Testimony before the House Committee on Science, Space and Technology's Subcommittee on Research and Science Education

Hearing on "Nanotechnology: Oversight of the National Nanotechnology Initiative And Priorities for the Future"

Dr. Jeffrey Welser
Director
Nanoelectronics Research Initiative

Introduction

My name is Jeffrey Welser and today I'm testifying on behalf of the Nanoelectronics Research Initiative (NRI), Semiconductor Research Corporation (SRC), and Semiconductor Industry Association (SIA). I'd like to thank Chairman Brooks, Ranking Member Lipinski, and other members of the Subcommittee on Research and Science Education for inviting me to testify before you. Thank you for your commitment to science and technology and nanotechnology advancement. Your Committee's role in providing a vision that ensures the technological leadership needed to drive economic growth to build America's future has never been more important than it is today, when we are faced with an unprecedented fiscal challenge which will require difficult decisions in every area of Federal spending.

Your Committee fostered the ecosystem that enabled innovation-driven economic growth and high tech job creation in the past. By insuring we are spending limited Federal resources wisely to maintain that ecosystem, you will also enable entire new industries for the 21st Century. The subject of today's hearing, nanotechnology research, is a foundation for those future industries.

In a time of limited resources, it is crucial to insure adequate support for those areas of research that have proven to be drivers of the economy and job growth broadly and long-term. I come here today representing major organizations in the area that has arguably been the most important driver of the U.S. economy over the past half-century, built on America's world-leading research and university capability: semiconductor electronics – or as they are commonly referred to, chips.

The Nanoelectronics Research Initiative (NRI), which I direct, is a consortium that supports university research in novel computing devices with the goal of enabling technology advances that will carry the semiconductor industry beyond the approaching limits of the current silicon-based technology. NRI leverages industry, university, and government funds (local, State, and Federal) to support research at U.S. universities, driven by industry needs, to ensure that the United States will be the world leader in the nanoelectronics revolution, reaping the economic and security benefits that leadership provides.

Semiconductor Research Corporation (SRC) is the premier industry consortium that invests in university research to solve the technical challenges facing the semiconductor industry and to develop technical talent for its member companies. SRC and its subsidiaries manage several semiconductor research programs, including NRI. Since its founding nearly three decades ago, SRC has managed in excess of

$1.2 billion in research funds, supporting nearly 9,000 students and 2,000 faculty at 257 universities, resulting in more than 50,000 technical documents and 373 patents. In 2007, SRC was awarded the National Medal of Technology with a citation recognizing the unique value of this organization: "For building the world's largest and most successful university research force to support the rapid growth and 10,000-fold advances of the semiconductor industry; for proving the concept of collaborative research as the first high-tech research consortium; and for creating the concept and methodology that evolved into the International Technology Roadmap for Semiconductors."

The Semiconductor Industry Association (SIA) is the voice of the U.S. semiconductor industry, America's largest export industry over the last five years and a bellwether of the U.S. economy. Semiconductor innovations form the foundation for America's $1.1 trillion dollar technology industry affecting a U.S. workforce of nearly 6 million. Founded in 1977 by five microelectronics pioneers, SIA unites more than 60 companies that account for 80 percent of the Nation's semiconductor production. SIA seeks to strengthen U.S. leadership in semiconductor design and manufacture by working with Congress, the Administration and other industry groups. SIA works to encourage policies and regulations that fuel innovation, propel business and drive international competition in order to maintain a thriving semiconductor industry in the United States.

Executive Overview

The U.S. technology-based economy in general, and the semiconductor industry in particular, relies heavily on the pipeline of new scientific ideas, breakthroughs, and highly-trained students that can only come from the broad research enabled by consistent Federal funding of the U.S. university system. Within that spectrum of research, the National Nanotechnology Initiative (NNI) has played a key role in accelerating progress at the leading edge of nanoscale science and engineering—an area that is critical to the future of the semiconductor industry. As you consider the NNI and its future, the main points that I want to leave you with are as follows.

1. **Nanoelectronics is a priority** for the economy, for high paying jobs, and for the nation's ability to innovate and compete in the future. As Congress works to reduce the Federal deficit, it must give priority to those expenditures that create the long term economic growth and jobs that will expand our tax base and raise our standard of living.

