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Semiconductor Industrial Base Focus Study – Final Report

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Executive Summary

In the early years of the semiconductor industry, the 1960s and 1970s, the Department of Defense (DoD) was a major buyer of integrated circuits (IC). From its position in the marketplace, DoD could both steer the direction of technology evolution and command the attention and interest of IC suppliers. DoD was willing to pay premium prices for early access to the nascent technology that allowed it to miniaturize and harden the electronics in its systems such as the Minuteman II missile. IC producers leveraged this premium to maintain leadership in the market and to push the frontiers of the underlying technology.

Today, the total market for semiconductors has grown to about $333 billion and the situation for DoD is very different. In terms of market share, DoD systems and programs account for just under 1% of the global semiconductor output, and DoD no longer wields the influence of a major customer. The demand for semiconductor components in communications, computing, automotive, industrial, and consumer markets accounts for most of the output these days. Commercial end-uses, in particular, are driving high volumes, especially at the leading edge of manufacturing technology.

Other market dynamics have affected DoD's ability to obtain leading-edge IC technology early, especially custom ICs. In the early years of the IC industry, U.S. companies that fabricated devices in the United States dominated the competitive landscape, and DoD maintained strong relationships with many of them. Today, domestic companies hold about 50% of the world's market in terms of sales, but many no longer fabricate in the United States and rely on offshore foundries for their products.

The semiconductor industry, however, is global, and overseas companies dominate some IC market segments. Companies competing in the semiconductor industry these days focus their resources on innovating and producing ICs for commercial end-uses. This leaves DoD in the position of scrambling to maintain the technical superiority of its weapons systems. It has to compete with all others for early access to advanced IC technology and regular access to other process offerings.

To date, DoD has been able to meet its semiconductor technology needs, even with the changed market conditions. The situation in the future, however, is less clear. There are real concerns about how the marketplace will evolve over the next 5 to 10 years. As emerging technologies become available only from global suppliers, where will DoD be able to procure the IC technology that it will need to maintain technological advantage and security of supply/access? Will globalized and perhaps foreign entities be willing to sell the newest technology to DoD? Will DoD be able to trust that the devices are free from malicious elements or other forms of tampering?

To address these types of general questions, the Manufacturing and Industrial Base Policy (MIBP) office formed and led a small government team that visited selected industrial semiconductor facilities. The team included representatives from MIBP, the National Reconnaissance Office (NRO), the National Security Agency (NSA), the Defense Micro-Electronic Activity (DMEA), the Institute for Defense Analyses (IDA), and the Defense Contract Management Agency (DCMA). Team members had a broad range of subject matter expertise in semiconductors, microelectronics, research and development (R&D), and defense procurement.

IDA assisted in scheduling a series of visits to companies that the team agreed represented a cross section of key commercial semiconductor manufacturers, in formulating key questions to guide the discussions, in leading the discussions, and finally, in summarizing and reducing these discussions to key recommendations. Where visits were not practical, the team got input through telephone interviews or sidebar meetings at other venues. This report captures the overall inputs that the team obtained from its contacts with integrated device manufacturers (IDM), foundries, defense microelectronics companies, leading-edge research organizations, and companies that are members of the infrastructure and industry associations.

A number of prior studies have looked at the structural issues that the semiconductor supply chain poses for DoD. Many of these prior studies have identified and analyzed the challenges that DoD faces. Most of these studies, however, did not contact and solicit inputs from semiconductor manufacturing experts in industry. This team had very candid and frank meetings with people from industry with responsibilities in manufacturing. This analysis focused on gaining direct perspectives from individual experts and technical groups within the domestic industry on the future directions of semiconductor manufacturing and on how the government might better interact with the industry for access to technologies as the industry evolves.

Key Observations

IDA collected and summarized the team's observations. These observations, and the recommendations that follow, are a synthesis and compilation of inputs from the team and are not intended to reflect a team consensus. Team members provided comments to the report content during drafting; they were also invited to provide their own independent inputs, but none did.

General Industry Observations

- The commercial semiconductor industry is fully globalized, with global sales and global supply chains. It consists of global corporations that provide products to global customers. Companies operate geographically distributed engineering and fabrication facilities, and they employ a globalized workforce. Aspects of this globalization of the workforce tend to prevent commercial semiconductor companies from easily implementing International Traffic in Arms Regulations (ITAR) or Trusted certifications. A high number of non-U.S. citizens work in U.S. design and manufacturing facilities, and commercial companies desire to make the most efficient use of global design and manufacturing resources.
- Currently, complementary metal-oxide-semiconductor (CMOS) fully scaled production below 65 nm is available only from companies serving commercial markets. Foundries offer client engagement opportunities for access to advanced semiconductor technologies at features less than 65 nm for custom ICs based on CMOS. Such access, however, is subject to the caveats detailed in this report.
- Consolidation is occurring across the industry, and this trend is likely to continue. It often involves purchases of U.S. companies by foreign entities, and such foreign ownership can terminate Trust accreditations issued by DoD.
- Building a leading-edge commercial fabrication facility for the next processing node will cost over $10 billion. Such a facility has a product service life of only about five years before depreciation and new capabilities that require a new manufacturing line render the facility obsolete for leading-edge manufacturing. Only a few commercial companies have sufficient resources to support this level of periodic investment.
- Integrated device manufacturers tend to focus their product strategies on market end-use application areas for which they are able to be in leadership positions. IDMs operate their own fabrication facilities and may have a good business that produces specialized parts in older technologies or targets markets that do not differentiate solely by transistor density, such as analog products, radio frequency (RF) components, and automotive control electronics. In addition, many IDMs also work with foundries for product manufacturing capacity to augment their own internal production and to provide access to deeply scaled technologies.
- Competitors in semiconductor foundry fabrication tend to focus on customers that need high volumes of a narrow set of devices. This business model maximizes efficiency, and leads to high manufacturing volumes and yields. Asian-based foundries dominate market share and manufacturing capacity, and they are highly regarded by commercial industry customers.

DoD-specific Observations

- Generally, commercial semiconductor companies are interested in serving U.S. Government and DoD needs, but they are reluctant to do so if it imposes significant burdens or restrictions on commercial activities, or requires oversight beyond the usual commercial sector requirements.
- Leveraging commercial capabilities would be efficient from the government's perspective, but the industry is very dynamic and conditions can change quickly and in unanticipated ways. This path will require DoD to be far more agile and flexible in their requirements and acquisitions related to semiconductors than they currently are.
- The number of IC devices that a typical DoD program needs is very small relative to the output capacity of any of today's state-of-the-art fabrication facilities. However, a wide range of technologies is being utilized and is needed. The industry increasingly focuses on high-volume commercial markets, especially at the leading edge of technology. Consolidation of legacy electronics components into systems-on-chip can be effective but requires access to advanced design and manufacturing.
- No single dedicated fabrication facility alone could meet all of DoD's needs given the breadth of technologies being used and the practical difficulties of transferring products and processes. The technologies not available from the dedicated facility would remain an issue.
- The fabrication infrastructure has optimized to support high-volume manufacturing. The costs of the required processing tools, facilities, and consumables do not scale linearly with capacity. From a purely economic perspective, this limits the savings that a dedicated low-volume facility could offer. The semiconductor learning curve also comes into play for leading-edge and specialty technologies. The breadth of technologies needed by defense programs is also a consideration for such a dedicated facility.
- Commercial and captive IC fabricators undertake substantial R&D activities to support new products and to preserve and expand business models. DoD can continue to leverage these efforts, but it will need to sponsor the development of any specialty capabilities for leading-edge technologies or elements that fall outside industry's scope. During site visits, industry expressed interests in nearly every technical topic related to R&D and acknowledged the importance of semiconductor R&D sponsored by DoD and other government agencies, but they did not believe that such sponsorship alone would be an effective lever for DoD to gain better access to manufacturing lines. Industry also expressed general interests in

R&D for IC security enhancements, provided the enhancements do not restrict their commercial businesses.

