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Executive Summary

The long-term strategic impact from future supply chain disruptions, including the potential inability of the U.S. to produce leading-edge[1] integrated circuits (ICs) domestically, is a critical risk. This, coupled with the fact that demand for production is outpacing current manufacturing capacity, will have long-term consequences for the Department of Defense (DoD), Department of Energy, Department of Homeland Security, and the National Intelligence communities when ensuring national security objectives are achievable.

Integrated circuits (ICs) are a fundamental, foundational element of electronics in components and systems. For the U.S. Army specifically, ICs are critical in weapon systems, core business systems, key communications systems, and artificial intelligence (AI) computational systems. Once a global leader, the United States finds itself in a position of decreasing control and influence in the leading-edge IC markets, a critical segment for enabling U.S. dominance. The lack of technical advancement from trusted foundry participants, strategic and production defects by U.S. companies, prohibitive capital expenditure required to join the market, and foreign state-subsidized competitors have all contributed to limiting trusted supply options for the U.S. Army and other U.S. government entities. This quick look report details the impacts facing the Army strategically in this competitive market.

DoD defines leading-edge chips as those at 7nm and below.[2] Semiconductors and ICs are a critical supply item for DoD systems. These components are the backbone of electronic-based functions in application-specific processes, computing memory, timing, and more. In the past, DoD stood up many programs to ensure trust in these critical components, but such an approach is increasingly difficult to sustain. DoD is a relatively minor consumer with respect to the total number of ICs being developed worldwide. One study identified the DoD as having less than 1% of the market share.[3] Although the United States is still a leader in the design of ICs, it is facing a diminished role in manufacturing, accounting for only 12%[4] of semiconductor manufacturing worldwide and even less for leading-edge manufacturing of chip sets at the 7nm and below range. DoD finds itself at a

[1] The DoD defines the leading edge as a digital CMOS node less than or equal to 7nm.

[2] https://nstxl.org/wp-content/uploads/2020/12/219G019-RAMP-C-RFS_FINAL-1-28-21.pdf.

[3] https://apps.dtic.mil/dtic/tr/fulltext/u2/a524792.pdf.

[4] https://fortune.com/2020/06/30/america-tech-semiconductor-manufacturing-investment/.

disadvantage to influence market practices and buy down the risks potentially compromising its ability to perform its mission.

DoD categorizes risks to ICs into three main segments: counterfeits, malicious insertion, and supply chain disruption. Counterfeits and malicious insertion have been a focus of the DoD for many years, investing in development of countermeasures and mitigations. Supply chain disruptions have been difficult to address directly, as commercial investment decisions are not necessarily within the DoD's span of control. Further, this may contribute to an increased risk of counterfeits and malicious insertions, limiting the DoD's control over and access to the IC market it depends on.

The DoD risk associated with supply chain disruption is centered on the access it needs, flexibility to accommodate supply shortages along various points within the chain, the restrictions on use of foreign ICs, and increasing lack of trusted alternatives. Typically, when the supply chain is closer to the consumer, the consumer has more control and there are fewer opportunities for defects. In response to the risks, DoD created the Trusted Foundry program to enable an assured U.S.-based supply chain for microelectronics. One study describes the critical relationship of a trusted semiconductor industry and U.S. dominance as follows:

> Because the semiconductor is the backbone of the defense electronics industry, the health of the integrated circuit market serves as an indicator of the ability of the U.S. to sustain economic growth and maintain competitive advantage in producing the best technology and products for the nation and the war-fighter.[5]

The future of that relationship, however, is in doubt for leading-edge production. Microelectronics is a global industry. DoD has been facing the challenges of offshore trending in the microelectronic industry for decades. Although, Intel is still a dominant producer of microprocessors, with a focus on commercial chips, no U.S. manufacturer, including Intel, seeks to participate in the evolving leading-edge market. IBM decided to go fabless[6] in 2014[7] to focus on the design market. Texas Instruments is focused on manufacturing analog controller chips, and Micron is producing memory chips; neither of their fabrication facilities are capable of leading-edge processes.

Uneven Playing Field

[5] Ibid.

[6] "A fabless semiconductor company is a company that designs, verifies, and sells semiconductors under its own brand or for other brands but does not own the fabrication plant to make the semiconductors. Instead, a fabless company outsources its chip fabrication to a semiconductor foundry, such as TSMC, GlobalFoundries, and UMC." Semiconductor Engineering. https://semiengineering.com/knowledge_centers/manufacturing/fabless-semiconductor-companies/.

[7] https://www.pcmag.com/news/whats-the-fallout-as-ibm-goes-fabless.

Intel's foreign competitors in manufacturing receive state subsidized investments or government preferential treatment or both. DoD domestic production of semiconductors will be competing against subsidized, government-supported businesses and an uneven playing field created by businesses' decisions, influencing different components of the supply chain. Intel competes on quality and the cutting edge. When Taiwan Semiconductor Manufacturing Company (TSMC) attained the cutting edge, Intel's traditional model no longer became sustainable. TSMC is exclusive in contracts manufacturing and is dominant in the market servicing Big Tech firms that need leading-edge IC in their products. Apple, for example, which has historically used Intel-based chips in its Macs, developed an Advanced RISC Machines (ARM)-based architecture that TSMC will produce for all foreseeable future products.[8] Microsoft, a longtime partner of Intel, recently announced that it will also design its own chips for PCs and servers[9] using an ARM-based architecture built by TSMC. Cloud computing is also moving heavily toward TSMC; Amazon Web Services (AWS) runs almost exclusively on ARM-based chips made by TSMC.[10]

An important aspect of the competition from TSMC and Samsung comes from deliberate policy by state governments to promote the tech sector in Taiwan and South Korea. Since the 1970s and 1980s, both countries have engaged in strategic efforts to move away from commodities and into high-tech manufacturing. In an effort to make South Korea a major player in telecommunications, South Korea's Ministry of Communications provided semiconductor research and funding to Samsung in the 1980s.[11] Further, Samsung is a conglomerate that has received several forms of state assistance as one of South Korea's "chaebol" (conglomerate) companies. Favorable government policy and a diversity of industries in its portfolio has led Samsung to account for 15% of South Korea's GDP.[12]

DoD acknowledges that the Trusted Foundry program no longer meets its needs for IC manufacturing. The program successfully provided a secure method of building and developing custom IC chips for DoD's use through IBM, but once IBM went fabless, the foundry capable of operating at the leading edge was lost.[13] The trusted foundry was novated to Global Foundries, the entity that acquired the former IBM facilities. In response

[8] https://www.wired.com/story/apple-mac-intel-switch-guide/.

[9] https://www.cnbc.com/2020/12/18/intel-falls-on-report-microsoft-will-design-own-chips-for-pcs-servers.html.

[10] https://www.nytimes.com/2018/12/10/technology/amazon-server-chip-intel.html.

[11] Peter Evans, *Embedded Autonomy*, Princeton University Press, Princeton, NJ. 1995.

[12] Peter Pham, "What Is South Korea's Secret Weapon?" *Forbes,* May 13, 2018. https://www.forbes.com/sites/peterpham/2018/05/31/what-is-south-koreas-secret-weapon/?sh=77159c416b2f.

[13] GAO-16-185T.

to the risk of an unsecure IC supply chain, the Navy and the Office of the Secretary of Defense developed three programs to help secure the DoD supply chain for IC.

Will this be enough? Can DoD tolerate the risk of increasingly relying on foreign suppliers and manufacturers for IC that are designed into critical components covering a broad range of requirements including GPU-based advanced processing systems, mission relevant AI systems, long-range hypersonic missiles, space technology, and other emerging technology sets?

In the near term, increased participation in the DoD programs could assist the U.S. Army in securing the minimal supply of trusted ICs for its most critical efforts. Long term, the U.S. Army should consider a strategic role in advocating for its own and joint forces' needs for trusted U.S.-based manufacturing to secure the necessary substantial funding and buy-in from the U.S. Government, U.S. industry, and the American public.

Contents

Figures and Tables

1. Risks to Integrated Circuit Supply Chains and DoD Mitigations

The Department of Defense (DoD) is concerned about the long-term strategic impacts from future supply chain disruptions, including the potential inability of the U.S. to produce leading edge[14] 7nm chip sets domestically. Institute for Defense Analyses (IDA) researchers anticipate that this, coupled with the fact that demand for production is outpacing current capacity, will have long-term consequences and may contribute to an increased risk of counterfeits and malicious insertions as the DoD and the U.S. lose control over, and access to, the IC industry they depend on.

Semiconductors and ICs are a critical supply item for DoD systems. These components are the backbone of electronic-based functions, from application specific processes, to computing memory, to timing, and more. In the past, DoD has stood up many programs to ensure trust in these critical components, but such an approach is becoming increasingly difficult to sustain. Compared with global consumers, DoD is a minor user with respect to the total number of ICs being developed worldwide, with one study identifying DoD as having less than 1% of the market share.[15] Although the United States is still a leader in the design of ICs, it is facing a diminished role in manufacturing, accounting for only 12%[16] of semiconductor manufacturing worldwide and even less for leading-edge manufacturing of chip sets at the 7nm and below range. DoD finds itself at a disadvantage to influence market practices and buy down the risks that could compromise its ability to perform its mission or, worse, the safety of the warfighter. Should the ICs controlling the electronics of the F-35 fail or the ICs enabling missile precision targeting be compromised, the consequences would be high.

DoD categorizes risks to ICs into three main segments: supply chain disruption, counterfeits, and malicious insertion. Counterfeits and malicious insertion have been on the DoD radar for many years, resulting in investments in and a focus on developing countermeasures and mitigations. Supply chain disruptions have been of concern but not directly addressed because commercial investment decisions are not necessarily within DoD's span of control.

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[14] The DoD defines the leading edge as a digital CMOS node less than or equal to 7nm.

[15] https://apps.dtic.mil/dtic/tr/fulltext/u2/a524792.pdf.

[16] https://fortune.com/2020/06/30/america-tech-semiconductor-manufacturing-investment/.

A. Supply Chain Disruption

The DoD risk associated with supply chain disruption is centered on the access it needs, flexibility to accommodate supply shortages along various points within the chain, the restrictions on use of foreign ICs, and increasing lack of trusted alternatives. Typically, the closer the supply chain is to the consumer, the consumer has more control and there are fewer opportunities for defects. However, microelectronics is a global industry. DoD has been facing the challenges of offshore trending in the microelectronic industry for decades, but there was still a competitive, U.S.-based manufacturer available for this critical segment of the market in the Intel Corporation. In response to the risks, DoD created the Trusted Foundry program to enable an assured U.S.-based supply chain for microelectronics. One study describes the critical relationship of a trusted semiconductor industry and U.S. dominance as follows:

> Because the semiconductor is the backbone of the defense electronics industry, the health of the integrated circuit market serves as an indicator of the ability of the U.S. to sustain economic growth and maintain competitive advantage in producing the best technology and products for the nation and the war-fighter.[17]

The future of that relationship, however, is in doubt for leading-edge production. Beyond Intel, no other U.S. manufacturer seeks to participate in the leading-edge technology. IBM decided to go fabless[18] in 2014[19] to focus on the design market. Texas Instruments is focused on manufacturing analog controller chips, and Micron is producing memory chips; neither of their fabrication facilitates are capable of leading-edge processes. Figure 1-1 depicts all of the current and planned leading-edge manufacturing locations, globally.

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[17] Ibid.

[18] "A fabless semiconductor company is a company that designs, verifies, and sells semiconductors under its own brand or for other brands but does not own the fabrication plant to make the semiconductors. Instead, a fabless company outsources its chip fabrication to a semiconductor foundry, such as TSMC, GlobalFoundries, and UMC." Semiconductor Engineering. https://semiengineering.com/knowledge_centers/manufacturing/fabless-semiconductor-companies/.

[19] https://www.pcmag.com/news/whats-the-fallout-as-ibm-goes-fabless.