2. Strong university research correlates geographically with leading edge technology development and flourishing technology businesses. **If the United States is to lead in nanoelectronics, it needs a robust university research effort in nanoelectronics**. Government and private sector funded university research should be done in a coordinated or, better yet, collaborative manner.

3. The electronics industry is facing a challenge similar to the 1940's, when vacuum tubes were replaced by semiconductor chips. **The nation that is first to discover and develop the key nanotechnologies—i.e., the next logic "switch"—will lead the nanoelectronics era,** much like the United States has led the microelectronics era for the past half century. This fact is recognized by countries around the world and U.S. leadership is far from guaranteed.

4. **NRI is an industry-driven consortium that funds a coordinated program of university research in partnership with Federal and State government agencies**. Thanks in large part to NRI, the United States is the current leader in nanoelectronics at this early stage. But the challenges are great and the global competition is growing.

5. **Funding university scientific research educates our technology workforce**. A pipeline of science and engineering graduates is critical to growing and keeping the very businesses that will help to rebuild the economy. Funding for the NNI and other scientific research ensures the pipeline is adequately filled. NRI-funded students also have meaningful interactions with industry mentors, which enhance their education, expose them to career opportunities, and allow them to contribute productively once they graduate.

Recommendations for strengthening the NNI and ensuring the United States' leadership in nanoelectronics:

1. The Federal government should continue its support for the National Nanotechnology Initiative, especially in the "Signature Initiative" on long-term nanoelectronics research.

2. Congress should reauthorize the NNI and the participating agencies, to make clear its desire to see nanotechnology research remain a priority by the agencies that fund science and engineering research today.

3. The NNI agencies that are part of the nanoelectronics Signature Initiative should leverage each other's investments and those of NRI, to get the most out of every dollar spent.

4. The participating agencies should develop interdisciplinary nanotechnology initiatives that are supported by multiple NNI agencies and that support significant national priorities (as outlined in the NNI Supplement to the President's Budget for 2012, the 2011 NNI Strategic Plan and as called for by PCAST in its 2010 assessment of the NNI).

5. In choosing research priorities, NNI agencies and the interagency coordinating bodies should give strong consideration to the potential long-term economic impact of the research area, with key positive indicators being:
    a. Support of a broad research agenda that will create enabling breakthroughs for a large market segment, rather than choosing to focus on just one or two specific technologies
    b. Early engagement of industry to facilitate rapid transfer of knowledge and ideas from university scientific research into the hands of those who can use them in commercial applications.

Federal investment in Nanoelectronics research is priority for continued U.S. economic growth

Nanotechnology is the understanding and control of matter on the scale of atoms and molecules. Nanotechnology is making it possible to build machines on the scale of human cells and create materials and structures from the bottom up, building in desired properties.

Nanotechnology and research supported by the NNI is impacting many industries, but I would like to highlight the enormous impact the investment in nanoelectronics in particular could have on the future of the semiconductor industry and the potential scale of that impact on the U.S. economy.

Semiconductor industry of today

From its beginnings in the 1940's, the semiconductor industry has grown to become the largest U.S. exporter over the last five years (see Appendix 1a). In 1980, worldwide semiconductor revenues were under $20 billion. This year that figure will exceed $300 billion. American semiconductor companies alone generated $144 billion in sales -- representing nearly half the worldwide market in 2010. In the United States, there are 182,200 jobs directly associated with the domestic semiconductor industry and the average annual salary is $99,622.

The remarkable growth in semiconductor jobs and revenues through the years has been made possible by continuous technological advances based on the semiconductor transistor; it is the "switch" that creates the ones and zeros in our digital world and is the fundamental building block in electronics. Transistors are in the "chips" that permeate modern life, enabling computers, smart phones, the internet, national defense applications such as night vision goggles and unmanned aircraft, video entertainment, automobile systems such as antilock brakes and traction control, medical imaging devices, factory robotics, and countless other uses (see Appendix 2b). Advances over the last 60 years have led to smaller and smaller transistors, which in turn have enabled dramatic increases in performance and function, and decreases in cost. The increase in the number of transistors per computer chip (or decrease in the size of an individual transistor) by a factor of two approximately every 18 months is known as "Moore's Law".