Industry's Overall Recommendations

IDA collected and summarized the industry's overall recommendations. The following high-level themes emerged from the team's interactions:

- The government should aggregate its IC needs as much as possible. This would mean coordinating procurements across the Services and programs. While difficult to implement, such a practice would allow the government to reach the volumes necessary to achieve some economies of scale.
- DoD should make use of commercial manufacturing process flows, and ideally look and act like a commercial customer. Some commercial companies are producing products for end-use sectors, such as automotive and financial, that have security and reliability concerns that align with similar concerns on DoD's part. Such mutual interests may offer a path for leveraging the government's investments with those of the industry. Industry suggested that DoD explore joint standards in areas of common interest like security.
- While industry has plans for large R&D outlays to support scaling, mainstream technology development, and product designs, DoD needs to be prepared to sponsor any R&D that falls outside of this scope. Specific manufacturing methods or technologies targeting DoD's unique future needs are not likely to be included in industry's plans. Industry suggested that if DoD better aligns its R&D efforts with commercial needs and directions, DoD is more likely to be successful at transitioning into manufacturing production.

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1. Statement of Problem

Global competitive factors are challenging U.S. leadership in advanced microelectronics technology and are affecting DoD's ability to maintain superiority.

Integrated circuits (IC) are critical to the performance of military systems. ICs represent the brains of smart weapons, they are the eyes and ears of the commander in the field, and they give our soldiers unprecedented warfighting capabilities. In recent conflicts, IC-enabled technology has allowed U.S. forces to engage opposing forces that outnumbered them on the battlefield, and to fight battles from a safe distance with remotely operated platforms or precision munitions. ICs are an important component of the technological superiority of our forces and systems.

U.S. scientists invented the transistor in 1947 and demonstrated the first IC in 1958. In the early years of the semiconductor industry, the 1960s and 1970s, the Department of Defense (DoD) was a major buyer of ICs. In the mid-1960s, DoD accounted for over 50% of the total market.[1] From its position in the marketplace, DoD could both steer the direction of technology evolution and command the attention and interest of IC suppliers.

Many domestic companies competed for DoD's business, and they offered many different technological approaches. DoD was willing to pay premium prices for early access to the nascent technology that allowed it to miniaturize and harden the electronics in its systems like the Minuteman II missile. Early IC producers leveraged this premium to maintain leadership in the market, and to push the frontiers of the underlying technology to drive integration and scaling.

Today, the situation is very different in the now global semiconductor industry. The semiconductor industry has grown to over $333 billion, partitioned along about a dozen distinct product segments, such as logic, memory, programmable logic devices, microprocessors, and analog, etc. In terms of market share, DoD systems and programs now account for a little less than 1% of the global industry output, and DoD no longer has the influence of a major customer. Demand for semiconductor components in communications, compu-

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1 John E. Tilton, *International Diffusion of Technology: The Case of Semiconductors,* The Brookings Institution, Washington DC, 1971, p. 91.

ting, automotive, industrial, and consumer markets accounts for most of the industry's output and commands most of its focus and attention. Commercial end-uses, in particular, are driving volume, especially at the leading edge of manufacturing technology.

The overall industry profile has changed as well. Companies have merged and/or changed business models, while the costs of competing at the leading edge have grown steadily. Fabless semiconductor companies and foundries have emerged to manage the cost of competing. Many of the semiconductor companies that supply components and technologies to DoD use internal manufacturing capabilities that are state-of-the-art for their product stream, but are trailing-edge from the commercial scaling perspective.

DoD has a community of microelectronics suppliers that are producing important products for defense applications, such as read-out circuits for focal plane arrays and radiation-hardened memories. They are doing this, however, with technologies that are no longer at the leading edge as measured by the feature size. Production with older process technologies can be a very profitable and good business for a company that services specialty niche markets. Volumes tend to decline, however, as technologies slip from the leading edge due to changes in market end-use, performance limitations of legacy technologies, competition from products based on newer technologies, and the economics of electronic product design and manufacturing.

A leading-edge fabrication facility is a major investment and undertaking for a company. To amortize the multi-billion dollar investment in a new fabrication facility, a leading-edge merchant commercial fabrication facility typically processes 30,000 to 60,000 or more 300 mm wafers per month. There are not many examples of leading-edge production fabrication facilities with smaller capacities, but several research facilities have leading-edge equipment and can process more modest wafer flows, albeit with unqualified process flows. The team visited one such facility, the Colleges of Nanoscale Science and Engineering (CNSE) in Albany, NY, to gain their perspectives. The magnitude of the investment, the scale of the market consumption, and need for geographic diversity to provide resilience against natural disasters provide a practical upper limit on fabrication facility capacity.

Leading-edge fabrication facilities are highly automated and have integrated control systems to maximize yield and to enhance intellectual property (IP) protection. Inside a facility, wafers move in 25-wafer batches housed in a sealed carrier called a front opening unified pod (FOUP). Depending on the specific die size, a single lot of wafers in one FOUP can produce a high number of ICs. As an example, a pod of 300 mm wafers produces about

100,000 4- by 4-mm die size ICs.[2] Relative to most DoD program-level needs, this represents a very large quantity of ICs.

The main problem is that processing low-volume lots in a high-volume facility can be disruptive and is generally not attractive to merchant commercial firms, especially at the leading edge of technology. Some equipment requires a setup with each change that reduces utilization at low volumes, and that tends to drive up the cost of ownership. Product variability is the enemy of efficient utilization, scheduling, and yield in a semiconductor manufacturing plant.[3] Therefore, fabrication facilities give the highest priority to customers who order large quantities of a single IC, and the facilities themselves tend to focus on a limited number of process technologies to maximize the likelihood of success.

Fabrication facilities find that supporting a low-volume customer can be costly in terms of the resources required. Leading-edge technology designs are very complex, and customers typically require significant engineering support and other resources from the foundry to ensure that the product is manufacturable and that the process yields devices with the expected performance and functions. The resources that a foundry has available, however, limit the number of customer designs that the foundry can support at any one time. Assigning a support team to a small volume customer limits the resources that a facility would have to support other, potentially more profitable, higher-volume customers.

In this context, DoD does not fit into the ideal commercially focused business model for most merchant fabrication facilities. DoD's long-term Trusted Foundry capacity reserve contract with IBM, which DoD novated to GLOBALFOUNDRIES, helped solve problems of access to advanced commercial technologies at low volumes. At the time of this report, extensions of trusted access to leading-edge technologies available in a commercial facility were in discussion but had not yet been formally established.

The multi-project wafer (MPW) is an access approach that aggregates multiple separate designs into a single unified, overall design. It overcomes some of the difficulties associated with low-volume production, but it also has its limitations. An MPW run partitions the available mask area into smaller regions and sets the available processes, design rules, and other parameters of a run. A foundry offers MPWs at its discretion and approves the users in advance. A broker service such as MOSIS often acts as a coordinator and manages the interactions between the facility and the MPW riders.

Customers specify the amount of mask area that their designs need and submit their design files. The MPW broker assigns the designs to an area on the mask and arranges for

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2 A. Mahindroo, D. Rosensweig, and B. Wiseman, "Will Analog be as Good Tomorrow as it was Yesterday?" *McKinsey on Semiconductors*, Autumn 2011, p. 53.