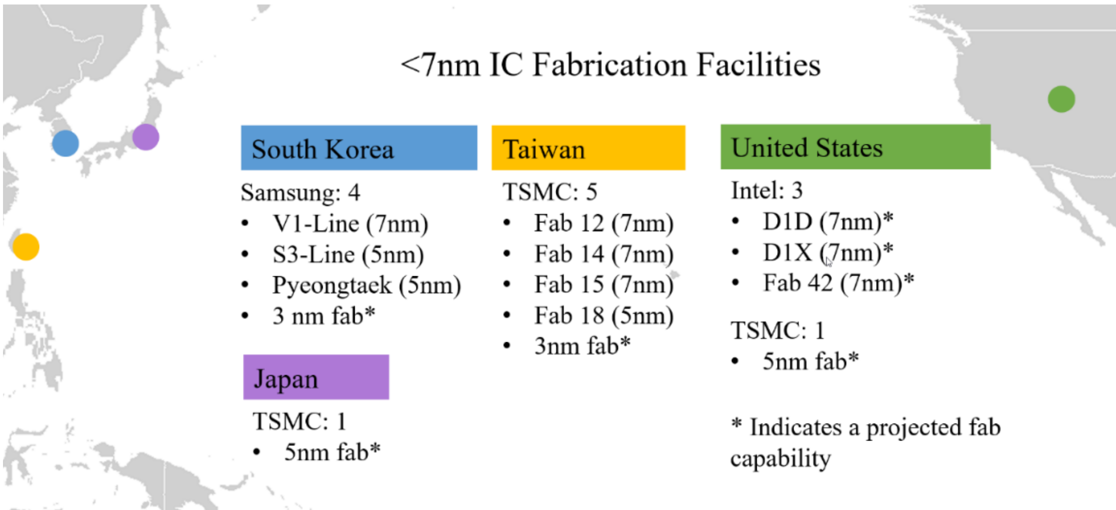

Figure 1-1. Global Leading-edge Manufacturing Locations

Now, as Intel struggles to refine its processes for 7nm, it is experiencing significant delays that have harmed its business relationships, and major customers are shifting to TSMC (subsidized by Taiwan) or Samsung (subsidized by South Korea) for manufacturing. Samsung has one plant based in Texas, but it is not leading edge (producing at the 14nm node), and TSMC is building a 5nm facility in Arizona, but production yields are not certain nor is it likely that DoD is a priority customer.

Significant up-front capital expenditures costs can be prohibitive for any U.S.-based companies seeking to participate in the market and expand the supplier footprint. An estimated $5 billion of capital investment is needed to build a fabrication plant. Profitability would not be realized for several years because it takes several cycles of production for chip yield to meet standards and be sellable. The TSMC plant being built in Arizona comes with a staggering $12 billion price tag.[20] Both TSMC and Samsung are subsidized by their respective governments with grants and tax incentives. This is a practice also being observed in Chinese investments as they quickly try to ramp up their own IC market. At this time, the U.S. government does not provide incentive structures for U.S.-based manufacturing,[21] though the FY21 National Defense Authorization Act (NDAA) could lay the groundwork.[22] DoD will be at a continued risk for a disrupted and untrusted supply chain as long as it is reliant on foreign suppliers. However, without significant investment, the U.S. is constrained when compared to peer competitors in the IC manufacturing marketspace. Among the near-term consequences to DoD is the uncertainty of how foreign suppliers will prioritize DoD requirements.

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[20] https://www.forbes.com/sites/willyshih/2020/05/15/tsmcs-announcement-of-a-us-fab-is-big-news/?sh=3bd48f042340.

[21] https://fortune.com/2020/06/30/america-tech-semiconductor-manufacturing-investment/.

[22] https://www.congress.gov/bill/116th-congress/house-bill/6395/text.

As the number of leading-edge manufacturers shrinks, it is unclear whether DoD would be able to gain access to leading-edge IC manufacturing, even were the U.S. to have domestic manufacturing capability. Global foundry capacity is almost completely full, especially at the leading edge, where technology giants like Apple, NVIDIA, AMD, Microsoft, and Sony are all competing over the same 7nm or 5nm chip capacity.[23] According to publicly available reporting, TSMC requires customers of leading-edge chips to "sign wafer purchase agreements to allocate a certain number of contract wafers per quarter."[24] The DoD's needs make up less than 1% of the IC market. It is highly unlikely that DoD would be able to gain access to leading-edge node capacity through traditional commercial means for this critical need. Therefore, it will take a concerted effort by DoD, along with substantial resources, to ensure access to such a valuable technology.

Already, a U.S. national security supercomputer could be impacted because of the delay in the ability for the U.S. to manufacture at the 7nm node. The Department of Energy (DOE) Argonne National Laboratory is planning to build a supercomputer, codenamed Aurora, with Intel's 7nm graphics processing unit (GPU).[25] Intel's 7nm production continues to face delays, delaying production to 2023, and the company has recently announced it will contract with TSMC for 7nm production. As depicted in Figure 1-1 above, currently all of TSMCs 7nm fabs are located in Taiwan. Intel has three planned fabrication plants for the 7nm node, and TSMC has one facility planned at the 5nm node within the U.S., but these are several years away with unproven yields. Without the ICs being developed in the U.S., it is unclear whether the DOE program can move forward. There is significant concern that the U.S. will not have any domestic leading-edge foundries in the short term and that, even when it does, DoD's access to the yield will compete against prioritized customers.

B. Counterfeits and Malicious Insertion

The likelihood of counterfeits or malicious insertion into the DoD supply chain increases with foreign development and manufacturing. The U.S. has little control over facilities that are overseas, nor can it test along the development chain to ensure unwanted hardware or software is not added to a chip. The major risk with counterfeits is that the quality and reliability do not match the expected device's standards, leading to device failure or degraded performance. Also, counterfeits cause legitimate businesses to lose market share and profits. It is estimated that suppliers lose about $100 billion of global revenue every year due to counterfeiting.[26] There is also little doubt that counterfeits have

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[23] https://www.tomshardware.com/news/tsmc-prioritizing-apple-consoles.

[24] Ibid.

[25] https://www.tomshardware.com/news/us-governments-aurora-supercomputer-delayed-due-to-intels-7nm-setback.

[26] https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=6856206.

already made their way into the DoD supply chain. A 2012 Senate Armed Services Committee investigation found 1,800 incidents of counterfeit electronic parts in defense equipment.[27]

Although counterfeits provide an avenue for device failure, malicious insertion is an indication of targeted nation state compromise. Overseas fabrication locations could be infiltrated by malicious actors, and the U.S. does not have a substantial mechanism to monitor and assess risk on any given day. Without available options within the U.S., the Army may need to focus on investing in advanced testing practices and countermeasures to apply once the parts are delivered. Even then, it is unlikely the risk can be fully mitigated from a targeted advanced supply chain attack in an environment fully outside of U.S. control.

C. What Is DoD Doing to Mitigate Risk?

DoD acknowledges that the Trusted Foundry program no longer meets its needs for IC manufacturing. The program successfully provided a secure method of building and developing custom IC chips for DoD's use through IBM, but once IBM went fabless, the foundry capable of operating at the leading edge was lost.[28] In response to the risk of an unsecure IC supply chain, the Navy and the Office of the Secretary of Defense developed three programs to help secure the DoD IC supply chain. The first program, State-of-the-Art Heterogeneous Integrated Packaging (SHIP) began in 2019 (though based on a much earlier DARPA program) with the purpose of providing a module platform with which DoD intellectual property and commercial intellectual property can be seamlessly integrated.[29] The second program, started in 2020, is the Rapid Assured Microelectronics Prototypes (RAMP). Its primary purpose is the replacement of DoD's "obsolete" chip design process, contracting development of a new process to U.S.-based, fabless companies.[30] The final program, Rapid Assured Microelectronics Prototypes—Commercial (RAMP-C), was launched in January 2021. RAMP-C is designed to address the most significant DoD risk: lack of a U.S.-based, leading-edge foundry.[31] Although there are critical questions about whether the programs will be successful, these projects show several lines of effort taken to address the risks currently posed by the IC supply

[27] https://www.americanmanufacturing.org/blog/americas-semiconductors-supply-chain-faces-big-cybersecurity-risks/.

[28] GAO-16-185T.

[29] https://nstxl.org/opportunity/request-for-designs-rapid-assured-microelectronics-prototypes-using-advanced-commercial-capabilities-ramp-phase-ii/.

[30] https://nstxl.org/opportunity/rapid-assured-microelectronics-prototypes-using-advanced-commercial-capabilities-ramp/.

[31] https://nstxl.org/opportunity/rapid-assured-microelectronics-prototypes-commercial-ramp-c/.

chain disruption. At this time, the Navy appears to be the primary participant using and leading the programs.

Beyond the DoD programs, the U.S. Congress has also acknowledged the risks of non-U.S.-based IC manufacturing. Recently, lawmakers consolidated two bills, the Creating Helpful Incentives to Produce Semiconductors for America Act (CHIPS for America Act) and the American Foundries Act, into the 2021 NDAA.[32] The NDAA authorizes federal incentives for the creation of new U.S.-based foundries and the U.S. semiconductor industry as a whole.[33] The language in the NDAA indicates that policymakers at the highest level acknowledge the risks posed by a declining American IC manufacturing base and are actively considering measures that will help secure it for national security purposes. However, the U.S. government does not provide direct support for Intel in the same way non-U.S.-based companies are supported by their home countries.

In the near term, increased participation in the DoD programs could assist the U.S. Army in securing the minimal supply of trusted ICs for its most critical efforts. Long term, the U.S. Army should consider a strategic role in advocating for its own need, and the joint forces' need, for trusted U.S.-based manufacturing to secure the necessary substantial funding and buy-in from the U.S. Government, U.S. industry, and the American public.

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[32] https://www.aip.org/fyi/federal-science-bill-tracker/116th/creating-helpful-incentives-produce-semiconductors-chips.

[33] https://www.prnewswire.com/news-releases/semiconductor-industry-applauds-ndaa-enactment-urges-full-funding-for-semiconductor-manufacturing-and-research-provisions-301199880.html.

2. Key Actors in Leading-edge IC Markets

DoD defines leading-edge chips as those at <7nm and below.[34] Fundamentally, an IC is an assembly of microelectronic devices in a thin substrate of semiconductor material and interconnected by multiple layers of metal wiring. Components on an IC can include active devices (e.g., transistors and diodes) and passive devices (e.g., capacitors and resistors). Over time, these devices have shrunk significantly in size due to continual advances in the underlying fabrication technology. As transistors get smaller, the processes and equipment used to make them are substantially different from those used for previous generations, requiring capital, expertise, and commercial feasibility. This led to the significant reduction in the number of companies able to participate in leading edge sectors, with only one U.S.-based company pursuing the market -- Intel.

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A. The Last U.S. Leading-edge IC Manufacturer

Intel is the remaining U.S.-based integrated device manufacturer (IDM) company that designs and manufactures its own chips, after Advanced Micro Devices (AMD) and IBM sold their fabrication facilities to GlobalFoundries in 2009 and 2014, respectively. Intel's decision to focus on processors for servers instead of mobile technology throughout the 2000s prohibited the company from capitalizing on the massive growth trend in mobile, reducing their overall global competitiveness.[35] Intel's 10-K filings from the past few years have shown how the cost of manufacturing forced the company to restructure and cut costs in business lines that were not seeing growth. For example, Intel's Data Center Group's revenue grew 46% between 2015 and 2019, and its semiconductor production business (Programmable Solutions Group PSG, the former Altera FPGA business) only grew 15% over the same time, with a 6.4% annual decline in 2019.[36] In comparison, TSMC grew 27%

[34] https://nstxl.org/wp-content/uploads/2020/12/219G019-RAMP-C-RFS_FINAL-1-28-21.pdf.

[35] https://www.extremetech.com/computing/227816-how-intel-lost-the-mobile-market-part-2-the-rise-and-neglect-of-atom.

[36] "Form 10-K," Intel Corporation, January 24, 2020. https://www.intc.com/filings-reports/all-sec-filings/content/0000050863-20-000011/0000050863-20-000011.pdf.

from 2015 to 2019[37] and Samsung Electronics showed 7% growth over the same time with no annual declines.[38]

The fact that Intel has failed to keep up in the race to produce chips at higher levels of precision after multiple delays could be a sign that self-producing chips past a certain level of precision is no longer possible with the company's current practices.[39] Intel has acknowledged its trend in slower innovation timelines and has been trying to counter it for several years.[40] Although Intel has contracts with DoD that could encourage some of its operations to serve national security applications, DoD does not buy enough to keep operations in the U.S. As a result, further outsourcing and offshoring of U.S. semiconductor manufacturing will present more risks to the supply chain of a necessary component in all DoD systems.