The ability to make chips smaller, better, and cheaper has had enormous economic impact beyond the semiconductor industry itself. For example, semiconductors **enable 6 million jobs in the U.S.** including software engineers, network administrators, home entertainment system installers, medical imaging technicians, ATM service personnel, and desktop publishers. This figure does not include all of the jobs that are made more productive by IT—pharmacists who check drug interactions, real estate agents who use computer listings and virtual tours, and on-line retailers, to name just a few. Harvard economist Dale Jorgenson has noted, "The economics of Information Technology (IT) begin with the precipitous and continuing fall in semiconductor prices." Professor Jorgenson attributed the rapid adoption of IT in the United States to driving substantial economic growth in the nation's gross domestic product since 1995, concluding, "[from 1995-2005], Information Technology industries have accounted for 25 percent of overall economic growth, while making up only 3 percent of the GDP (see Appendix 3b). **As a group, these [IT] industries contribute more to economy-wide productivity growth than all other industries combined.**"[1]

The phenomenal advances in semiconductor technology and the ability of the U.S. industry to remain the world leader flows from the unique U.S. "innovation ecosystem", comprising university, industry, and government scientists and engineers performing a range of complementary research and development activities. On the industry side, U.S. semiconductor companies invest an average of 17% of revenues in product-related R&D, which totaled about $25 billion in 2010. This is one of the highest percentages for any industry. Coupled with capital expenditures of 11% of sales, our industry invests nearly 30% of its revenues to drive future growth. Even in the midst of decreasing revenues in the recession, SIA member companies sustained their R&D investments.

---

[1] Dale W. Jorgenson. "Moore's Law and the Emergence of the New Economy" in "2020 is Closer than You Think"; 2005 SIA annual report.

Whereas industry carries out primarily near-term research and development, the long-term fundamental science research that underpins new technologies is largely performed at universities that are funded principally by the Federal government. **University or "basic" research adds to the body of knowledge from which all companies benefit and which no one company can afford alone. In addition, university research is the means by which scientists and engineers are educated and trained for careers in technology.** University research and education are inextricably linked; one would not exist without the other.

The Federal government also funds scientific research to meet its own needs, for example in the area of national security, often paying a premium to be the first customer. But in multiple instances, such investments have led to whole new industries. As noted by the President's Information Technology Advisory Council, "Since World War II, the Federal government has funded advanced information technology research to meet its own requirements, which have ranged from critical national-defense applications to weather forecasting and medical sciences. Federal funding has seeded high-risk research and yielded an impressive list of billion-dollar industries (the Internet, high performance computers, RAID disks, multiprocessors, local area networks, graphic displays, etc.)."[2] The Federal government played a similar role in the area of semiconductors, funding the development of early integrated circuits for missile and other space applications where the weight of the current electronic technology was prohibitive.

Unique among all industries, the semiconductor industry has taken steps to connect its internal science and engineering research to the academic sector by forming and funding the Semiconductor Research Corporation (SRC). Through SRC, the industry supports university research that is pre-competitive; totaling $240 million from 2005 to 2010. SRC includes several research initiatives that address different aspects of the industry's long term research needs. SRC brings together industry and academic experts thereby insuring feedback during the course of the research and technology transfer. In the process, SRC supports 1500 students annually.

Nanoelectronics industry of tomorrow

The semiconductor industry by any measure has been hugely successful. But today's transistor technology is approaching fundamental physical limits that will prevent further improvements; and technological and economic advancement that has been fueled by Moore's Law for the last fifty years could slow to a trickle. You might ask, "Why do we need even more capable technology?" Imagine a future in which a child with diabetes no longer has to prick her finger to check her glucose or get insulin shots thanks to an implanted artificial pancreas; when smart tools and sensors enable a highly efficient electric grid that saves billions of dollars in wasted energy costs and avoids the need for new power plants based on non-renewable energy; or powerful systems to design and manufacture new materials for radically lighter, yet safer, cars and planes. Each of these is a grand challenge for science and engineering, but underlying them all are nanoelectronics—the devices that will make our future world smart and efficient, and without which many solutions will remain out of reach.