3 H. Bauer, I. Kouris, G. Schlogl, T. Sigrist, J. Veira, and D. Wee, "Mastering Variability in Complex Environments," *McKinsey on Semiconductors*, Autumn 2011, pp. 71–76.

fabrication at a foundry. The broker then receives the processed wafers, makes a series of saw cuts to singulate the individual projects, and allocates the die to the respective customers. In this way, many customers share the cost and output from a single run. DoD and the trusted foundry program have made good use of MPWs to provide efficient access to fabrication resources for prototyping and other purposes.

An MPW, however, limits the fabrication process options of each customer on a run since all customers must use the same process steps. This in turn, may limit the type of third-party blocks of proven design, known as silicon intellectual property (IP) that a customer can implement. The IP used must be compatible with the designated process steps. The process of aggregating multiple customers, nailing down all of the design rules, and checking and repairing any design issues introduces time delays and overhead. MPWs also can impose area limitations on individual circuit projects, the shape of a die, the packaging, and the total number of die returned.

At the time of this report, GLOBALFOUNDRIES was offering Trusted access to commercial technologies in their 200 mm fabrication facility in Burlington, Vermont, and their 300 mm facility in East Fishkill, New York. The 300 mm facility is the only Trusted facility for CMOS below 65 nm down to 32 nm. The rest of the DoD's cadre of Trusted semiconductor suppliers that offer dedicated access to their internal foundries use 200 mm, 150 mm, or smaller-sized wafer manufacturing platforms. They often support low-volume customers with Defense specialty needs that the merchant commercial companies with 300 mm manufacturing platforms and technologies cannot.

These foundries are state-of-the-art for their technologies, however, and can only process using trailing-edge technologies from feature size perspective. Some of these suppliers offer unique process technologies, such as silicon-germanium (SiGe), radiation hardened silicon, compound semiconductors like gallium arsenide (GaAs), indium phosphide (InP) or gallium nitride (GaN), as well as specialized assembly and packaging processes like those incorporating lead-containing solder bumps. The processes themselves may be state-of-the-art for the specific product, such as for read-out ICs, which use higher voltage transistors than those typically provided by leading-edge processes.

Other market dynamics have affected DoD's ability to obtain early access to leading-edge IC technology, especially for custom ICs. In the early years of the IC industry, during the 1960s and 1970s, U.S. companies fabricating devices in the United States dominated the competitive landscape. DoD maintained strong relationships with many of them and accessed their facilities for custom products.

In the 1980s, Japanese companies arose rapidly to capture market share. Their ascent threatened U.S. semiconductor leadership in many areas, ranging from materials and equipment to IC products. In the late 1980s, DoD co-funded SEMATECH, the industry consortium with 14 U.S. semiconductor member companies. SEMATECH's objective was to initiate and support major efforts that enhanced the competitiveness and quality of U.S. semiconductor manufacturing. SEMATECH often receives credit for helping U.S. semiconductor companies survive a difficult competitive environment.[4]

Today, U.S. semiconductor companies are still under intense global competitive pressure. U.S.-headquartered companies hold about half the world's market share in terms of semiconductor sales.[5] A significant number of U.S. companies, however, are fabless, and overseas foundries manufacture their products. Many U.S. companies have a significant manufacturing presence overseas through global partnerships and alliances. This, in turn, limits DoD's options in terms of a trusted supply.

Over the years, the latest advances in ICs have been a major source of technological superiority for U.S. weapons systems. To date, DoD has been able to meet its semiconductor technology needs, even in the changing global market environment. The situation for the future, however, is less clear. Increasingly, U.S. adversaries will have early access to, and will adopt advanced IC technology into their weapons systems. DoD will have to scramble to maintain technical superiority. The practices of some foreign nations of pursuing industrial policies that are altering the industrial and technological landscape will further complicate the situation.

There are real concerns over how the marketplace will evolve over the next 5 to 10 years. As leading-edge emerging technologies become available only from global suppliers, and those suppliers increasingly focus on commercial markets, where will DoD be able to gain access to and procure the IC technologies that it will need to maintain technological advantage? If globalization increases and the industry continues to grow in Asia, will globalized and perhaps foreign entities be willing to sell new technology to DoD? Will DoD be able to trust that the devices it receives are free from malicious elements? Does U.S. industry share any of these concerns, and are they working on their own strategies to address these issues? How will future mergers and acquisitions affect the industrial landscape and capabilities available to the DoD?

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[4] R. van Atta and M. M. G. Slusarczuk, "The Tunnel at the End of the Light – The Future of the U.S. Semiconductor Industry," *Issues in Science and Technology*, Spring 2012.

[5] Semiconductor Industry Association, "The U.S. Semiconductor Industry: 2015 Factbook" Section 1: Industry Overview, p. 3. http://www.semiconductors.org/clientuploads/Industry%20Statistics/2015%20Factbook/2015%20Factbook%20-%20Complete%20Updated%20-%2008062015.pdf

2. Approach

Assign a group of subject matter experts to explore the industry's perspective on the future and identify ways that DoD could collaborate with industry to maintain technological leadership for the foreseeable future.

The Institute for Defense Analyses (IDA) and others in the government community have studied and analyzed the issues that the changing structure of the semiconductor supply chain presents for DoD. These prior efforts, however, have not generally included visits to commercial semiconductor facilities and did not include a focused effort to gain industry's perspectives.

In particular, these studies did not solicit directly industry's perspective on how companies might be willing to work with the government to satisfy government needs for advanced semiconductor devices. This analysis, on the other hand, addresses the question, What should the government change in the way it deals with the industry so that it becomes a desired customer?

The office of Manufacturing and Industrial Base Policy (MIBP) formed and led a small government team that visited selected industrial semiconductor facilities. The team included representatives from MIBP, the National Reconnaissance Office (NRO), the National Security Agency (NSA), the Defense Micro-Electronic Activity (DMEA), IDA, and the Defense Contract Management Agency (DCMA). Appendix D provides the biographic summaries of the team participants.

IDA assisted in scheduling a series of visits to companies that the team agreed represented a cross-section of key commercial semiconductor manufacturers, in formulating key questions to guide the discussions, in leading the discussions, and finally, in summarizing and reducing these discussions to key recommendations. The companies visited included integrated device manufacturers (IDM), foundries, defense microelectronics companies, and a semiconductor mask maker.

The main objectives of the visits were to engage with representative members of the U.S. semiconductor industry, to assess the present state of the semiconductor industry in terms of its relationship with DoD, and to seek industry's recommendations on the directions DoD could take vis-a-vis the semiconductor supply chain. For completeness, the team also met with people involved in manufacturing research and development (R&D). The team sought to gain an understanding of the global commercial companies, their businesses, their outlooks on changing market conditions, and their roadmaps for future technology development. Very frank and open discussions characterized these meetings.

The team wanted to identify existing and new trends in the marketplace, and to understand how companies planned to address them through partnerships, acquisitions, and outsourcing. It sought to understand how the business climate affects business decisions and investments by the companies. At times, individual team members also had other interests that entered the discussions. This report provides background on the industry landscape and captures the team members' observations and discussions with industry.

Prior to each site visit, the team sent each company the same set of questions. The intent of these general questions was to help guide the overall discussions and not to serve as questions for an interview. Appendix B provides the questions that the team sent in advance. At the start of the visit, the team gave an informal presentation explaining the purpose of the visit. The questions and presentation guided the subsequent discussions.

Most importantly, during the site visits, the team focused on directing discussions toward concerns that are specific to DoD as a customer. Topics included the issue of how DoD could obtain access to state-of-the-art capabilities even though it only needs small volumes of any given IC, and, How could DoD assess and achieve trustworthiness in a globally distributed supply chain?