Intel traditionally plans its development and research model over a 10-year period, and in 2010, it released a projected roadmap from 2010 to 2020 to shareholders (see Figure 2-1).[41]

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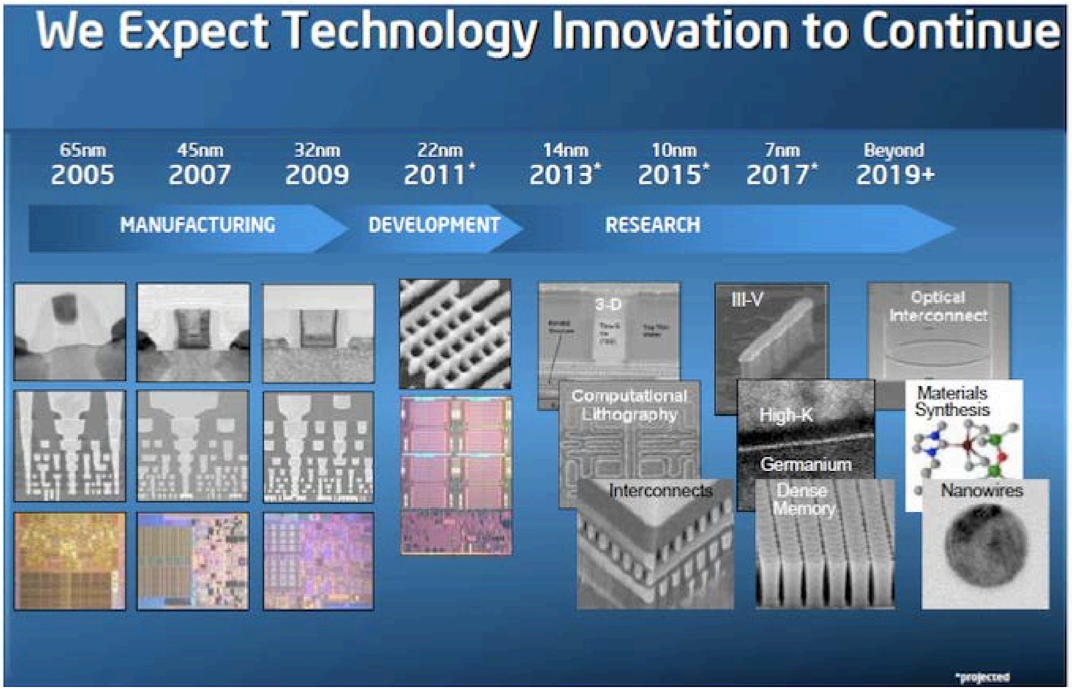
[37] "TSMC Annual Report 2019 (I)," Taiwan Semiconductor Manufacturing Company Limited, 12 March 2020. https://investor.tsmc.com/static/annualReports/2019/english/pdf/e_all.pdf.

[38] "2019 Business Report," Samsung Electronics Co. Ltd. https://images.samsung.com/is/content/samsung/p5/global/ir/docs/2019_Business_Report.pdf.

[39] David Rotman, "We're Not Prepared for the End of Moore's Law," *MIT Technology Review*, February 24, 2020. https://www.technologyreview.com/2020/02/24/905789/were-not-prepared-for-the-end-of-moores-law/.

[40] Rotman, "We're Not Prepared for the End of Moore's Law," op. cit.

[41] https://www.anandtech.com/show/13405/intel-10nm-cannon-lake-and-core-i3-8121u-deep-dive-review/2.



Note: Intel, 2010.

Figure 2-1. Planned Investor Roadmap

According to the roadmap, Intel planned to begin manufacturing of 10nm chips in 2015 and 7nm chips in 2017. The roadmap was initially on track with announcements in a 2013 10-Q[42] about the start of development for the 10nm chips; however, Intel has been plagued with delays in its 10nm manufacturing process. These issues, primarily with the level of yield,[43] continually pushed back the release date for Intel 10nm chips. As a result of these delays, development of the 7nm chips did not start until 2017.[44] However, Intel finally released its 10nm chips to market in 2019[45] and announced that the 7nm chips would be released in 2021[46]. Unfortunately, the 7nm manufacturing process has struggled with issues similar to those that plagued the 10nm process, and a flaw identified in the process has pushed manufacturing back until 2022 or 2023.[47] Figure 2-2 shows the significance of

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[42] https://www.intc.com/filings-reports/all-sec-filings/content/0000050863-13-000104/0000050863-13-000104.pdf.

[43] https://www.anandtech.com/show/12693/intel-delays-mass-production-of-10-nm-cpus-to-2019.

[44] https://www.intc.com/filings-reports/all-sec-filings/content/0000050863-17-000048/a2017q3-10qdocument.htm.

[45] https://www.pcgamer.com/intel-finally-launches-its-10th-gen-10nm-ice-lake-processors/#:~:text=Three%20years%20later%20than%20originally,changes%20to%20Intel's%20CPU%20architecture.

[46] https://d1io3yog0oux5.cloudfront.net/_d7114a2480a562d32f576af500351dd0/intel/db/861/7789/pdf/2019-Intel-Investor-Meeting-Davis.pdf.

[47] https://www.tomshardware.com/news/intel-announces-delay-to-7nm-processors-now-one-year-behind-expectations.

this delay, as it will push Intel two entire nodes behind its nearest competitors (TSMC and Samsung). However, factors other than transistor performance and node sizes must be considered when comparing Intel, Samsung, and TSMC.

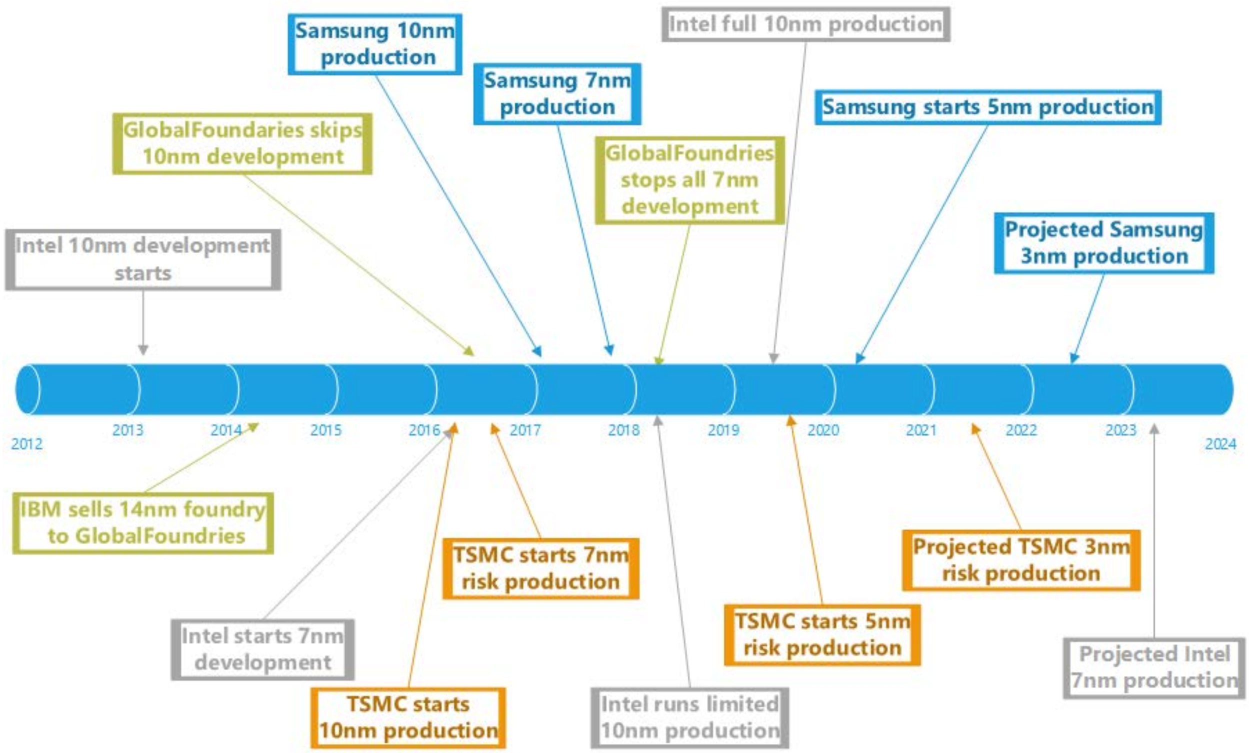

Figure 2-2. Leading-edge IC Timeline

Due to the continual delays putting Intel further and further behind its competitors, Intel made an agreement to use TSMC as a third-party foundry. Initial production will only be for Intel's lower-end chips starting in 2021 using TSMC's 5nm node but will eventually begin for the mid- to high-end chips later in 2022 using TSMC's 3nm node.[48] Intel also reported that its new 7nm discrete GPU will be built by TSMC.[49] This may impact Argonne's Aurora supercomputer, which was to use Intel's 7nm GPU.[50] Although both companies believe this to be more of a one-time deal,[51] with Intel stating that it still plans

48 https://www.patentlyapple.com/patently-apple/2021/01/intel-to-outsource-5nm-core-i3-processor-with-tsmc-in-h2-2021-and-higher-end-3nm-core-processor-by-h2-2022.html#:~:text=its%20Technological%20Lead-,Intel%20to%20Outsource%205nm%20Core%20i3%20Processor%20with%20TSMC%20in,Intel%20beginning%20on%20February%2015.

49 https://www.datacenterdynamics.com/en/news/intel-reportedly-plans-switch-tsmc-make-7nm-gpus/.

50 https://www.tomshardware.com/news/us-governments-aurora-supercomputer-delayed-due-to-intels-7nm-setback.

51 https://www.pcgamer.com/intel-tsmc-not-long-term/.

to have the majority of production within its own fabs by 2023,[52] there is still significant concern that the U.S. will not have any domestic leading-edge foundries in the short term.

B. State-subsidized Foreign Competitors

Intel's competitors in manufacturing receive state investment or government preferential treatment or both. DoD will be seeking proposals for incentives for domestic production of semiconductors, which will have to compete against subsidies, government support, individual businesses' decisions, and tacit knowledge at different levels of the supply chain. Intel competes on quality and the cutting edge. When TSMC attained the cutting edge, Intel's traditional model no longer was sustainable.

An important aspect of the competition from TSMC and Samsung comes from deliberate government policy to promote the tech sector in both Taiwan and South Korea. Since the 1970s and 1980s, both countries have engaged in strategic efforts to move away from commodities and into high-tech manufacturing. Samsung's semiconductor business received state promotion in its initial stages in the 1980s in an effort to make South Korea a major player in telecommunications, with semiconductor research and funding provided by South Korea's Ministry of Communications.[53] Further, Samsung is a conglomerate that has received several forms of state assistance as one of South Korea's "chaebol" (conglomerate) companies. Favorable government policy and a diversity of industries in its portfolio led Samsung to account for 15% of South Korea's GDP.[54] Unlike other rivals in East Asia, Samsung, a huge conglomerate often compared to the Korean version of Keiretsu, has deep ties to the South Korea government, although it does not report any state-sponsored organizations as major owners.

In Taiwan, there are several avenues of state-led development. Through Taiwan's Industrial Research and Design Institute, government funds and grants have been employed to incubate high-tech companies including TSMC and UMC (United Microelectronics Corporation). According to Crunchbase, in 2019, the Industrial Research Institute received multiple grants from foreign entities, including a grant from Krypto Labs, a tech incubator based in Abu Dhabi.[55] One of TSMC's largest shareholders is the National Development Fund of Taiwan, founded in 1973 to facilitate economic development in Taiwan and operated by Taiwan's Executive Yuan, the executive branch of government.[56] Another top

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[52] https://www.tomshardware.com/news/intel-most-7nm-cpus-made-in-house-company-will-still-outsource.

[53] Peter Evans, *Embedded Autonomy*, Princeton University Press, Princeton, NJ. 1995.

[54] Peter Pham, "What Is South Korea's Secret Weapon?" *Forbes*, May 13, 2018. https://www.forbes.com/sites/peterpham/2018/05/31/what-is-south-koreas-secret-weapon/?sh=77159c416b2f.

[55] "Krypto Labs," *Crunchbase*, https://www.crunchbase.com/organization/krypto-labs.

[56] Op. cit., TSMC Annual Report 2019.

owner is the Government of Singapore Investment Corporation (GIC) listed in TSMC's 2019 annual report as Government of Singapore.[57] GIC is one of two sovereign wealth funds operated by the Singapore Ministry of Finance with the stated goal of "achieving good long-term returns above global inflation, and preserving and enhancing the international purchasing power of the reserves placed under our management."[58] These activities are separate from Singapore's other fund, Temasek Holdings, which is used "to own and manage its assets and investments on a commercial basis."[59] Government majority shareholder investment constitutes a 11.64% total ownership stake in TSMC, with 6.38% owned by the Taiwan National Development Fund, 2.93% owned by Singapore's GIC, and 0.92% owned by Taiwan's New Labor Pension Fund. The remaining 1.41% is from Norges Bank, the central bank of Norway, which administers Norway's sovereign wealth fund, Government Pension Fund Global. Such state backing can insulate a company from exogenous economic shocks such as market dynamics and economic recessions or depressions by taking on financial risk that would otherwise only be borne by private investors. The next largest shareholders are U.S.-based Capital Group (0.83%) and two Vanguard entities (combined 2.33%).