In addition to commercial applications, there are countless benefits to U.S. national security. "Taking nanotechnology seriously could single-handedly change the future for the better," wrote Dr. James Carafano of the Heritage Foundation in a recent op-ed. "Washington can build a military with cutting-edge capabilities at affordable cost, while laying the groundwork for a U.S. nanotechnology industry."

[2] *Information Technology Research: Investing in Our Future,* President's Information Technology Advisory Committee Report to the President, February 24, 1999.

Many of today's IT products and infrastructure were enabled by early-stage research at the Department of Defense (DoD) decades ago. "Today's iPads and iPods are descendents of the chips created for the Minuteman," concludes Carafano.[3]

In fact, **we are in a race to find a replacement technology for the transistor—to address technological needs and challenges, and to do so first.** U.S. researchers made the discoveries that led to the microelectronics industry, thanks to early support for research and development by the Federal government. The United States continues to dominate the development of new technology, due in large part to continued Federal support for scientific research. But today, many other countries have made it a goal to attract and build semiconductor businesses. When faced with generous financial incentives to locate not only manufacturing but also research facilities overseas, one factor that is in favor of locating operations in the United States is access to the best university faculty and student researchers.

Cutting funding for agencies that participate in the NNI neutralizes one of the main reasons why companies that will rely on nanotechnology advances stay in the United States. It cuts funding for current students and discourages future ones. And it threatens American leadership in an industry that seemingly every nation is doing its best to see take root within their own borders.

Nanoelectronics will create future jobs, contribute to budget deficit reduction

As Congress works to create high-paying jobs and reduce the Federal budget deficit it must give priority to expenditures such as nanoelectronics research that create long term economic growth and greater productivity. As mentioned above, today's **semiconductor technology enables 6 million U.S. jobs** directly and many more indirectly. Semiconductor technology has made computing and communications faster and less expensive, and nanoelectronics will continue these trends. Leadership in nanoelectronics research will allow U.S. companies to be first to market, creating entirely new industries and categories of jobs throughout the manufacturing and service economy. If the past is an indication of the future, nanoelectronics will contribute significantly to GDP, thereby expanding the tax base and helping to reduce Federal deficits.

While it may be tempting to cut Federal nanotechnology research budgets as part of an overall reduction in the Federal deficit, such across-the-board, arbitrary reductions would be shortsighted. Continued support for nanoelectronics research should instead be seen as an important element in any long-term Congressional Federal budget deficit reduction strategy.

NRI is leading the way in collaborative research in nanoelectronics

The Nanoelectronics Research Initiative (NRI) is a consortium within the SRC that leverages contributions from industry, universities, and governments (local, State and Federal) to fund collaborative research at thirty-five U.S. universities (see Appendix 4d). NRI is focused on the key challenge for continuing the progress in semiconductor electronics which has fueled the world economy for the past 50 years: finding the next "switch" and thereby keeping the United States at the forefront of the nanoelectronics revolution.

NRI funds multi-disciplinary research in physics, chemistry, materials science, and engineering that addresses fundamental problems standing in the way of progress toward "real world" applications. The consortium is open to any U.S.-based company and potentially useful technologies that emerge are

[3] James Jay Carafano: U.S. must gird for war in very small places. *Washington Examiner.* December 12, 2010.

efficiently shared with all team members. NRI not only funds the university research, it coordinates among the universities and between industry and academia, avoiding duplication and encouraging collaboration.

NRI research is extremely early stage, and like most scientific research, it is unlikely to become part of a commercial product for 10 years or more. Such long-term, high-risk research is typically funded by the Federal government. Yet NRI industry members (GLOBALFOUNDRIES, IBM, Intel, Texas Instruments, and Micron Technology) contribute millions of dollars each year because of the importance of the research to their long-term future. They also dedicate company researchers to work alongside the university researchers, helping to accelerate progress even at the beginning stages of the research and to insure strong technology transfer paths are in place for the future.