The team also solicited input on how DoD and the U.S. Government should address the realities of program budgeting and regulations. The team sought input on how to address the constraints imposed by long system-acquisition cycles, Federal policies, and DoD's need for a very wide range of technologies, from legacy and specialty to leading-edge. It also solicited industry's input on specific policies affecting the industry, such as those involving International Traffic in Arms Regulations (ITAR) and the Export Administration Regulations (EAR), as well as more general issues like maintaining competitiveness in a global marketplace. The team listened to industry's responses to gather and identify ideas on how DoD could meet its particular needs and become a "good customer."

3. Observations of Industry

A. Semiconductor Industry

As noted earlier, the semiconductor industry today is global, with global sales and global supply chains. The industry consists of global corporations that provide products to global customers. As global corporations, these companies operate geographically distributed fabrication facilities and attract workforce talent globally.

Currently, CMOS production below the 65 nm node is available only from commercial companies; there are no captive DoD capabilities at this technology level. Scaling has been a technology driver for CMOS production, consistently providing more transistors per IC with better performance. This section addresses the consequences of scaling on manufacturers and the associated industry restructuring.

In the current industry structure, there are IDMs who design and fabricate their own products, there are foundries who perform contract fabrication for others, and there are fabless companies that only design ICs and then contract with foundries for fabrication services. Some IDMs have their own manufacturing facilities but opt to supplement their production with foundries, and some IDMs also offer foundry services. Those companies that have chosen not to own and operate their own fabrication facility are generally comfortable with using foundries to build products for them at advanced nodes, even if the foundries are located outside of the United States.

Commercial companies are generally interested in serving U.S. Government and DoD needs, but they are reluctant to do so if becoming involved with government customers would impose burdens and oversight beyond what the commercial sector typically experiences. Their view is that complying with government audit or employee citizenship requirements would impose unacceptable burdens and lost opportunity costs. Many of these companies already have a multinational workforce, and some have global manufacturing resources that complicate meeting International Traffic in Arms Regulations (ITAR) requirements or the Trusted certifications needed for some government programs.

While leveraging commercial capabilities would be efficient from the government's perspective, the government needs to recognize that the industry is very dynamic and conditions can change quickly and in unanticipated ways. The current wave of mergers and acquisitions can change an entity's willingness or ability to engage with the government—virtually overnight. The new partner may be a foreign entity, which can create complications vis-à-vis providing certain types of services for the government. All these changes will require DoD to be far more agile and flexible in its requirements for and acquisitions of semiconductors than it currently is.

As a customer, DoD uses many different types of ICs, based on a variety of technologies and materials, designed to meet specific system requirements. This analysis and prior work done by IDA confirmed that, as a practical matter, no single fabrication facility would be capable of supplying all of the types of ICs, based on the various technologies, that DoD currently needs. Furthermore, a single source of all semiconductors would make DoD highly vulnerable to natural or man-made disasters. DoD needs to continue buying its ICs from multiple suppliers.

B. Costs of Staying Commercially Competitive

Building a leading-edge high-volume manufacturing facility for CMOS production can cost $10 to $14 billion. In addition to the cost of building and equipping the physical plant, operating and maintaining the facility and developing the processes needed to fabricate devices at advanced nodes can add an additional several billion dollars to the cost. Historically, such a facility has a practical service life of only about five years before the technology is no longer at the commercial state of the art and a company needs to replace it with a new facility.

Semiconductor fabrication is a series of photolithographic, chemical, and thermal processing steps in which patterns are transferred onto a wafer to define regions where materials are deposited, etched away, and implanted into multiple times. Photomasks contain the individual pattern information for each layer and are themselves critical and expensive components to produce. Photomasks are dedicated to a product. Processing cycle times are generally proprietary, but typically, the time from start to finish of a wafer ranges from 6 to 12 weeks. The statistical process controls employed throughout the industry mandate that a leading-edge facility operate virtually continuously, and with high throughput. Such throughput is necessary to maintain the manufacturing processes within the limits of statistical process control and to generate the production cycles to advance along the learning curve.

Maintaining process control is critical for yield. The fabrication process consists of hundreds of process steps, and each one must yield over 99.9% to yield enough working finished ICs. The inability to directly measure important device parameters makes process control a complex undertaking. Determining the root causes of yield loss is major team effort within a fabrication facility. Yield enhancement drives design decisions and process tuning, involving multiple trade-offs and interdependencies.

The steep learning curve of semiconductor processing drives the industry to focus on producing higher-volume products. Semiconductor fabricators typically place a priority on customers that need high volumes of a narrow set of devices. This ensures that the facility operates at maximum efficiency, and has the highest yields that drive the maximum knowledge capture of the process.

As a result, the industry increasingly focuses on high-volume commercial markets, especially at the leading edge of technology. The number of IC devices that a typical DoD program needs, however, is very small relative to the output that a state-of-the-art fabrication facility can produce. The low volumes preclude DoD from being priority customer.

C. Commercial Industry Recommendations for U.S. Government Small Volume Access

Several of the experts and companies interviewed suggested that the government would be in a better position if it could aggregate its volume. If government organizations would aggregate their IC needs upfront to the fullest extent possible, they would find the commercial industry more amenable to taking them on as a customer. Others have suggested aggregation in the past, but DoD customers have been unwilling or unable to transition their IC requirements into a new design or process, or agree on a common IC technology.

Aggregation will likely be possible only if DoD implements a requirement for all users to use the minimum number of facilities possible. However, a single facility could not meet all of DoD's requirements because of the system-level needs for diverse semiconductor technologies. These include substrates, i.e., bulk silicon versus silicon on insulator (SOI) versus compound semiconductors; operation in a terrestrial environment versus space or high radiation; and the need for different process streams, i.e., complementary metal-oxide-semiconductor (CMOS) for digital circuits versus the bipolar implementations for radio frequency analog/mixed signal circuits that some DoD systems need. Accomplishing such aggregation would require coordinating procurements across the Services and programs. Such a practice would be difficult to implement and would introduce a host of limitations for some programs, but it would allow government purchases to approach the volumes necessary to achieve economies of scale.

Another suggestion, cited by several companies and experts, was for the government to use commercial technologies and not request special dispensations. DoD should make use of commercial manufacturing process flows, and ideally look and act like a commercial customer. Some commercial companies are producing products for end-use sectors, such as automotive and financial, which have security and reliability concerns that align with similar concerns on DoD's part. Such mutual interests may offer a path for leveraging the government's investment. Industry suggested that DoD explore joint standards in areas of common interest like security.

Industry suggested that the industrial best practices for IP protection might actually be sufficient to meet DoD security needs for most situations. In some cases, however, these practices would require programs to make trade-offs of potential security risks for technology access.

R&D was an active discussion topic during team visits. The semiconductor industry is unique relative to other industries with respect to the large fraction of revenue that it devotes to R&D. The people and companies that the team met cautioned that most of the industry effort goes toward supporting product development and mainstream advancements and improvements of the base process technology. As an example, manufacturing methods or technologies aimed at specialized defense objectives such as low-volume production using unique patterning approaches are not likely to be directly included in industry's mainstream manufacturing R&D plans.

The people whom the team met did not give direct guidance on specific technologies but gave a basic recommendation that external R&D efforts that are aligned with commercial needs and directions are more likely to be successful in the transition into industry, and to end up in production. There were individual interests in all of the R&D topics that came up, including multi-beam lithography, design for security, and software-defined circuits. The main caution was that a critical mass of volume and applicability was likely required for a technology to transition to the production floor, and that R&D engagements will not necessarily ease DoD access to manufacturing lines.