TSMC is not the only semiconductor production business in which GIC has an interest. There is reporting of GIC's interest in investing in the Chinese chipmaker Semiconductor Manufacturing International Corp. (SMIC), the largest China-based chipmaker.[60] Through government funding, the Chinese government provides for infrastructure, construction, and even housing for new IC manufacturing efforts.[61] In August 2020, the Chinese government announced a tax policy exempting companies from corporate income taxes, if they are able to produce at certain levels of precision.[62] SMIC mostly produces at the low end of precision while struggling to produce at internationally competitive levels, seeking to provide low-cost commodity chips while attempting to indigenize more advanced manufacturing.

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[57] "Report on the Management of the Government's Portfolio," *GIC*, 2019. https://www.gic.com.sg/wp-content/uploads/2019/07/GIC-Report-2018-19.pdf

[58] Ibid.

[59] "FAQs," Temasek. https://www.temasek.com.sg/en/faqs#does-temasek-and-gic-same.

[60] https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/chinese-chipmaker-to-chase-more-advanced-technology-with-ipo-proceeds-59327563.

[61] Kevin Fogarty, "Chinese Chipmaker to Chase More Advanced Technology with IPO Proceeds," *S&P Global*, July 7, 2020, https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/chinese-chipmaker-to-chase-more-advanced-technology-with-ipo-proceeds-59327563.

[62] Op. cit., "Government Incentives and US Competitiveness in Semiconductor Manufacturing."

C. Specific Research on TSMC

With the exception of Samsung, there is no company, globally, with the same scaling capability as TSMC within the manufacturing precision growth sector. GlobalFoundries ended efforts to attain 10nm and 7nm levels of precision, further narrowing the competitive market. Part of TSMC's ability to out-compete Intel arises from its status as a contractor for chip production. This enables the company to receive revenue from a variety of contracts and increases its return on investment in new manufacturing equipment while producing commodity, low-precision chips. TSMC benefits from never being a designer of chips—only a manufacturer of others' chips—and thus does not bear the costs or take the risks required to develop chips at an increasingly higher level of precision.

TSMC's competitive edge has increased over the last two years, acquiring major customers that had been with Intel for decades. As seen in Figure 2-1, TSMC has been pursuing a very aggressive strategy in constantly pushing to achieve the next node for manufacturing. This has led TSMC to gain a competitive edge at the leading edge of ICs. Because TSMC exclusively contracts manufacturing, it has dominated the market for Big Tech firms that need leading-edge IC in their products. Apple, for example, which has historically used Intel-based chips in its Macs, developed an Advanced RISC Machines (ARM)-based architecture that TSMC will produce for all foreseeable future products.[63] Microsoft, a longtime partner of Intel, recently announced that it will also design its own chips for PCs and servers[64] using an ARM-based architecture built by TSMC. Cloud computing is also moving heavily toward TSMC; Amazon Web Services (AWS) runs almost exclusively on ARM-based chips made by TSMC.[65]

TSMC is currently building a $12B fab in Arizona where several other high-tech manufacturers reside (including Intel). Current projections indicate that the fab is likely targeting the 5nm node for full-scale production at about 20,000 wafers per month.[66] Reports indicate that TSMC may have opened this facility as a means to curry favor with the U.S. government, which has allegedly pressured TSMC to open up a facility in the U.S. to specifically support business with the U.S. military.[67] The U.S. has been taking a critical look at TSMC due to its close relationship to Huawei and its potential to be influenced by the Chinese government due its geographic proximity and economic practices imposed on any company doing business in China.[68] In response, recent U.S. export controls and

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[63] https://www.wired.com/story/apple-mac-intel-switch-guide/.

[64] https://www.cnbc.com/2020/12/18/intel-falls-on-report-microsoft-will-design-own-chips-for-pcs-servers.html.

[65] https://www.nytimes.com/2018/12/10/technology/amazon-server-chip-intel.html.

[66] https://www.forbes.com/sites/willyshih/2020/05/15/tsmcs-announcement-of-a-us-fab-is-big-news/?sh=776f6f742340.

[67] https://hothardware.com/news/tsmc-under-pressure-to-build-chips-in-us.

[68] Ibid.

sanctions against Chinese businesses, including Huawei, effectively bar TSMC from doing business with Huawei. As TSMC is reliant on U.S. technology to produce ICs—mainly design intellectual property and some manufacturing equipment—it is therefore subject to U.S. controls.[69] TSMC has reported compliance with these requirements and has already moved to offset lost revenue from previous Huawei orders with new customers.[70]

D. Differences in Leading-edge Chip Sets

Currently, only TSMC and Samsung have full-scale manufacturing capabilities for leading-edge chip sets. Intel is currently trying to fix its 7nm design process.[71] SMIC in China is reportedly capable of making a 7nm chip but does not have the ability to move it into mass production.[72] However, node size does not always indicate a more advanced chip, as chip manufacturers have diverged from having uniform components that are directly comparable to one another, making node size more a marketing term rather than a true performance metric.[73] A better metric is the number of transistors that can be fit on a die of the node. The metric that more closely aligns with the performance of individual chips is *transistor density*, as it more accurately represents the performance of chips when compared to each other. However, this metric also has some comparability issues, as different manufacturers have unique chip specifications. Table 2-1 provides a comparison of current transistor densities across the four leading IC manufacturers.

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[69] https://asia.nikkei.com/Spotlight/Huawei-crackdown/TSMC-halts-new-Huawei-orders-after-US-tightens-restrictions.

[70] https://www.reuters.com/article/us-taiwan-economy/taiwan-minister-says-tsmc-has-offset-lost-huawei-orders-idUSKBN23T1E3.

[71] https://www.bbc.com/news/technology-53525710.

[72] https://www.tomshardware.com/news/chinese-smic-tapes-out-first-n-7-nm-chip-but-mass-production-uncertain

[73] https://semiengineering.com/knowledge_centers/manufacturing/process/nodes/.

Table 2-1. Representative Performance of Process Nodes

Process Node	14nm		12nm	10nm			7nm			5nm	
Company	Intel	Samsung	Global Foundries	Intel	Samsung	TSMC	Samsung	TSMC	TSMC	Samsung	TSMC
Transistor Density	37.5	30.59	36.71	100.76	51.82	52.51	95.3	96.5	113.88	126.5	173.1
Production Year	2014	2015	2017	2018	2017	2017	2018	2016	2018	2020	2019
Production Type	SADP	LELE	SAQP	SAQP	LELELE	SAQP	EUV	SAQP	EUV	EUV	EUV
Generation	1	1	1	1	1	1	1	1	2	1	1
Process Name	P1272	14LPP	12LP	P1274	10LPE	10FF	7LPE	7FF	7FFP	SLPE	N5

Intel's 10nm is currently more powerful than Samsung's 7nm and is marginally out performed by TSMC's second-generation 7nm node, with a density of 100.76 to 113.88, respectively. However, TSMC and Samsung have moved beyond the 7nm node and have started full-scale production of 5nm—TSMC's 5nm has significantly more transistors than Intel's 10nm. TSMC is also slated to start production of its 3nm node in 2021, which is marketed as having almost twice the transistor density of its 5nm line.[74] If Intel is able to replicate its performance targets for its 7nm node, then it is possible it will be competitive against the 5nm from TSMC and Samsung. However, there is still uncertainty on when Intel will be able to produce at the 7nm node and below. As seen in Table 2-1, the only other advanced foundry in the U.S. is GlobalFoundries, but it has decided not to invest below the 12nm node, and even there it is outperformed by the other manufacturers.

E. The Shift in Node Labeling

The use of node size has become more of a marketing label than any real measurement of performance. As discussed, Intel's 10nm node is physically smaller with comparative density to TSMC's 7nm node.[75] For older chip nodes (i.e., those greater than 20nm), the nanometer measure was a "real physical measurement inside the chip," but this

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[74] https://www.anandtech.com/show/16024/tsmc-details-3nm-process-technology-details-full-node-scaling-for-2h22.

[75] https://www.oled-a.org/intel-lost-the-marketing-war-but-not-the-chip-density-competition_112920.html#.

measurement diverged when foundries adopted a new manufacturing model, the fin field-effect transistor (FinFET), during the 20nm node development.[76] *FinFET* is a transistor method that replaces the older planar transistor with a new transistor that adds "fins" onto the gate of the transistor, which allows for much better control of the electrical current passing through the gate and reduces leakage when the gate is in the "off" state.[77] Intel successfully introduced the FinFET process for its 20nm nodes, but the other manufacturers (i.e., TSMC, Samsung, and GlobalFoundries) struggled with theirs. When the other manufacturers had to reiterate and develop additional methods for the 20nm node, they decided to label the yield as 16nm/14nm, as if it were the next generation even though the size was not actually physically less than 20nm.[78] From there, the other manufacturers, but not Intel, took to naming the next iteration of their products according to these skewed conventions (shrinking the measure about 30% each time) leading to significant difference between Intel's nodes and the other IC foundry nodes. These conventions are why Intel's nodes will appear behind other leading-edge manufacturer's nodes, but the performance will likely be comparable.

F. The Shift in Node Lithography

The generation prior to 7nm was the 10nm node, which was created using a lithography process known as *self-aligned quadruple patterning* (SAQP).[79] This patterning develops the outlines on the silicon, allowing chip manufacturers to surpass the physical limitations on the size of a node by enhancing the precision of the lithography used. The method involves layering multiple patterns on a chip, giving chipmakers the ability to operate on a much more detailed level.[80] The method differs from the older *litho-etch-litho-etch* (LELE) as it simplifies the process by cutting down the number of steps it takes to complete a chip. However, it should be noted that Samsung was able to move to a 10nm node with a LELE process,[81] which likely increased its production costs significantly, while both TSMC and Intel did it with the SAQP method.

One of the defining characteristics of the leading-edge node is the new lithography method needed for mass productions to be effective. *Extreme ultraviolet* (EUV) lithography produces an ultrafine wavelength, which allows for a much higher level of precision then SAQP in the lithography process, letting manufacturers again push for

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[76] Ibid.

[77] https://blog.lamresearch.com/tech-brief-finfet-fundamentals/.

[78] Ibid.

[79] https://semiengineering.com/knowledge_centers/manufacturing/patterning/multipatterning/.

[80] Ibid.

[81] https://www.eetimes.com/apple-huawei-use-tsmc-but-their-7nm-socs-are-different/2/.

smaller and smaller nodes.[82] EUV uses an entirely different wavelength then the previous SAQP method, and requires specialized machinery for the process to work.[83]

[82] https://semiengineering.com/knowledge_centers/manufacturing/lithography/euv/.
[83] Ibid.

3. Shifting Economics of the IC Manufacturing Market

Multiple manufacturing models are used by companies in the semiconductor industry. The three main types are integrated device manufacturers (IDMs), fabless companies, and pure play foundries (PPFs).

IDMs are the traditional model, with Samsung and Intel being prominent examples. These companies are "vertically integrated," and handle IC chip development from the system specification; to the architectural, functional, and logical design; to the circuit and physical design; and finally, to the physical verification process. They own and build their own fabrication facilities, which allow them to fabricate their own products, and they are capable of putting their ICs on the market wholesale.

Fabless and PPFs, by comparison, are more specialized. Fabless companies handle the design and sale of their devices, but outsource the physical manufacturing to PPFs. They typically do not own fabs of their own, which removes them from the fabrication step in the vertically integrated development process of ICs. NVIDIA and Qualcomm are examples of fabless companies. PPFs focus exclusively on owning fabs to perform the physical manufacture of ICs designed by other companies. PPFs only take part in the fabrication process of the "vertically integrated development" process of ICs while under contract for other companies without actually providing or participating in the design layers of the process. The foundry business model—pioneered by TSMC, the current market PPF leader—seeks to optimize productivity.

Although the IC IDM model is under threat within the U.S., other segments such as chip design, also known as electronic design automation (EDA), and intellectual property are thriving and equipment manufacturing remains a strong component of the U.S. economy, though specialized and competitive. Figure 3-1 provides a depiction of the semiconductor economic value chain. Of note, outsourced semiconductor assembly and test (OSAT) and materials, such as rare earth metals, are both components that have major presence overseas. Additional research is needed in these areas but are not the focus of this document.