NRI is partnering with the Federal government

In addition to having members from industry, NRI partners with Federal agencies whose missions align with NRI's. The National Institute of Standards and Technology (NIST), which has a mission to promote U.S. innovation and industrial advancements, co-funds the university research and contributes in-house resources (staff and facilities). The National Science Foundation (NSF) is the primary funding agency of physical science and engineering university research and funds a number of Nanoscale Science and Engineering Centers related to nanoelectronics. NRI provides additional support and engages Center researchers in annual reviews and web-based workshops and seminars. In 2011, NSF and NRI will jointly fund about 10 nanoelectronics research teams that meet the selection criteria of both organizations. All of these partnerships have been enabled by the strong support and focus the NNI has brought on to nanoelectronics.

The NRI partnerships with NIST and NSF make sense. Without Federal funding for scientific research, there would be devastating consequences for the NRI mission. And **bringing together industry, university, and government scientists and engineers benefits all parties.** University researchers are more aware of the diverse, longer-term challenges faced by industry. Industry stays abreast of academic research and develops relationships with top-notch faculty. Government scientists and program managers understand future industry needs and can thereby enhance the value of their own research missions.

In addition to jointly funding research with NRI, the Federal government has built and maintained the world's best university system through the NNI and its broader research initiatives. American research universities produce graduates with advanced degrees who lead the world in innovation—creating new products, new businesses, and even new industries. NRI's modest and targeted investments are effective—and in fact are only possible—because of the ongoing Federal support for university research broadly. **Sustained Federal support for science and engineering research is absolutely vital if government-university-industry initiatives like NRI are to succeed.**

Technology transfer is built into NRI

A benefit of NRI is the seamless transition of research results from the university researchers to NRI member companies. Because industry has "skin in the game", industry representatives are more engaged—providing feedback during the course of the research and taking results back to others in the company. In addition, as students graduate and are hired, they bring with them detailed understanding of the research. This approach has worked well. NRI is hopeful that agencies that support nanoelectronics research in addition to NIST and NSF will also elect to join.

Supporting research supports education and workforce development

In fact, NRI has two primary outputs, both of which are valuable to member companies and to the greater science and technology enterprise. One output is the research results, which researchers are allowed to make public and disseminate broadly. The other is the students who perform the research as part of their studies and who are highly sought after as employees upon graduation. Graduates are well prepared and are able to contribute to nanoelectronics research and development once hired.

NRI-funded students are not obligated to take a position with a member company, although many do. NRI graduates also take positions as university or government researchers, or in other parts of the private sector. Through its publications, presentations, and graduates, NRI is benefiting a much larger segment of the U.S. economy than just its members.

NRI and NNI leading edge science and engineering research produces new ideas and people that are critical to American innovation in the critical area of nanoelectronics.

SRC and SIA applaud the NNI Signature Initiative on "Nanoelectronics for 2020 and Beyond"

NNI has taken steps to focus some of its investments in areas of potentially high impact. The 2011 NNI Strategic Plan includes a goal to, "develop at least five broad interdisciplinary nanotechnology initiatives that are each supported by three or more NNI member agencies and support significant national priorities." In addition, NNI identified nanoelectronics as one of its Signature Initiatives in the 2011 and 2012 budget requests.

We are pleased that the NNI agencies recognize that the field of nanoelectronics has the potential for significant economic contributions. As the leading nanoelectronics research entity, we look forward to working with other "target agencies", in addition to NSF and NIST, to coordinate and collaborate on research that will provide the greatest value and lead to the greatest progress.

Finally, we appreciate the recommendation by the President's Council of Advisors on Science and Technology (PCAST) in its 2010 assessment of the NNI that the, "Federal Government should launch at least five government-industry-university partnerships, using the Nanoelectronics Research Initiative as a model." We trust that this is also a recommendation for continued participation in NRI.

Other factors influencing the U.S. semiconductor industry's ability to compete internationally

While providing Federal funding for pre-competitive nanoelectronics research will enable the industry to compete tomorrow, there are a number of additional immediate challenges to maintaining U.S. leadership in semiconductors today. The industry depends on a highly skilled workforce and therefore improvements to the STEM education system are necessary in the long-term. In the short-term, we must reform our immigration system to allow bright foreign nationals that graduate from U.S. universities in STEM fields to stay here after they graduate. These innovators create jobs for Americans as they develop small businesses or create entire new product lines. Tax and regulatory policies are equally important factors that businesses consider when deciding to expand operations and add jobs.