4. Important Aspects of the Semiconductor Industry for DoD

A. Economies of Scale Drive Advanced Semiconductors

The cost of the manufacturing facility, its productivity, and lifetime are key factors underlying the industry's economics. Just a decade ago, an advanced semiconductor fabrication facility cost about $2 to $3 billion. Today, that number has grown significantly. In May 2015, Samsung announcing that it was breaking ground on a facility that will cost $14 billion.[6] Figure 4-1 shows the trend of fabrication facility costs. These facilities are often only useful for five to seven years before newer technologies completely overtake them. This means that the facility must pay for itself over that relatively short length of time.

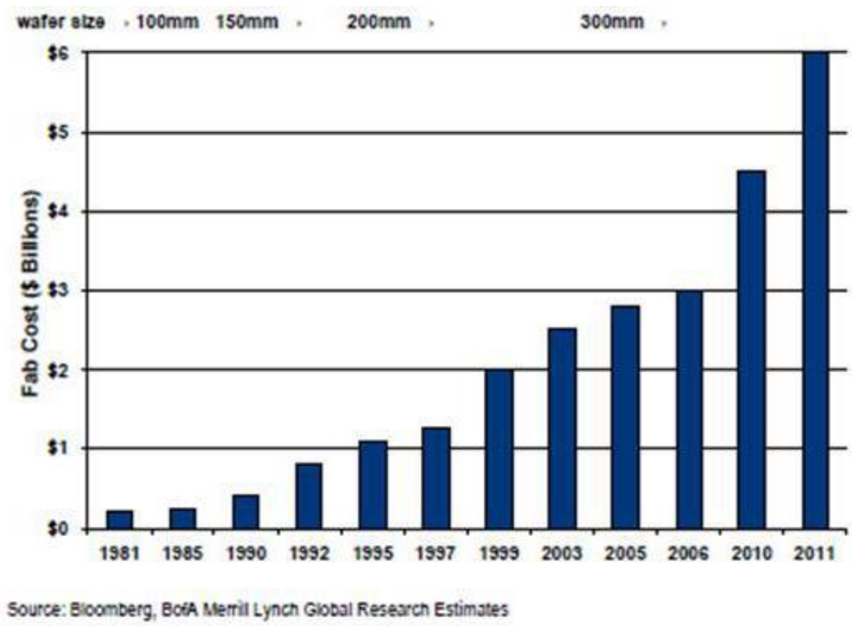

Figure 4-1. Cost of a new fabrication facility[7]

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6 R. Colin Johnson, "Samsung Breaks Ground on $14 Billion Fab," *EE Times*, May 8, 2015. http://www.eetimes.com/document.asp?doc_id=1326565

7 Michael Fu, "Intel: The Other Side Of The Coin," Mar. 25, 2013, Seeking Alpha. http://seekingalpha.com/article/1297851-intel-the-other-side-of-the-coin

The long-term trend in the industry is that capital spending as a percentage of sales has declined to about 18%. According to this model, it would take more than $11 billion per year in revenue from ICs to justify the high capital investment needed for a facility. Clearly, the magnitude of the investment to open a leading-edge fabrication facility means that only the companies that can produce high volumes of products, sold at the right price, can economically justify the investment in the most advanced semiconductor fabrication facilities. As Table 4-1 shows, only one foundry, Taiwan Semiconductor Manufacturing Company (TSMC), has the revenue to justify the required investment in a next-generation facility. Certainly, investor funds or revenues from other business areas can also provide the revenue offset needed.

Table 4-1. Top 15 foundries by revenue[8]

Rank	Company & Subsidiary	Foundry Type	Headquarters	Revenue (million $USD)	Max capacity (300 mm wspm)	Max capacity (200 mm wspm)
1	TSMC	Pure-Play	Taiwan	19,850	782,417	493,267
2	GlobalFoundries	Pure-Play	U.S.	4,261	223,333	214,000
3	UMC	Pure-Play	Taiwan	3,959	180,000	282,000
4	Samsung Semi.	IDM	S. Korea	3,950	307,000	90,000
5	SMIC	Pure-Play	China	1,973	147,000	165,000
6	Powerchip	IDM	Taiwan	1,175	90,000	N/A
7	Vanguard (VIS)	Pure-Play	Taiwan	713	N/A	135,000
8	Huahong Grace	Pure-Play	China	710	N/A	168,000
9	Dongbu HiTek	Pure-Play	S. Korea	570	N/A	94,000
10	TowerJazz	Pure-Play	Israel	509	N/A	109,000
11	IBM	IDM	U.S.	485	30,000	35,000
12	MagnaChip	IDM	S. Korea	411	N/A	151,000
13	Win Semi.	Pure-Play	Taiwan	354	N/A	50,000 (150mm)
14	Shanghai Belling	IDM	China	Unknown	N/A	75,000
15	XMC	Pure-Play	China	Unknown	60,000	N/A

The ultimate in semiconductor economy of scale is high-volume manufacturing of a single circuit design using a single process. In this case, the recurring expenses (RE) of the manufacturing production line tend to dominate, and factors like yield and line productivity are critical. Companies offer many, but not all, products manufactured in high volume for purchase as individual components.

The story, however, changes with smaller runs of products. For low-volume runs, the non-recurring expenses (NRE) associated with each product and its run can be a significant factor in determining the final product cost. NRE costs include things like design, masks, and yield ramp-up. Figure 4-2 shows that the NRE costs of new product at 32 nm can be

8 Table created by IDA using data from Semico, Semiconductor Industry Association (SIA), corporate financial filings, and other publically available information.

as much as $100 million. More advanced nodes carry an even higher NRE. The final IC production cost is the sum of the NRE and RE, making it straightforward to calculate whether a commercial IC will be viable at a given volume of production.

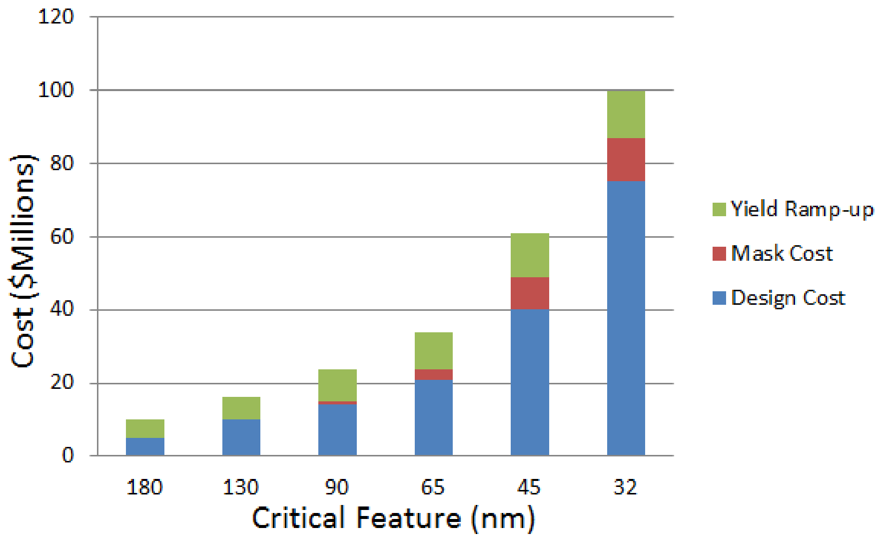

Figure 4-2. The NRE cost by advanced node[9]

B. Fabrication Facility Source Options by Technology Node (130 nm and below)

The semiconductor industry's annual revenue growth since the year 2000 has been a relatively small 5% per year as compared with the 1980s, when the growth was 22%. As the scaling continued with shrinking transistor size, the cost of design, masks, packaging, and test has escalated. These changes have resulted in severe economic pressure on companies trying to remain profitable.