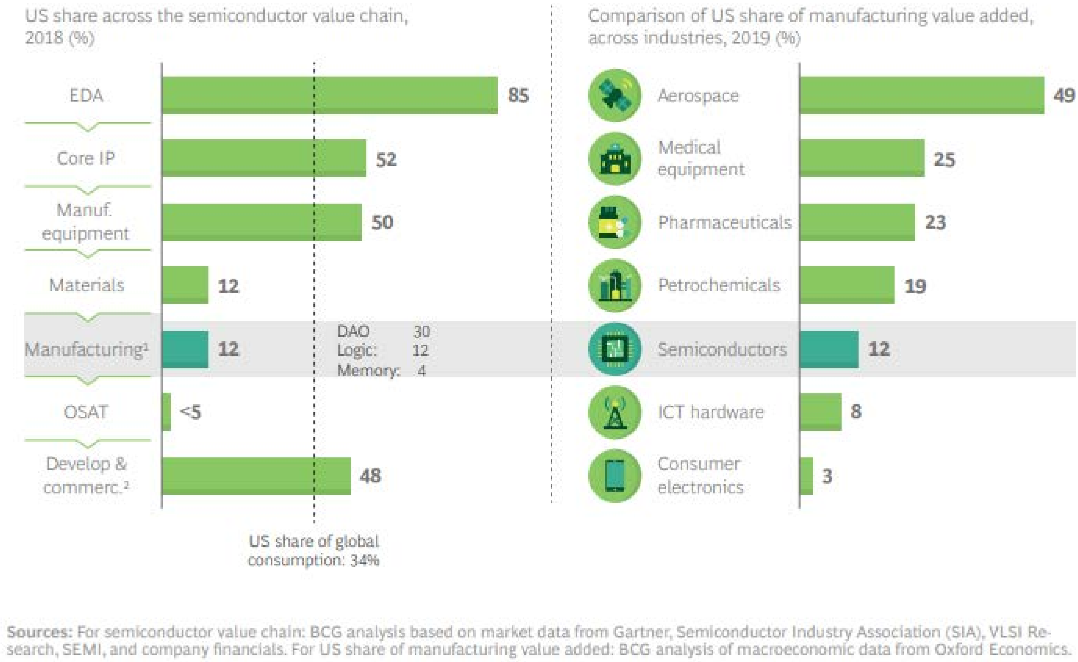

Figure 3-1. Semiconductor U.S. Value Chain

A. IC Design

With major capital expenditure required for manufacturing chips and rising costs in design, several U.S. firms decided to outsource manufacturing to cut costs and focus on a new business model. Chip design has become increasingly expensive over time. One estimate describes the following increase in designing a new IC chip: “In 2016, designing a chip for 10nm nodes cost around $170 million; in 2020, designing one for 5nm nodes costs more than $540 million.”[84] This is due to the high precision and number of features desired by customers and the specialized knowledge required for the research and development process.[85] A specific source of costs is the industry-standard, critical software required to create new chips, which is available from only three U.S.-based firms: Cadence Design Systems, Synopsys, and Mentor. The high concentration of chip design software in the U.S. allows this step in the semiconductor value chain to command the highest margins.[86] Examples of companies that design chips and contract their manufacturing include Apple, Qualcomm, Broadcom, AMD, and NVIDIA.

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[84] Rotman, “We’re Not Prepared for the End of Moore’s Law,” op. cit.

[85] Scott Jones and Arun Ghosh, “Evolving the D&A of Semiconductor R&D,” *KPMG*, 2017. https://assets.kpmg/content/dam/kpmg/us/pdf/2017/12/semiconductor-da-brochure.pdf

[86] Jan-Peter Kleinhans and Nurzat Baisakova, “The Global Semiconductor Supply Chain,” *Stiftung Neue Verantwortung*, October 2020. https://www.stiftung-nv.de/sites/default/files/the_global_semiconductor_value_chain.pdf.

B. Manufacturing Equipment

The equipment required for manufacturing ICs is highly specialized and made by a handful of major companies based in the U.S. (e.g., Applied Materials, Lam Research, KLA), Europe (e.g., ASML), and Japan (e.g., Tokyo Electron, Dainippon Screen).[87] Other firms supply specific display and ink technology such as SEMES (a subsidiary of Samsung); Hitachi Kokusai Electric America, Ltd.; Hitachi High-Tech; Teradyne; and Nikon.[88] Intel, TSCM, and Samsung have used a mix of equipment from these manufacturers for different chip manufacturing processes.[89] As the number of companies that fabricate their own chips is decreasing, these equipment manufacturers are seeing fewer buyers and are dependent on fewer companies for revenue. Leading-edge chip sets also require increasingly specialized equipment, as the reductions in size require more precision lithography. EUV lithography is the emerging technique for 7nm and below. Currently, only ASML, based in the Netherlands, produces the necessary equipment. ASML's machinery costs $120 million per machine.[90] Those machines can "only process 170 wafers per hour," meaning that a large-scale fab would need multiple machines to meet production requirements.[91] Also, ASML can produce only a maximum of 20 of those machines a year, and estimates put the company's backlog at as many as 49 machines.[92] Both the capital costs and time constraints of EUV contribute to the ever-growing cost of leading-edge IC, making it more and more difficult for companies to compete in the global market without government support. Overall, these equipment manufacturers play a critical role in IC manufacturing, and their supply chains should be monitored closely for risk and competition activity.

C. Fabrication Facilities

While manufacturing can be found in the U.S., the underlying conditions for operating new fabs are not ideal. According to a Boston Consulting Group study commissioned by the Semiconductor Industry Association, the biggest barriers to U.S. IC manufacturing include higher labor costs compared with offshore facilities and high, unsubsidized capital expenditure on infrastructure. Fabrication of IC require the use of cleanrooms, where the

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[87] Ibid.

[88] Griffin Holcomb, "Semiconductor Machinery Manufacturing in the U.S.," *IBISWorld*, August 2020. https://my.ibisworld.com/us/en/industry/33329a/major-companies.

[89] "Fab Semiconductor Equipment," *Intel*, October 2020. https://www.intel.com/content/www/us/en/resale-corporation/intel-resale-corporation-fab.html.

[90] https://www.forbes.com/sites/willyshih/2020/05/15/tsmcs-announcement-of-a-us-fab-is-big-news/?sh=776f6f742340.

[91] Ibid.

[92] https://www.anandtech.com/show/15428/asml-ramps-up-euv-scanners-production-35-in-2020-45-50-in-2021#:~:text=In%20fact%2C%20some%20market%20observers,as%2049%20EUV%20scanner%20orders.&text=We%20shipped%20six%203400C%20systems,2.8%20billion%20euros%20in%202019.

entire environment is controlled to prevent contaminants in the air from compromising the chip. Purified chemicals are needed and even the slightest imperfection during processing, a speck of dust, or intense light, can have major consequences on the quality of the product.[93] A cleanroom must control airborne particulates, temperature, humidity, air pressure, airflow patterns, air motion, vibrations, noise, lighting, and all living organisms.[94] The International Organization for Standardization (ISO) provides guidance on the cleanliness and zoning for cleanrooms under ISO 14644.[95] If these standards are not met, fabrication will not succeed. Building or converting a facility to meet these requirements is complex and expensive. The new leading-edge fabrication plant TSMC is building in Arizona is estimated at $12 billion.[96] Annual water and power costs are a continued expense. It can take years for chip processing to become profitable. Without government assistance (like that given to TSMC and Samsung), it has become increasingly difficult to convince U.S. companies to remain invested or initiate investment in this area. Without investment, the U.S. will be entirely at the mercy of foreign state-backed manufacturing enterprises. Figure 3-2 depicts the current fabrication locations for 14nm and below, which are spread across several countries with a strong U.S. presence. Figure 3-3 represents just the fabrication locations for leading edge (7nm and below). There is not yet any actual operational presence in the U.S., but Samsung has three operational facilities in South Korea and TSMC has four within Taiwan.

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[93] https://www.airsystems-inc.com/air-purification-news/importance-cleanrooms-semiconductor-manufacturing/.

[94] Ibid.

[95] https://www.mecart-cleanrooms.com/learning-center/cleanroom-classifications-iso-8-iso-7-iso-6-iso-5/.

[96] https://www.forbes.com/sites/willyshih/2020/05/15/tsmcs-announcement-of-a-us-fab-is-big-news/?sh=3bd48f042340.

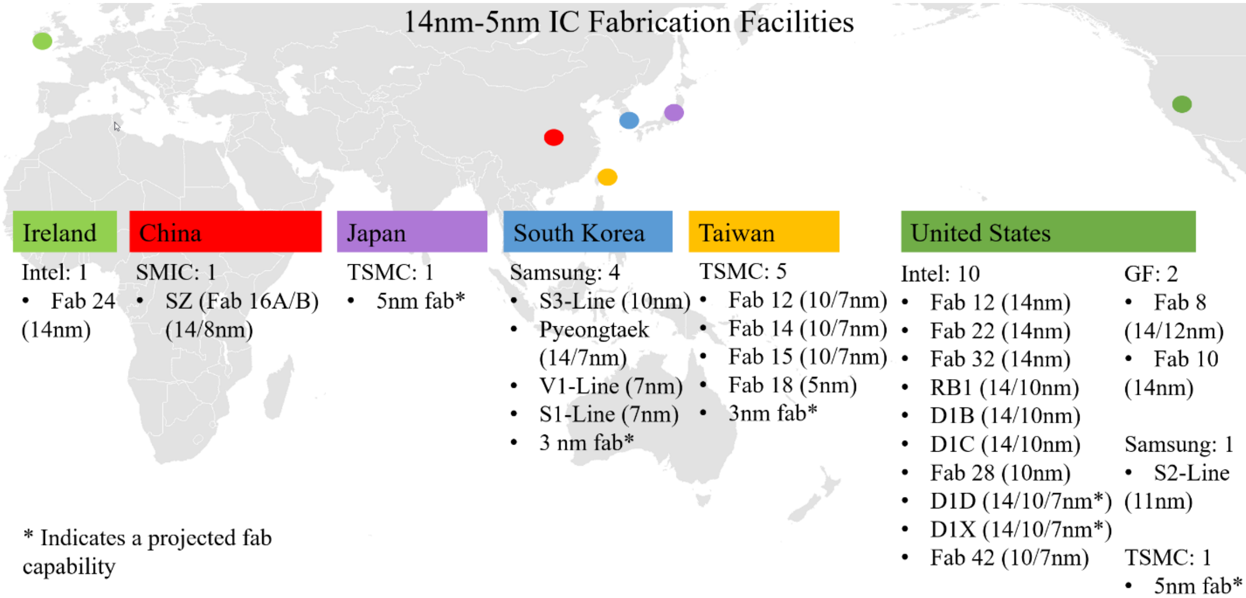

Figure 3-2. Global Fabrication Facilities for 14nm–3nm Nodes

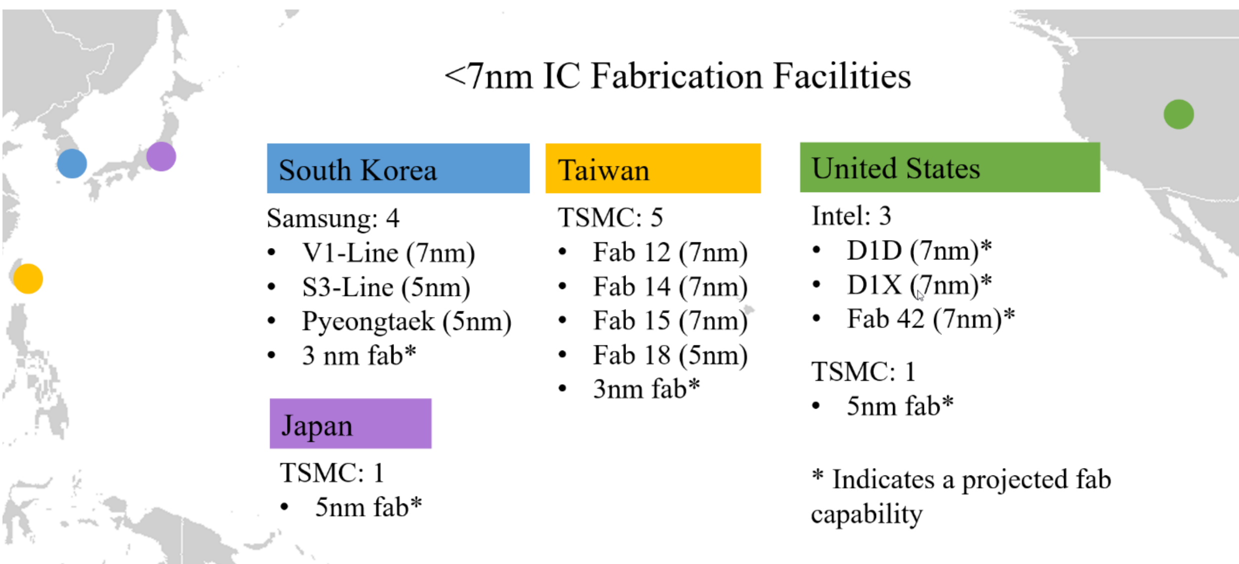

Figure 3-3. Global Fabrication Facilities for 7nm–3nm Nodes

D. Contracting, Market Placement, and Economies of Scale

As the market expands and the demand for commodity advanced chip sets grows, some manufacturing models are more attuned to capitalize on scaling. The production of a new commodity chip that meets a chip designer's specifications necessitates integrating multiple design architectures into concurrent manufacturing processes. For PPFs, this can increase the returns for equipment because they can flex to design options across multiple customers.[97] Those suppliers solely doing chip design can also focus on specific mechanisms to scale their processes to support bulk manufacturing and decrease unit costs. For IDMs, it can be difficult to compete and scale, as they must split resources into both design and manufacturing advancement. The PPF model is proving successful as it dominates capacity production, with Samsung producing 15% and TSMC producing 12.8% of the world output in 2019, as seen in Figure 3-4.[98]