Throughout the world, governments have identified the semiconductor industry as a strategic industry because of its implications on economic growth, societal welfare, and national security (see Appendix 5e). These same governments have implemented policies and structured investment incentives with the aim of significantly growing semiconductor manufacturing and R&D in their countries.

Conclusion

Our nation faces a challenge that can be compared with the transitions that occurred from vacuum tubes to the transistor and on to integrated circuits and to large scale semiconductor systems. The United States led the semiconductor industry through these challenging transitions. We led because of our public and private research strengths and our formidable university research infrastructure. It required substantial investment of Federal funds to create the first semiconductor diode, initially for military use. Those investments launched the entire IT industry, which has driven the economy ever since. We led because entrepreneurs incorporated this research into products that created new industry segments. And the Federal government played a critical role all along the way.

Today, the U.S. semiconductor industry has nearly fifty percent of the $298 billion worldwide market share. Sustained research funding, along with sensible tax, trade, workforce, education, and regulatory policies are all factors that influence the semiconductor industry's ability to compete internationally.

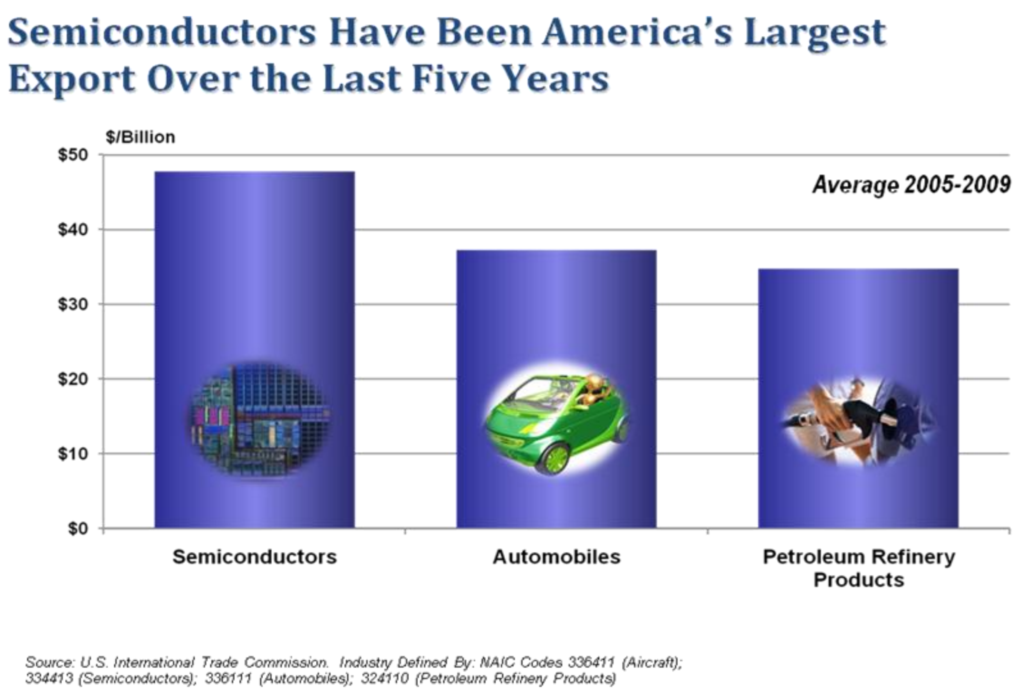
In a globalized economy, research must begin far in advance of the technological transitions we will encounter. Luckily, we know the broad outline of some of these challenges, and by funding research in nanoelectronics, Congress will lay the bedrock for new U.S. jobs and industries of the future, much like those that were enabled by the transistor age. We are creating something wholly new with untold potential, and this research is taking place here in this country through the NRI and other SRC programs, our public-private partnerships, and nanoelectronics focused programs at NSF, NIST, DoD and the Department of Energy.

Future nanoelectronics-enabled products will be designed and manufactured in the United States if we choose to be the region that discovers and markets these new technologies first. The latter is largely dependent upon making strategic choices today and acknowledging that nanoelectronics infrastructure and scientific research provide our nation the best return on its tactical and strategic economic investments.