The first result of this pressure is that fewer and fewer companies can make a viable business case for spending the capital needed to compete at the most advanced nodes. This started to have a dramatic effect on the industry at 90 nm, the point at which many companies' available markets could not support the available facility output. Industry analysts predict that at the 14–16 nm node, only four to five companies will produce ICs. Figure 4-3 shows a snapshot of how this consolidation and movement to the foundry model has affected the industry.

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9 Ilkka Tuomi, "The Future of Semiconductor Intellectual Property Architectural Blocks in Europe," European Commission, Joint Research Centre, Institute for Prospective Technological Studies, EUR 23962 EN, 2009, p. 75. http://ftp.jrc.es/EURdoc/JRC52422.pdf

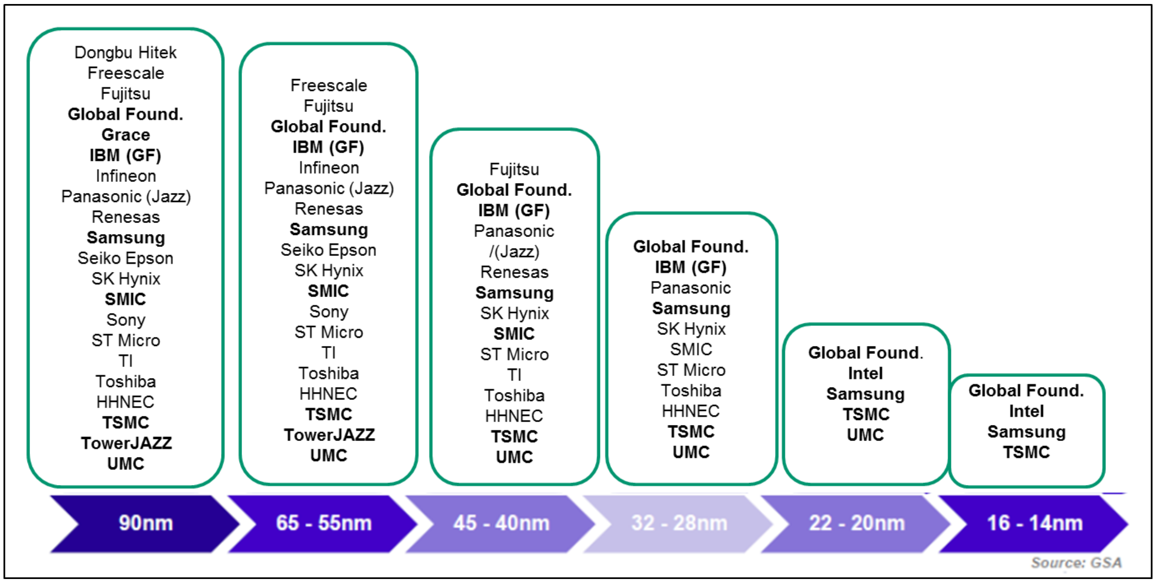

Figure 4-3. Fabrication facility source options by technology node (bold lettering indicates foundries)[10]

Such a chart represents only a snapshot in time, in this case October 2014. Some companies that currently compete at, for example, 45 or 32 nm may choose at some later time to either consolidate or exit the semiconductor manufacturing business and become fabless. Their current willingness to compete at a particular node does not automatically imply future availability of that capability.

Companies that do not invest to keep up in the competitive business of advanced semiconductor manufacturing do one or more of the following things. They merge with or acquire other companies, they reorganize to follow a fabless model,[11] or they try to survive with products using the less-demanding, trailing-edge technologies that are fully amortized and well characterized. Some companies have been quite successful at carving out market niches without pursuing scaling. Trailing-edge processing technologies are fully adequate for some market segments, such as analog ICs and microwave ICs based on gallium arsenide.

Companies merge and acquire other companies to increase their available market size and gain in efficiency. In 2015, the semiconductor industry saw unprecedented worldwide merger and acquisition volume, more than $125 billion. Much of this acquisition came

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[10] Figure derived from slide by the Global Semiconductor Alliance (GSA).

[11] For example, in 2009, Advanced Micro Devices (AMD) divested its manufacturing arm to form GLOBALFOUNDRIES. AMD then became a fabless supplier while GLOBALFOUNDRIES went on to expand through the acquisition of Chartered Semiconductor in 2010. It further expanded through the acquisition of IBM Microelectronics in 2015.

from entities in China, which is trying to expand its presence in the semiconductor industry. This consolidation is a strategy to gain technologies, increase scale, leverage R&D, and become more competitive.[12]

[12] For a good presentation on the topic, see, W. Rhines, "Merger Mania," Mentor Graphics User2User Conference, Santa Clara, CA, April 26, 2016. https://supportnet.mentor.com/files/u2u/sc-2016/AM%20Keynote_Rhines_U2U%20Keynote%20W%20Rhines%202016%20FINAL.pdf (Registration required for access)

5. Summary

Semiconductor integrated circuits are critical to the performance of military systems and commercial consumer electronic equipment. In the early years of the industry, DoD was a major early adopter. U.S. companies competed fiercely to advance and dominate the technology. A very capable domestic industrial base, with leading-edge technologies was resident in both defense prime contractors and among the merchant industry serving dual-use markets. Both served DoD's needs well at the time.

For many years, DoD was a major customer. Over the years, however, commercial demands have grown to dominate the industry's focus and dedication of its resources. DoD's share of the market is now less than 1%. This has diminished DoD's ability to influence the industry and to gain access to leading-edge technologies and related services. The semiconductor industry has evolved, in the process specializing and globalizing. Globalization has led to a new industrial landscape, with new relationships.

Federal procurement policies, the realities of program budgeting, and regulations such as ITAR and EAR also complicate DoD's access to commercial technologies. The long system acquisition cycles, Federal policies, and DoD's need for a very wide range of technologies that range from legacy and specialty to leading-edge, impose significant constraints on the available industrial base for IC technology.

MIBP formed and led a small government team that visited selected industrial facilities involved in semiconductor manufacturing and related businesses. The team sought industry's knowledge, experience, and outlook on the high-level problem of the global competitive factors challenging U.S. leadership in advanced microelectronics technology and their effect on DoD's ability to maintain weapon system superiority.

The team met with individuals involved in manufacturing and production to gain their perspectives on the technical and business matters related to semiconductors for DoD applications. IDA assisted in scheduling the visits to companies, formulating key questions to guide the discussions, leading the discussions, summarizing the discussions, and reducing industry's inputs to key recommendations. This report provides a general description of the industrial landscape, the details of each visit and meeting, a summary of the team's observations, and a synopsis of overall industry recommendations.

The specific inputs and recommendations from the meeting participants were very valuable and gave the team a good perspective on the industry landscape and competitive forces. These are important considerations for DoD as it develops a broader microelectronics strategy. The government will need to reassess the situation continuously because the industrial landscape is highly dynamic and will continue to change in the future.

A. Key Observations

IDA collected and summarized the team's observations. These observations, and the recommendations that follow, are a compilation of inputs from the team and not intended to reflect a team consensus.