(Monthly Installed Capacity in Dec 2019, 200mm-equivalents)

2019 Rank	2018 Rank	Company	Headquarters Region	Dec-2018 Capacity (K w/m)	Dec-2019 Capacity (K w/m)	Yr/Yr Change	Share of Worldwide Total	Inclusion or Exclusion of Capacity Shares from JV Fabs
1	1	Samsung	South Korea	2,934	2,935	0%	15.0%	
2	2	TSMC	Taiwan	2,439	2,505	3%	12.8%	shares of SSMC & VIS
3	3	Micron	North America	1,685	1,841	9%	9.4%	share of IM Flash in '18
4	4	SK Hynix	South Korea	1,630	1,743	7%	8.9%	
5	5	Kioxia/WD	Japan	1,361	1,406	3%	7.2%	

Source: Companies, IC Insights' *Global Wafer Capacity 2020-2024 Report*

Figure 3-4. Worldwide Wafer Capacity Leaders

TSMC strategically decided to upgrade only some of its fabrication facilities in order to use some of the older processes for mass-produced commodity chips that could flex to a variety of mobile architectures, thus gaining a foothold in that market. In contrast, Intel designs and produces its own chips and seeks to make all of its fabrication facilities as advanced as possible, using a "Copy Exactly" strategy. Samsung and TSMC are able to make chips with higher precision than Intel using different chip architectures, making their processes more suitable for chip designers focusing on the mobile market, where smaller chips are key to devices such as smartphones.[99] Intel's mobile design architecture does not have a strong market presence compared to competitors such as Broadcom, Apple, and Qualcomm. Until recently, Intel was primarily focused on computer and server applications and exclusively manufactured chips for that sector. Intel is now in a position where it struggles to supply the needs of the mobile market and compete across design and manufacturing. As depicted in Figure 3-5, the mobile sector holds a large market share that is projected to grow larger over time.

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[97] John Lee and Jan-Peter Kleinhans, "Taiwan, Chips, and Geopolitics: Part 1," *The Diplomat*, December 10, 2020. https://thediplomat.com/2020/12/taiwan-chips-and-geopolitics-part-1/.

[98] "Five Semiconductor Companies Hold 53% of Global Wafer Capacity," *IC Insights*, February 13, 2020, https://www.icinsights.com/data/articles/documents/1235.pdf.

[99] Angelo Zino, Jia Yi Young, "Semiconductors & Semiconductor Equipment, October 2020," *CFRA*, October 2020.

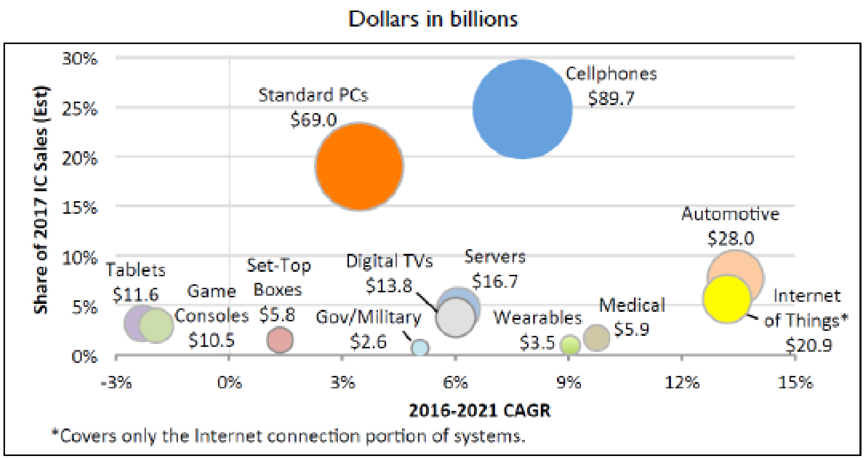

Figure 3-5. Market Share of IC End Use Sectors

Computers and servers are still present in the market space but do not have the same growth and market share opportunities that mobile and even IoT and automotive present.[100]

There are two other major IDMs in the U.S.: Texas Instruments (TI) based in Dallas, TX, and Micron, based in Boise, ID. TI ranks within the top 10 semiconductor companies in terms of revenue[101] while making a variety of other tech products. Micron is one of the most prolific chip manufacturers in the world by volume while being involved in founding other memory-related U.S. companies. Both companies are U.S.-based manufacturers, but they are not focused on the low-nanometer manufacturing race but on specific applications instead. While Intel is known for its microprocessors, TI manufactures analog and controller semiconductors, and Micron produces memory chips. For these companies, the investment barrier to produce at the highest precision and to produce microprocessors would be high and would require conversion to new manufacturing techniques and commitment to high-cost research and development.

[100] Congressional Research Service. Semiconductors: U.S. Industry, Global Competition and Federal Policy, October 26, 2020.

[101] Nathan Reiff, "10 Biggest Semiconductor Companies," *Investopedia*, July 30, 2020, https://www.investopedia.com/articles/markets/012216/worlds-top-10-semiconductor-companies-tsmintc.asp.

4. DoD Programs in Microelectronics

DoD established the Trusted Foundry Program in 2003 to provide mission critical defense systems access to leading-edge ICs, which at the time were 90nm chips.[102] It is managed by the Defense Microelectronics Activity (DMEA)[103]. NSA participated at the beginning of the program. The program was later expanded in 2007 to cover the entire microelectronic supply chain and accreditation process and protect against the possibility of "Trojan horses" within the chain.[104] In 2004, IBM was awarded the first contract that was able to meet DoD needs with leading-edge integrated circuits at the time, for various weapon systems and programs.[105] The expansion of the program with additional suppliers in 2006 only led to establishing a trusted supply chain for mature "non-leading-edge" technologies, and officials in 2015 noted that their use was minimal in comparison to IBM.[106] The expansion led to several other companies being added to the trusted foundry system to facilitate a trusted IC ecosystem; however, this capability only extended to older, more mature chip technology.[107] In 2014, IBM announced its intent to sell its foundry business, which included its Trusted Foundry practices, to GlobalFoundries, a U.S.-based but foreign-owned entity. In 2015, the acquisition was completed, and GlobalFoundries took over the role of providing leading-edge IC to DoD, but there were serious concerns as to whether GlobalFoundries could meet DoD's needs.[108] GlobalFoundries has had repeated setbacks since acquiring IBM's foundries, being forced in 2014 to buy Samsung's 14nm designs.[109] In 2016, GlobalFoundries admitted it would skip 10nm,[110] and it ultimately dropped any future expansion in 2018 after announcing it would not pursue

[102] https://www-03.ibm.com/press/us/en/pressrelease/392.wss.

[103] https://dodtechspace.dtic.mil/dodtechspace/docs/DOC-25228 (CAC secured website).

[104] Ibid.

[105] GAO-16-185T.

[106] Ibid.

[107] Ibid.

[108] Ibid.

[109] https://www.globalfoundries.com/news-events/press-releases/samsung-and-globalfoundries-forge-strategic-collaboration-deliver-multi.

[110] https://www.electronicdesign.com/technologies/embedded-revolution/article/21805175/globalfoundries-prepares-smaller-silicon-after-skipping-10-nanometers#:~:text=Jun%2014%2C%202017-,Last%20year%2C%20GlobalFoundries%20said%20that%20it%20had%20skipped%20the%2010nm,rivals%20like%20TSMC%20and%20Samsung.

7nm.[111] With that announcement in 2018, the Trust Foundry program no longer has a supplier of leading-edge IC and can only supply "mature" chips for DoD use.

Unfortunately, the risks that the foundry program was set up to address have not disappeared. The Trusted Guidebook from DMEA lists the top three risks associated with IC in the DoD supply chain as malicious insertion, counterfeiting, and supply chain disruption,[112] and these risks are why the Trusted Foundry Program was instituted. DoD policy reflects the need to address these risks in DoD Instruction (DoDI) 5200.44, which states, "integrated circuit-related products and services shall be procured from a trusted supplier using trusted processes accredited by the Defense Microelectronics Activity (DMEA) when they are custom-designed, custom manufactured, or tailored for a specific DoD military end use." The guidebook states that, if a system is designated "critical program information," the trusted foundry system must be used. However, there is no longer a supplier in the trusted foundry system for leading-edge IC since GlobalFoundries decided to no longer pursue 10nm or 7nm nodes. In the future, when weapon systems need leading-edge IC to stay competitive against adversaries, DoD will likely need to rely on an unsecure supply chain in another country to meet those needs.

DoD is aware of the critical need to have a secure supply chain for IC components, and over the past two years, it has developed a series of programs to address the current shortcomings. The following are a synopsis of the new developments.

A. Rapid Assured Microelectronics Prototypes (RAMP)

In March 2020, the Navy and Air Force, in support of the Office of the Secretary of Defense, released a request for proposals (RFP) for the Rapid Assured Microelectronics Prototypes (RAMP) program.[113] The project was developed to replace the "obsolete practices utilized by the United States Government in support of State-of-the-Art (SOTA) custom IC and System-on-a-Chip (SoC) design."[114] These designs are for chips that are "≤ 22nm node Si CMOS,"[115] which means they are for more mature IC manufacturers. Due to the much larger node size, this program's foundry needs could be met by the Trusted Foundry Program, which has foundries (such as GlobalFoundries) that could make chips of nodes less than 22nm, down to 12 nm. However, there is no domestic U.S. foundry that meets the requirement for leading-edge nodes (≤7nm). The RAMP program is currently

[111] https://www.anandtech.com/show/13277/globalfoundries-stops-all-7nm-development.

[112] https://dodtechspace.dtic.mil/dodtechspace/docs/DOC-25228 (CAC secured website).

[113] https://nstxl.org/opportunity/rapid-assured-microelectronics-prototypes-using-advanced-commercial-capabilities-ramp/.

[114] Ibid.

[115] Ibid.

funded for $24.5 million, awarded jointly to Microsoft and IBM.[116] However, both Microsoft and IBM are fabless manufacturers and do all of their leading-edge custom chip manufacturing through foundries with TSMC. As of January 29, 2021, phase two of RAMP was officially launched, with a public posting of a Request for Designs.[117]

B. State-of-the-Art Heterogeneous Integrated Packaging (SHIP)

In 2019, the Naval Surface Warfare Center–Crane Division released an RFP on the State-of-the-Art Heterogeneous Integrated Packaging (SHIP) Prototype Project that was awarded through the DoE Strategic & Spectrum Missions Advanced Resilient Trusted Systems (S2MARTS)[118] contracting vehicle. SHIP is developed from a DARPA project for Common Heterogeneous Integration and IP Reuse Strategies (CHIPS), and it attempts to put the DARPA project into practice for microelectronics.[119] The program is designed to "help close the gap between commercial advanced microelectronics technologies and those securely integrated into DoD systems."[120] The program will have its own design, assemble, and test facility, which will help secure the supply chain by having an environment that will allow for integration of DoD intellectual property (IP) with commercial IP.[121] SHIP, however, is designed to be at the end of the supply chain for IC and is focused around integration of chips into assemblies, as seen in Figure 4-1.

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[116] https://www.defense.gov/Newsroom/Releases/Release/Article/2384039/department-of-defense-announces-1972-million-for-microelectronics/.

[117] https://nstxl.org/opportunity/request-for-designs-rapid-assured-microelectronics-prototypes-using-advanced-commercial-capabilities-ramp-phase-ii/.

[118] https://govtribe.com/opportunity/federal-contract-opportunity/state-of-the-art-heterogeneous-integrated-packaging-ship-prototype-project-s2marts-n0016419snc10.

[119] https://www.navsea.navy.mil/Media/News/Article/2005099/nswc-crane-leverages-ota-to-ensure-that-the-us-government-has-access-to-secure/ (CAC Required Site).

[120] Ibid.

[121] Ibid.