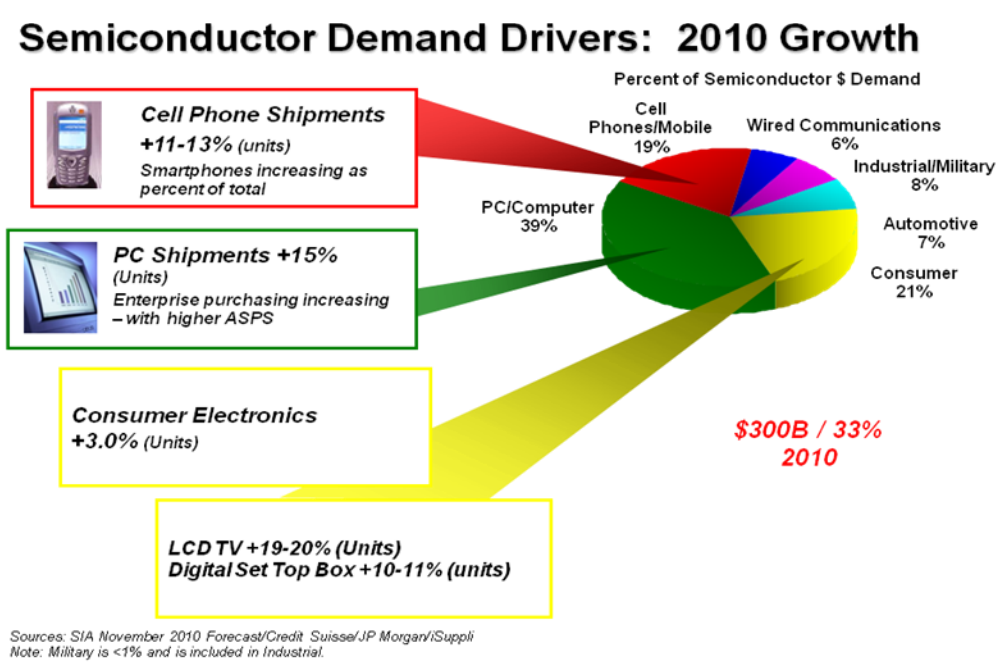
In the middle of the last century, Silicon Valley grew from innovation built on Federal research. What are the names of the companies that will dot the horizon of the new "Nanoelectronics Valley?" The question is not whether this place will exist, but rather where will it be.

Appendix

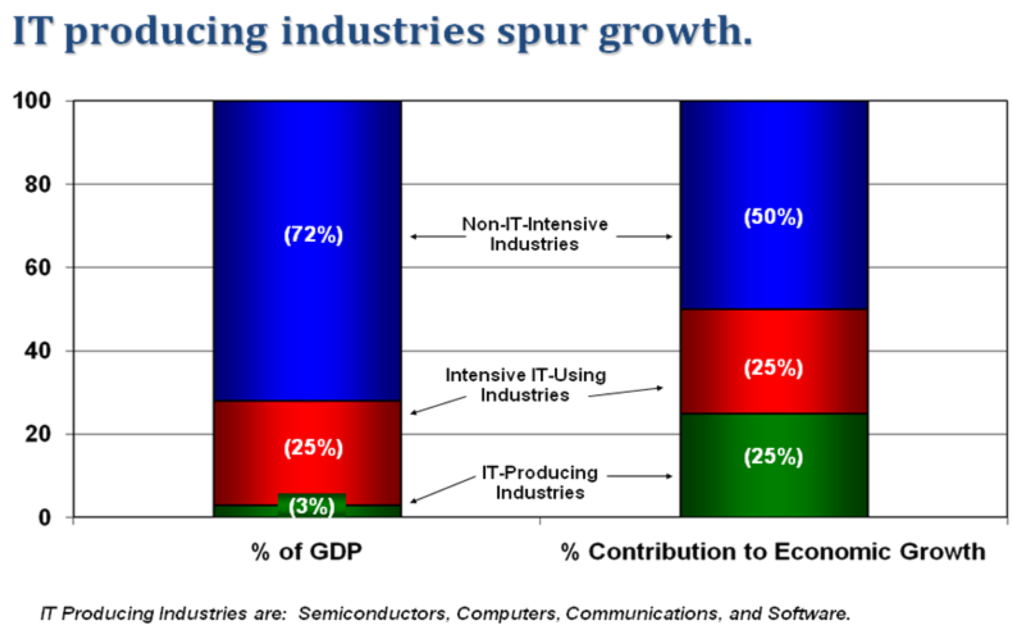
1a)