1. General industry observations

- The commercial semiconductor industry is fully globalized, with global sales and global supply chains. It consists of global corporations that provide products to global customers. Companies operate geographically distributed engineering and fabrication facilities, and they employ a globalized workforce. Aspects of this globalization of the workforce tend to prevent commercial semiconductor companies from easily implementing ITAR or Trusted certifications. A high number of non-U.S. citizens work in U.S. design and manufacturing facilities, and commercial companies desire to make the most efficient use of global design and manufacturing resources.
- Currently, complementary metal-oxide-semiconductor (CMOS) fully scaled production below 65 nm is available only from companies serving commercial markets. Foundries offer client engagement opportunities for access to advanced semiconductor technologies at features less than 65 nm for custom ICs based on CMOS. Such access, however, is subject to the caveats detailed in this report.
- Consolidation is occurring across the industry, and this trend is likely to continue. It often involves purchases of U.S. companies by foreign entities, and such foreign ownership can terminate Trust accreditations issued by the DoD.
- Building a leading-edge commercial fabrication facility for the next processing node will cost over $10 billion. Such a facility has a product service life of only about five years before depreciation, and new capabilities that require a new manufacturing line render it obsolete for leading-edge manufacturing. Only a few commercial companies have sufficient resources to support this level of periodic investment.
- Integrated device manufacturers tend to focus their product strategies on market end-use application areas for which they are able to be in leadership positions. IDMs operate their own fabrication facilities and may have a good business producing specialized parts in older technologies or targeting markets that do not differentiate solely by transistor density, such as analog products, RF components,

and automotive control electronics. In addition, many IDMs also work with foundries for product manufacturing capacity to augment their own internal production, and to provide access to deeply scaled technologies.

- Competitors in semiconductor foundry fabrication tend to focus on customers that need high volumes of a narrow set of devices. This business model maximizes efficiency, and leads to high manufacturing volumes and yields. Asian-based foundries dominate in terms of market share and manufacturing capacity, and they are highly regarded by commercial industry customers.

2. DoD-specific observations

- Commercial semiconductor companies are generally interested in serving U.S. Government and DoD needs, but are reluctant to do so if becoming involved with government customers would impose significant burdens or restrictions on commercial activities, or require oversight beyond the usual commercial sector requirements.
- Leveraging commercial capabilities would be efficient from the government's perspective, but the industry is very dynamic and conditions can change quickly and in unanticipated ways. This path will require DoD to be far more agile and flexible in their requirements and acquisitions related to semiconductors than they currently are.
- The number of IC devices that a typical DoD program needs is very small relative to the output capacity of any of today's state-of-the-art fabrication facilities. However, a wide range of technologies is being utilized and is needed. The industry increasingly focuses on high-volume commercial markets, especially at the leading edge of technology. Consolidation of legacy electronics components into systems-on-chip can be effective but requires access to advanced design and manufacturing.
- No single dedicated fabrication facility alone could meet all of the DoD's needs given the breadth of technologies being utilized and the practical difficulties of transferring products and processes. The technologies not available from the dedicated facility would remain an issue.
- The infrastructure has optimized to support high-volume manufacturing. The cost of the required processing tools, facilities, and consumables does not scale linearly with capacity. From a purely economic perspective, this limits the savings that a dedicated low-volume facility could offer. The semiconductor learning curve also comes into play for leading-edge and specialty technologies. The breadth of technologies needed by defense programs is also a consideration for such a dedicated facility.

- Commercial and captive IC fabricators undertake substantial R&D activities to support new products and to preserve and expand business models. DoD can continue to leverage these efforts, but it will need to sponsor the development of any specialty capabilities for leading-edge technologies or elements that fall outside industry's scope. During site visits, industry expressed in nearly every technical topic related to R&D, and the industry acknowledged the importance of semiconductor R&D sponsored by DoD and other Government agencies, but they did not believe that such sponsorship alone would be an effective lever for DoD to gain better access to manufacturing lines. Industry had general interests in R&D for IC security enhancements, provided they do not bring restrictions on their commercial businesses.

B. Industry's Overall Recommendations

IDA collected and summarized the industry's overall recommendations. During the visits and interactions, some companies provided the team with recommendations on very specific items like processes or capabilities that government investment could advance. The following high-level themes emerged from the team's interactions:

- The government should aggregate its IC needs as much as possible. This would mean coordinating procurements across the Services and programs. While difficult to implement, such a practice would allow the government to reach the volumes necessary to achieve some economies of scale.
- DoD should make use of commercial manufacturing process flows, and ideally look and act like a commercial customer. Some commercial companies are producing products for end-use sectors, such as automotive and financial, that have security and reliability concerns that align with similar concerns on DoD's part. Such mutual interests may offer a path for leverage. Industry suggested that DoD explore joint standards in areas of common interest like security.
- While industry has plans for large R&D outlays to support scaling, mainstream technology development, and product designs, DoD needs to be prepared to sponsor any R&D that falls outside of this scope. Specific manufacturing methods or technologies targeting DoD's unique future needs are not likely to be included in industry's plans. Industry suggested that if DoD better aligns its R&D efforts with commercial needs and directions, DoD is more likely to be successful at transitioning into manufacturing production.

Appendix A
Acronyms and Abbreviations

AMD	Advanced Micro Devices
BS	Bachelor of Science
C4ISR	Command, Control, Communications, Computer, Intelligence, Surveillance, and Reconnaissance
CEO	Chief Executive Officer
CMOS	Complementary Metal-Oxide-Semiconductor
CNSE	Colleges of Nanoscale Science and Engineering
CTO	Chief Technology Officer
D	Dimension
DARPA	Defense Advanced Research Projects Agency
DCMA	Defense Contract Management Agency
DMEA	Defense Micro-Electronic Activity
DMSMS	Diminishing Manufacturing Sources and Material Shortages
DoD	Department of Defense
DTRA	Defense Threat Reduction Agency
DTSA	Defense Technology Security Administration
EAR	Export Administration Regulations
EBDW	Electron Beam Direct Write
FOUP	Front Opening Unified Pod
GaAs	Gallium Arsenide
GaN	Gallium Nitride
HEOMD	Human Exploration and Operations Mission Directorate
IARPA	Intelligence Advanced Research Program Activity
IB/SCM	Industrial Base and Supply Chain Management
IC	Integrated Circuit
IDA	Institute for Defense Analyses
IDM	Integrated Device Manufacturer
IEEE	Institute of Electrical and Electronics Engineers
InP	Indium Phosphide
IP	Intellectual Property
IT	Information Technology
ITAR	International Traffic in Arms Regulations
ITRS	International Technology Roadmap for Semiconductors
JV	Joint Venture

MBA	Masters of Business Administration
MIBP	Manufacturing and Industrial Base Policy
MPW	Multi-Project Wafer
MS	Master of Science
NASA	National Aeronautics and Space Administration
NIST	National Institute of Standards and Technology
NRE	Non-Recurring Expense
NRO	National Reconnaissance Office
NSA	National Security Agency
R&D	Research and Development
RE	Recurring Expenses
RF	Radio Frequency
SIA	Semiconductor Industry Association
SiGe	Silicon Germanium
SMC	Space and Missile Command
SME	Subject Matter Expert
SOA	State-of-the-Art
SOI	Silicon-On-Insulator
TAPO	Trusted Access Program Office
TSMC	Taiwan Semiconductor Manufacturing Company
UCLA	University of California at Los Angeles

Appendix B
Questions Sent to Companies Before Meetings

1. What do you think your company will look like in 2020?
   - Will you align with the International Technology Roadmap for Semiconductors (ITRS)[13]?
   - If not, what is your technology plan?
2. Will you be doing your own research and development?
   - If not, will you be using foundry development or be participating in a joint venture (JV)?
3. Where will your next generation fab facility be located?
   - If not announced, what regions are you considering?
   - What are the driving factors behind the decision?
4. What is the best model to insure survival in this age of manufacturing consolidation?
   - Fabless, fab-lite, vertical integration, other?
5. What will the microelectronics industry in the U.S. look like in 2020 and after?
6. Will the U.S. continue to lead in microelectronics technology?
   - By what definition?
   - Market share?
   - Percent of leading edge manufacturing onshore?
7. What factors would foster an economic climate in this country where a healthy leading edge semiconductor manufacturing industry can thrive?