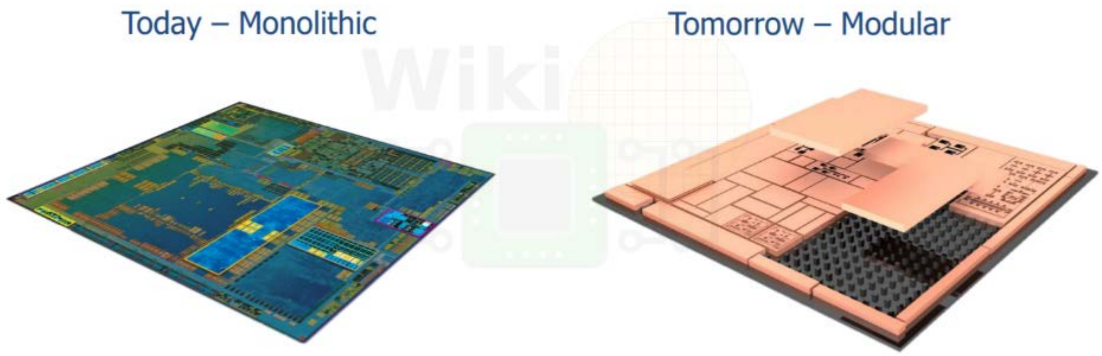

Figure 4-1. SHIP Concept

Intel's federal business and Xilinx (acquired by AMD October 28, 2020, with an expected close date in 2021 for the transaction) were announced as awardees for the digital components of the SHIP project, with Northrop Grumman, General Electric, Keysight Technologies, and Qorvo Texas for the program's RF component.[122] Phase 2 of SHIP is currently funded for $172.2M.[123]

C. Rapid Assured Microelectronics Prototype Commercial (RAMP-C)

The Navy along with the Office of Secretary Defense Research & Engineering (OSD R&E) posted an opportunity for Rapid Assured Microelectronics Prototypes – Commercial (RAMP-C), on January 14, 2021.[124] The purpose of the RAMP-C program is to resolve the issue of lack of domestic leading-edge foundries by incentivizing the creation of a sustainable, leading-edge, domestic foundry solution for the United States.[125] According to planning documents, phase one of the project has been funded for $309 million, with the expectation that the program will have an additional two phases that will ultimately produce a "U.S. located foundry capable of complex System on a Chip (SoC) fabrication using 7nm/5nm Si CMOS technology."[126] This program is designed to be complementary to both SHIP and RAMP, as shown in Figure 4-2.

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[122] https://www.govconwire.com/2019/11/navy-selects-6-companies-for-ship-microelectronics-tech-devt-project/.

[123] https://www.defense.gov/Newsroom/Releases/Release/Article/2384039/department-of-defense-announces-1972-million-for-microelectronics/.

[124] https://nstxl.org/opportunity/rapid-assured-microelectronics-prototypes-commercial-ramp-c/.

[125] Ibid.

[126] https://nstxl.org/wp-content/uploads/2020/12/219G019-RAMP-C-RFS_FINAL-1-28-21.pdf.

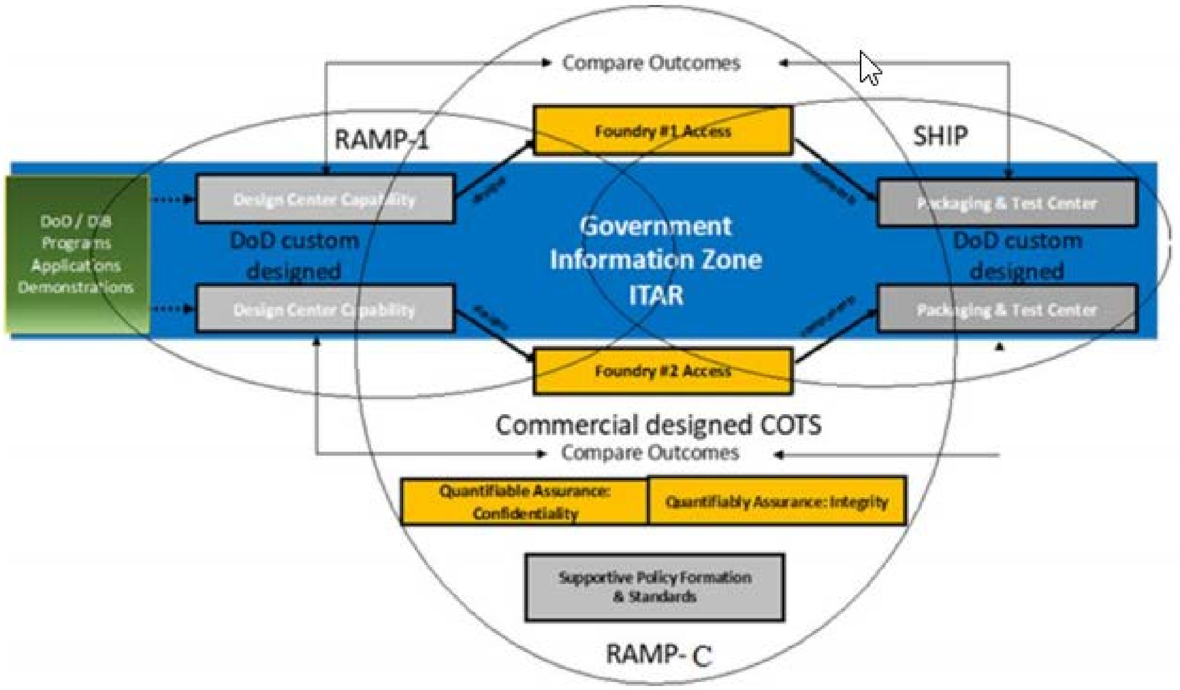

Figure 4-2. DoD IC Program Diagram[127]

RAMP will provide the design center for custom chips, SHIP will provide the packaging and testing for the end product, and RAMP-C will provide the leading-edge foundries for both custom and commercial over-the-shelf (COTS) products.

Several questions still remain and may prove difficult to resolve, particularly with the RAMP-C program. In the short term, the U.S. has no leading-edge foundries, and Intel appears to have lost the competitive edge against longtime rival TSMC. Also, GlobalFoundries has publicly stated it will no longer pursue leading-edge IC.[128] There are foreign-owned foundries in the U.S., such as Samsung's foundry in Austin, but that facility does not have the ability to operate at the leading edge without major retrofitting.[129] TSMC is building a foundry that is targeting 5nm in Arizona,[130] which would theoretically fit the needs of RAMP-C program, but new foundries often take 3–5 years before their clean rooms are perfected.

There are also additional concerns about the level of control the U.S. might have over a foreign manufacturer operating in the United States. If the program were aimed at encouraging U.S.-based companies to start up a new foundry, the up-front capital

[127] Ibid.

[128] https://www.anandtech.com/show/13277/globalfoundries-stops-all-7nm-development.

[129] https://www.sammobile.com/news/samsung-win-intel-failure-7nm/.

[130] https://www.forbes.com/sites/willyshih/2020/05/15/tsmcs-announcement-of-a-us-fab-is-big-news/?sh=776f6f742340.

requirements would be in the range of $10–20B, which the current incentives of the program would likely not be able to support. Intel is, of course, still moving toward leading-edge capabilities, but has historically not done any contract manufacturing at the scale needed to support the RAMP-C program. Intel is committed to being an IDM and has never produced non-Intel chip designs in its foundries. This may be in conflict with the plan to work with fabless designers as laid out in both RAMP and RAMP-C.

The three programs are a step in the right direction for helping secure IC manufacturing for DoD. If TSMC is chosen as the foundry in Arizona, actions could be taken to mitigate the risk of using a foreign manufacturer, especially given that the foundry would be located in the U.S. If a U.S.-owned operator is needed, other options could be found, given significant enough incentives by DoD to the industry. Lastly, the Navy appears to be the primary driver of the three programs, which is surprising, as all branches of the military have secure IC manufacturing requirements.

D. NDAA 2021

In the NDAA for 2021, lawmakers consolidated two bills, the Creating Helpful Incentives to Produce Semiconductors for America Act (CHIPS for America Act) and the American Foundries Act.[131] The NDAA authorizes federal incentives for the creation of new U.S.-based foundries and the U.S. semiconductor industry as a whole.[132] It gives the Secretary of Commerce authority over the process and distribution of funds[133] and joint oversight responsibilities with the Secretary of Defense, Secretary of Energy, Secretary of Homeland Security, and Director of National Intelligence to ensure national security objectives are achieved. Although the sections authorizing support and research have been passed, appropriated funds are still needed. The language in the NDAA indicates that policymakers at the highest level acknowledge the risks posed by a declining American IC manufacturing base and are actively putting in place measures that will help secure it for national security purposes.

E. Lack of Capacity for DoD Access

Although the new DoD initiatives will likely help address the issue of packaging, designing, and testing for DoD IC, it is unclear whether the RAMP-C program will be able to ensure access to leading-edge foundry capacity. Currently, worldwide manufacturing capacity for almost all semiconductors is fully utilized. There are huge disruptions in the

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[131] https://www.aip.org/fyi/federal-science-bill-tracker/116th/creating-helpful-incentives-produce-semiconductors-chips.

[132] https://www.prnewswire.com/news-releases/semiconductor-industry-applauds-ndaa-enactment-urges-full-funding-for-semiconductor-manufacturing-and-research-provisions-301199880.html.

[133] https://www.govtrack.us/congress/bills/116/hr6395/text.

automotive supply chain due to lack of lower-end chips for cars,[134] whereas the leading-edge has all of the world's tech giants competing over capacity for their new products.[135] Access to leading-edge capacity requires agreement to a certain number of wafers per month,[136] and existing large-scale customers like Apple and Qualcomm appear to get priority on new nodes. TSMC also requires agreements several quarters in advance to gain access to its leading-edge capacity;[137] thus, DoD will need to plan years in advance to gain access to future leading-edge capacity.

To offset the capacity and time requirements, DoD will likely need to provide sufficient incentive for a contract manufacturer to work with the military. DoD does not have the volume needed to make it lucrative enough for commercial access to leading-edge capacity, with some reports saying DoD has less than 1% market share of the IC industry.[138] The money DoD is currently offerings pales in comparison to the cost of leading-edge manufacturing, which is only growing as the nodes advance. One EUV machine costs $120M, and new foundries with leading-edge capacity can cost $10–20B. Even if domestic leading-edge capacity were to have a resurgence, DoD would likely be relegated to older mature nodes that have commercial markets for the custom chips DoD needs, unless DoD invests in the time and incentives necessary to cultivate access to leading-edge capacity.

[134] https://www.ft.com/content/13094950-fb45-4686-9ef9-8199c674b90d.

[135] https://www.tomshardware.com/news/tsmc-prioritizing-apple-consoles.

[136] Ibid.

[137] Ibid.

[138] https://apps.dtic.mil/dtic/tr/fulltext/u2/a524792.pdf.

5. Gray Zone Competition Considerations

A. Gray Zone Competition Implications for the IC Supply Chain

Securing a supply of trusted ICs for DoD's most critical efforts requires a trusted US manufacturing base. Selected examples of IC supply chain risks with strategic and long-term implications that are negatively influencing the mission of the DoD through non-military engagement are presented below.

B. SolarWinds

In the recent SolarWinds incident, which involved the network intrusion backdoor attack codenamed SUNBURST, both NVIDIA and Intel were affected.[139] The IDA team reviewed passive DNS records and independently confirmed what appeared to be an Intel domain that was pinging the primary command and control server that the Russian threat actor identified in the media used.[140] Although both companies have denied being compromised in any way, the evidence of communication between the companies and the Russian C2 server implies there is still opportunity for compromise.. This targeting of U.S.-based IC firms shows, indicates adversarial intent from Russia to operate in this space.

C. Sanctions on Chinese IC

Huawei, one of China's largest telecommunication providers, was added to the U.S. Entity[141] list in 2019,[142] essentially blacklisting it from use by U.S. businesses and preventing it from directly purchasing U.S. technology. Due to a loophole in Export Administration Regulations (EAR), however, Huawei was still able to procure some

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[139] https://www.engadget.com/nvidia-intel-solarwinds-hack-002444049.html?guccounter=1&guce_referrer=aHR0cHM6Ly93d3cuZ29vZ2xlLmNvbS8&guce_referrer_sig=AQAAAH2PBKoVkqW0rVFH8hhmBXhBavCdJGLhrRt8jDq-dwvSA4EO_OOdSH4RdiaeX9_l2Nxx7YyH-ikYCG5eTeuy7ILuW6MZCMyBoF2fanl1Y1RH0wXYNN0vgwTmj0dKPaw3UJtDNsUr_BROwpNZooiBPj1Qtridg1tIHRIQ7UDjR7zP.