2b)

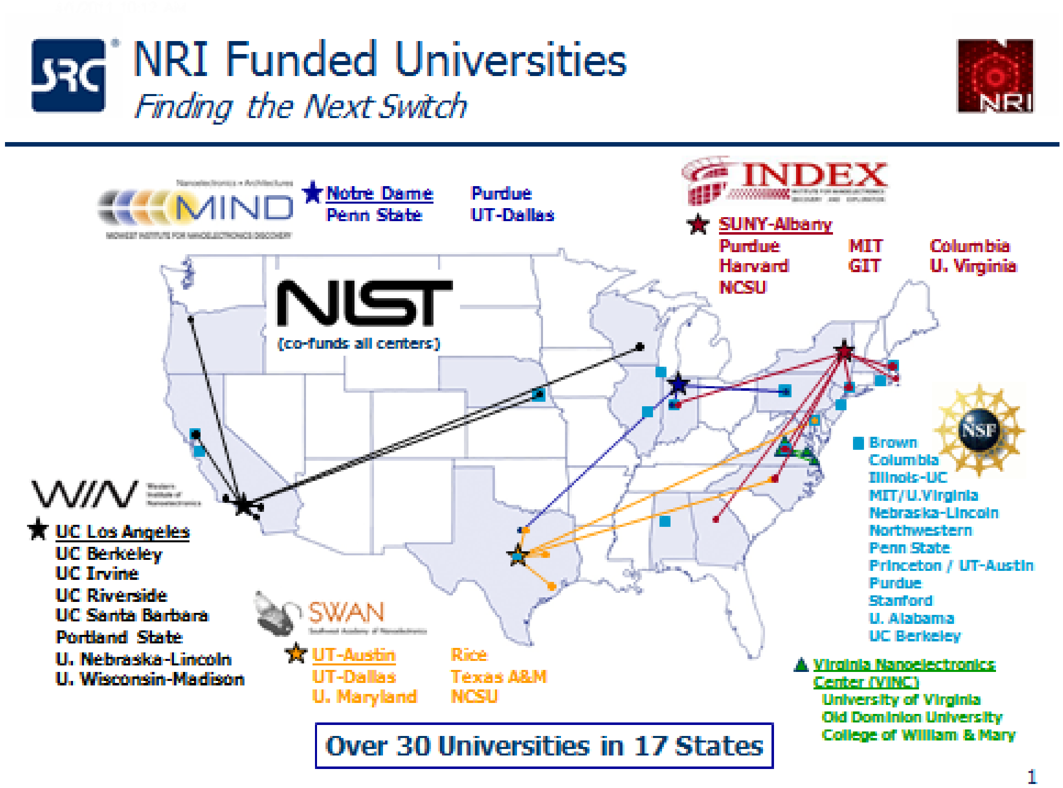


3c)



Source: Based upon Dale W. Jorgenson (Harvard University). "Moore's Law and the Emergence of the New Economy" in "2020 is Closer than You Think"; 2005 SIA annual report.

4d)



5e)

Semiconductors - Driving Innovation, Shaping The Future

EDUCATION

- Classroom computers
- Online learning
- Accessing information

ECONOMIC GROWTH

- Creating jobs
- Improving productivity
- Enabling innovation

ENERGY SOLUTIONS

- Enabling alternate energy sources
- Reducing transmission losses
- Energy-efficient homes and vehicles
- Fuel-efficient transportation

HEALTH CARE

- Technology drives advances in medical science
- New tools improve health care:
  - Diagnostic tools
  - Robotic surgery
  - Tools for minimally-invasive surgery
- IT lowers cost of delivery of health care

NAT'L & HOMELAND SECURITY

- Securing critical infrastructure
- Satellite imaging
- Field communications