What business model would you recommend that the government pursue with industry to maintain a strong domestic technology base?

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[13] The ITRS represents an industry wide effort to project technology requirements needed to maintain the continued capability to maximize the number of transistors and their performance at the wafer level. See http://www.itrs2.net/.

Appendix C
Team Biographies

A. Ms. Melinda K. Woods

Ms. Melinda K. Woods is Assistant Director of Strategic Programs for the Deputy Assistant Secretary of Defense for Manufacturing and Industrial Base Policy (MIBP) in the Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics. She serves as focal point for MIBP-wide technical engagements and strategic projects. Prior to January 2015, Ms. Woods managed the MIBP action officer team conducting DoD reviews of foreign investments for the Committee on Foreign Investment in the United States (CFIUS). Previously, Ms. Woods served as technical advisor on export licenses for electronics and information technology at the Defense Technology Security Administration (DTSA). Before joining DTSA, Ms. Woods worked as a Defense Intelligence Agency intelligence officer. Ms. Woods worked for Freescale Semiconductor as a Product Manager. She also worked in R&D, reliability and quality, design verification, and packaging. Ms. Woods received a Bachelor of Science (BS) and a Master of Science (MS) in Electrical Engineering from the University of Michigan and Georgia Institute of Technology respectively.

B. Mr. Ted Bujewski

Mr. Ted Bujewski is Senior Staff, Global Security of Supply Office of the Deputy Assistant Secretary of Defense for Manufacturing and Industrial Base Policy (MIBP). His responsibilities focus on ensuring the security of the supply of industrial resources to meet national defense requirements in a national emergency. He is also the MIBP lead and subject matter expert (SME) for Diminishing Manufacturing Sources and Material Shortages (DMSMS), cybersecurity, counterfeit parts, trusted suppliers, critical infrastructure, software assurance, telecommunications, and information technology. Previously, Mr. Bujewski was Chief, Industrial Base and Supply Chain Management (IB/SCM), for the Human Exploration and Operations Mission Directorate (HEOMD) at the National Aeronautics and Space Administration (NASA). Before NASA, he was a senior advisor with The Aerospace Corporation and was a sales executive with Lucent Technologies. Mr. Bujewski holds a Masters of Business Administration (MBA) from the University of Chicago, an MS in Computer Science from the University of California at Los Angeles (UCLA), and an MS in Operations Research and a BS in Applied Mathematics from Case Western Reserve University.

C. Mr. Lewis Cohn

Mr. Lewis Cohn is Chief, Advanced Space Vehicles Division of the Advanced Systems & Technology Directorate of the NRO, whose mission is to develop, demonstrate, and transfer advanced microelectronics technologies to flight systems. His current focus is on the adaptation of nano-scale microelectronics ($\leq$ 45 nm CMOS), including intellectual property, for space systems applications. His involvement also includes investigation and exploitation of advanced microelectronics, e.g., carbon nano-tube electronics, non-volatile memory technologies, low voltage power converters, and other state-of-the-art (SOA) microelectronics technologies.

D. Mr. Brian Hagerty

Mr. Brian Hagerty is a Systems Engineering and Technical Advisor for the Office of Secretary of Defense, Title III office, Defense Threat Reduction Agency (DTRA), and the Space and Missile Command (E). His role is to assist in evaluating the business models and technical merits of new Title III electronics opportunities, facilitating new manufacturing approaches, such as electron beam direct write (EBDW), providing assistance in maintaining the Domestic Microelectronics Industrial Base (including access), and assisting in the development, manufacturing, and qualification of state-of-art radiation-hardened microelectronics.

E. Ms. Mona Massuda

Ms. Mona Massuda is the Technical Director for National Security Agency's Trusted Access Project Office (TAPO). As the Technical Director, she is interested in better understanding the current microelectronics industrial base in terms of its capabilities and technology roadmaps. Her objectives are to better inform and guide TAPO's customers to meet their mission requirements. She has both government and industry work experience, including being a process engineer in a cleanroom fabrication facility, and conducting R&D in the fields of anti-tamper/protective technologies, electrostrictive/piezoelectric ceramics, and liquid-crystal polymers. Ms. Massuda has a BS in Chemistry, with an emphasis in organic chemistry, from Loyola College.

F. Mr. David Pentrack

Mr. David Pentrack is the program manager of the Trusted Foundry, and Chief of the Systems Assurance and Security Division at the Defense Microelectronics Activity (DMEA). He previously led efforts at DMEA to develop the Trusted Supplier accreditation criteria and to stand up the DoD Trusted Supplier Accreditation Program. He has over 25 years of experience at DMEA and its predecessor, the Air Force Engineering Division of the Sacramento Air Logistics Center, inserting advanced technology into DoD weapon systems and leading a variety of efforts in the area of mission assurance. He received his BS in Electronic Engineering from the California Polytechnic State University, San Luis Obispo in 1989.

G. Dr. Daniel Radack

Dr. Daniel Radack is Assistant Director in the Information Technology and Systems Division at the Institute for Defense Analyses, where he seeks solutions to hard problems related to microelectronics for the U.S. Government. He was previously with the Defense Advanced Research Projects Agency (DARPA), where he spent over eight years managing a portfolio of high-risk, high-payoff R&D programs to advance semiconductor technologies for defense and dual-use applications. His programs advanced the state of art of SiGe, Silicon-on-Insulator, design, packaging, heterogeneous integration/3D integration, and SEMATECH. Before that, he worked in the defense electronics industry and for the National Institute of Standards and Technology (NIST), where he studied dynamic test circuits and semiconductor metrology. He has a BS, MS, and Doctor of Philosophy (Ph.D.) in Electrical Engineering from the University of Maryland. Dr. Radack is a Fellow of the Institute of Electrical and Electronics Engineers (IEEE).

H. Mr. Bob Severance

Mr. Bob Severance is an Industrial Engineer with the Defense Contract Management Agency (DCMA) Industrial Analysis Center and is assigned to the Command, Control, Communications, Computer, Intelligence, Surveillance, and Reconnaissance (C4ISR) and Commodities Group as the lead analyst for the microelectronics industry. He focuses on enhancing the resiliency of the defense industrial base supply chain through risk identification and mitigation. Mr. Severance served as an aircraft maintenance officer in the United States Air Force. He re-entered government service after 18 years with Ford Electronics/Visteon Automotive Systems, where he was a manufacturing and industrial engineer. Mr. Severance has experience in facility operations and Lean Six Sigma, as well as manufacturing and process improvement. Mr. Severance is a graduate of the United States Air Force Academy.

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14. ABSTRACT

The evolution of the global markets that produce and consume microelectronic is producing rapid changes that are rippling through the industry. These changes are affecting the long-term interests of the DoD. In particular, the leading-edge of microelectronics and microsystems technology is driven by large commercial market interests and not DoD needs. This marked shift is affecting the DoD, creating a range of positive and negative consequences. This project focused on assisting DoD in developing an understanding of defense needs for microelectronics and the industrial base that can meet these needs. This was accomplished through a series of meetings with key people within the defense contractor and the U.S. and global commercial microelectronics industry base, in which the IDA team exchanged technical insights and identified the major trends in evolving technologies and business models and relationships. Engaging with representative companies and organizations involved in microelectronics industry is a basis for developing a better understanding of the overall semiconductor business and technical landscape in areas of importance to DoD.

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