[140] https://www.zdnet.com/article/partial-lists-of-organizations-infected-with-sunburst-malware-released-online/.

[141] The U.S. Entity List is a list of foreign businesses, individuals, governments, or other legal persons with specific license requirements related to export and transfer of goods, from Supplement 4 to Part 744 of the Export Administration Regulations; https://www.bis.doc.gov/index.php/policy-guidance/lists-of-parties-of-concern/entity-list.

[142] https://www.washingtonpost.com/world/national-security/trump-signs-order-to-protect-us-networks-from-foreign-espionage-a-move-that-appears-to-target-china/2019/05/15/d982ec50-7727-11e9-bd25-c989555e7766_story.html.

American-developed technology due to its being embedded in foreign-made products.[143] Huawei also stockpiled some components. The U.S. Government acted to remove this loophole and targeted the IC sector by banning U.S. semiconductor manufacturers and suppliers, and those that use their equipment or products, from doing business with Huawei.[144] This action blocks companies like TSMC from selling chips to Huawei because TSMC depends on U.S.-based software and equipment to design and make IC components. The ban has also affected the Chinese IC industry as a whole, as it prevents any company, even ASML in the Netherlands, the leading EUV lithography manufacturer, from selling equipment to Chinese semiconductor companies. China responded by massively ramping up investment in its own semiconductor industry to over $150 billion.[145] Although the actions the U.S. has taken to limit semiconductor production in China may be effective in slowing down the Chinese industry, it will not be long before China's strong state support for the industry puts them on an equal playing field with the U.S.

D. NVIDIA/ARM Deal

NVIDIA is a computer hardware company based in Santa Clara, CA. It is known for GPUs that are used for a variety of applications, most famously in high-performance PCs and gaming consoles, but increasingly in high-performance AI applications, including deep learning. GPUs are designed for executing a number of processes in parallel (i.e., *parallel processing*), which can significantly reduce the processing time for the calculations required in training machine learning used in predictive modeling and AI development. NVIDIA now sells developer kits that include GPUs to accelerate AI adoption and experimentation to capitalize on this trend. According to CFRA, NVIDIA was the most valuable single company in the semiconductor industry in 2020, valued at $333 billion.[146]

In September 2020, NVIDIA announced an agreement for the acquisition of ARM, a hardware company based in Cambridge, United Kingdom (UK) and currently owned by Japanese tech and finance conglomerate Softbank.[147] ARM is known for its ARM chip architecture, which is used in almost all mobile devices and a variety of telecommunications equipment. ARM is primarily a designer of chips that licenses its designs with modifications for each customer. Chips are manufactured on contract by

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[143] https://www.washingtonpost.com/business/2020/05/15/us-closes-huawei-loophole/.

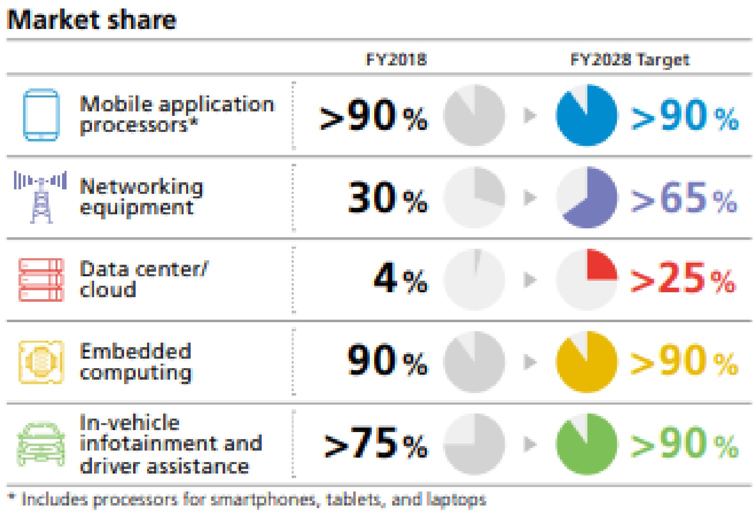
[144] https://www.commerce.gov/news/press-releases/2020/05/commerce-addresses-huaweis-efforts-undermine-entity-list-restricts.

[145] https://www.bloomberg.com/opinion/articles/2021-01-20/asml-china-s-150-billion-chip-push-has-hit-a-dutch-snag.

[146] Angelo Zino, Jia Yi Young, "Semiconductors & Semiconductor Equipment, October 2020," CFRA, October 2020.

[147] "NVIDIA to Acquire Arm for $40 Billion, Creating World's Premier Computing Company for the Age of AI," NVidia (Press Release), September 13, 2020, https://nvidianews.nvidia.com/news/nvidia-to-acquire-arm-for-40-billion-creating-worlds-premier-computing-company-for-the-age-of-ai/.

companies such as TSMC and Samsung. According to the financials of its parent company SoftBank (see Figure 5-1), ARM dominates 90% of the architecture IP for mobile application processors and 65% of architecture IP for "networking equipment," along with 90% of processing in autonomous vehicles and 90% of "embedded computing," meaning applications involving automation.[148]



Note: Softbank 2020.[149]

Figure 5-1. ARM Architecture Market Share Targets

NVIDIA intends to use the ARM acquisition to enhance its AI technology and plans to build an AI research center in Cambridge, UK.[150] The combination of NVIDIA and ARM technologies could create synergies between the server-based high computational power offered by NVIDIA technology and ARM's high-powered mobile and embedded architecture.

NVIDIA's intent to acquire ARM from Softbank, at a cost of almost $40 billion, was meant to be finalized by the end of 2021 or in 2022. However, due to competition concerns, the deal is in jeopardy. NVIDIA's acquisition of ARM would allow NVIDIA to own the ARM architecture, which is used by almost all major chip-designing competitors, including Broadcom, Qualcomm, Apple, Samsung, and AMD. For this reason, competition authorities from the U.S., EU, UK, China, and Japan have all opened inquiries or have been lobbied to determine the fairness and implications of the deal:

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[148] "2019 Annual Report," Softbank Group, 2019, https://group.softbank/system/files/pdf/ir/financials/annual_reports/annual-report_fy2019_02_en.pdf.

[149] Ibid.

[150] Joel Hruska, "Nvidia Buys ARM for $40 Billion, Plans New AI Research Center," *ExtremeTech*, September 14, 2020, https://www.extremetech.com/computing/314934-nvidia-buys-arm-for-40-billion-plans-new-ai-research-center.

- EU and UK regulators are said to be investigating the deal. The Competition and Markets Authority in the UK, where ARM is headquartered, officially asked for more information from interested parties to refute competition concerns at the end of 2020. Similarly, the EU Commission's Competition department is reported to be investigating the deal.[151]
- In December 2020, the U.S. Federal Trade Commission made a "second request" for additional documentation and information from NVIDIA, detailing how it intends to mitigate competition concerns with respect to its acquisition of ARM's IP, as many ARM architecture users are based in the U.S.[152]
- China's competition regulators from the State Administration for Market Regulation (SAMR) are being lobbied by Chinese tech firms to investigate the deal. ARM IP is critical to the Chinese telecoms industry, with ARM holding 49% of the market share in mobile device architectures in China.[153] For Chinese telecom firms such as Huawei, the deal could threaten their access to ARM architectures used in their own products, due to tensions with the U.S.[154,155] Access to U.S. technology has already been threatened due to the recent ban on Huawei products in the U.S. and the ban of U.S. sales and use of semiconductor manufacturing equipment to China. The ARM acquisition would be another threat to China's pursuit of high-technology industrial power.[156] Further, issues persist with the refusal of ARM China's CEO to vacate his position. He claims to remain CEO of ARM China (a joint venture with ARM and Chinese equity

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[151] "CMA to Investigate NVIDIA's Takeover of ARM," Competition and Markets Authority, January 6, 2021, https://www.gov.uk/government/news/cma-to-investigate-nvidia-s-takeover-of-arm.

[152] "FTC Asks for Documents in Nvidia's $40B Takeover," *Competition Policy International*, December 22, 2020, https://www.competitionpolicyinternational.com/ftc-asks-for-documents-in-nvidias-40bn-arm-takeover/.

[153] Cheng Ting-Fang and Lauly Li, "ARM China Asks Beijing to Intervene in Row with UK Parent," *Nikkei Asia*, July 28, 2020, https://asia.nikkei.com/Business/China-tech/Arm-China-asks-Beijing-to-intervene-in-row-with-UK-parent.

[154] Maria Ponnezhath, Amy Caren Daniel, ed., "Huawei, Other Chinese Tech Firms Raise Concerns on Nvidia's ARM Deal: Bloomberg News," *Reuters*, October 21, 2020, https://www.reuters.com/article/us-arm-holdings-m-a-nvidia-huawei/huawei-other-chinese-tech-firms-raise-concerns-on-nvidias-arm-deal-bloomberg-news-idUSKBN2760OJ.

[155] Ryo Yamaoka, "SoftBank's Plan to Sell ARM to NVIDIA Is Hitting Antitrust Wall around the World," *Nikkei Asia,* January 23, 2021, https://asia.nikkei.com/Business/Technology/SoftBank-s-plan-to-sell-Arm-to-NVIDIA-is-hitting-antitrust-wall-around-the-world.

[156] Xiuxi Zhu, "Potential U.S. Ban on SMIC Could Choke China's Semiconductor Supply Chain," *S&P Global*, September 22, 2020, https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/potential-us-ban-on-smic-could-choke-china-s-semiconductor-supply-chain-60375095.

firm Hopu Investments operating in China) while ARM Corporate states that he was fired.[157]

The NVIDIA/ARM deal would bring ARM's technology under the control of a U.S.-based company (NVIDIA is based in California), but ownership of the IP does not satisfy most security concerns. Similar to TSMC becoming the go-to manufacturer for so many advanced semiconductor chip designers (including Intel's 7nm designs), NVIDIA's acquisition of ARM presents a risky aggregation of ownership in advanced semiconductors. In this case, the aggregation is occurring with IP rather than with manufacturing capabilities. IP is especially critical to Chinese telecoms. The control of such a large amount of critical IP in global AI development, as well as mobile and embedded computational technology, by one conglomerate entity is a significant concern. With control of ARM's IP, NVIDIA could change the cost structure given the massive global dependence on ARM's designs as a result of concentration. Further, centralizing IP in such a large entity could encourage exfiltration attempts following complications with operations in China.

E. Conclusion

The DoD has developed three programs in response to the risk of an unsecure IC supply chain. Given the commercial and military risk, will this be enough? Can the DoD tolerate the risk of increasingly relying on foreign suppliers and manufacturers for IC that are designed into critical components covering a broad range of requirements including GPU-based advanced processing systems, mission relevant AI systems, long-range hypersonic missiles, space, and other emerging technologies sets?

Is a more direct strategic sourcing plan needed in which a company like Intel is categorized as a national asset? Should the U.S. government buy into the manufacturing of leading-edge IC by subsidizing sources and leveling the playing field with respect to foreign competition?

In the near term, increased participation in the DoD programs could assist the U.S. Army in securing the minimal supply of trusted ICs for its most critical efforts. Long term, the U.S. Army should consider a strategic role in advocating for its own and joint forces' needs for trusted U.S.-based manufacturing to secure the necessary substantial funding and buy-in from the U.S. Government, U.S. industry, and the American public.

[157] "Battle at ARM China Threatens $40bn Nvidia Deal," *Nikkei Asia*, November 4, 2020, https://asia.nikkei.com/Business/Technology/Battle-at-Arm-China-threatens-40bn-Nvidia-deal.

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13. SUPPLEMENTARY NOTES

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14. ABSTRACT

The Institute for Defense Analyses submits that the long-term strategic impact from future supply chain disruptions, including the potential inability of the U.S. to produce leading-edge integrated circuits (ICs) domestically, is a critical risk. This, coupled with the fact that demand for production is outpacing current manufacturing capacity, will have long-term consequences for the Department. Integrated circuits (ICs) are a fundamental and foundational element of electronics in components and systems. For the U.S. Army specifically, ICs are critical in weapon systems, core business systems, key communications systems, and artificial intelligence (AI) computational systems. Once a global leader, the United States finds itself in a position of decreasing control and influence in the leading-edge IC markets, a critical segment for enabling U.S. dominance. Although the United States is still a leader in the design of ICs, it is facing a diminished role in manufacturing, accounting for only 12% of semiconductor manufacturing worldwide and even less for leading-edge manufacturing of chip sets at the 7nm and below range. DoD finds itself at a disadvantage to influence market practices and buy down the risks potentially compromising its ability to perform its mission.

15. SUBJECT TERMS

Gray Zone Competition, Strategic Sourcing, Fabless, Leading-edge integrated circuits, Supply Chain disruption

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