforce	Educating the Workforce	Protect Critical Technologies
Export Controls	Research and Development	Enforce Trade Agreements
Environment		Stimulate Innovative Capacity
Effective Lobbying		Enhance Business Environment

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