United States Government Accountability Office

Report to Congressional Addressees

July 2022

SEMICONDUCTOR SUPPLY CHAIN

Policy Considerations from Selected Experts for Reducing Risks and Mitigating Shortages

GAO-22-105923

July 2022

SEMICONDUCTOR SUPPLY CHAIN

Policy Considerations from Selected Experts for Reducing Risks and Mitigating Shortages

GAO Highlights

Highlights of GAO-22-105923, a report to congressional addressees

Why GAO Did This Study

A global semiconductor shortage that began in 2020 has since affected multiple U.S. industries. Beyond having an immediate economic impact, the shortage has exposed long-term risks in the semiconductor supply chain. Further, U.S. policymakers have expressed concerns about the nation's declining share of global production. Accordingly, the U.S. Senate and House of Representatives have both passed bills aimed at incentivizing construction of new semiconductor manufacturing facilities in the U.S.

This report summarizes the views of selected experts on policy options to reduce semiconductor supply chain risks and help mitigate future shortages in the U.S.

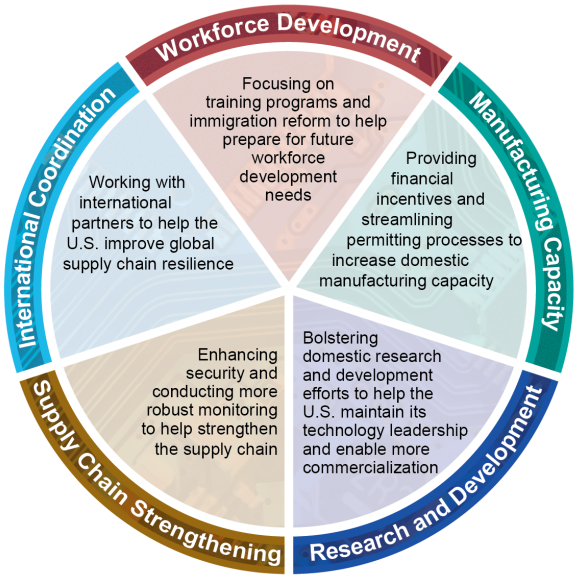
GAO conducted a literature review and compiled a list of potential policy options across multiple areas of federal activity. GAO then selected and interviewed 17 experts, including industry executives, government officials, and knowledgeable representatives from academia and nonprofits. In the interviews, GAO asked the experts about their views on which of the policy options had the greatest potential to mitigate supply chain risks.

View GAO-22-105923. For more information, contact Candice Wright, (202) 512-6888, wrightc@gao.gov

What GAO Found

Experts interviewed by GAO shared their views on policy options in several areas that could reduce semiconductor supply chain risks (see figure). Across these areas, workforce development was the one area where all 17 experts GAO interviewed agreed on the need to take action. At the same time, the experts generally emphasized the value of implementing policies in each of these areas and said that no single policy option would be sufficient. Instead, the experts recommended implementing a variety of policy options, such as addressing immigration reform and improving supply chain monitoring.

Federal Actions that Could Reduce Semiconductor Supply Chain Risks



Source: GAO analysis of expert interviews (information). raimundas/stock.adobe.com (images). | GAO-22-105923

The experts GAO spoke with discussed the need for identifying federal priorities and improving interagency collaboration in implementing policies to mitigate semiconductor supply chain risks. Examples of policy priorities that experts discussed related to semiconductor supply chain risks include national security, economic competitiveness, and increased resilience. Experts stated that identifying the most appropriate policy option depends on the federal priority. For example, one expert said the extent to which increasing semiconductor production in the U.S. is important depends on whether national security is the policy priority. Geographic diversity, including production outside the U.S., might be desirable if economic competitiveness of U.S.-headquartered companies or increased supply chain resilience are priorities. Additionally, experts noted that multiple federal agencies have activities related to semiconductor supply chains and described ways in which improved coordination among agencies would allow the U.S. to act more strategically. For example, one expert said that agencies working on semiconductor issues should identify current activities as well as the need for additional action.

Contents

Abbreviations

CHIPS	Creating Helpful Incentives to Produce Semiconductors
COVID-19	Coronavirus Disease 2019
DOD	Department of Defense
EU	European Union
NDAA	National Defense Authorization Act
R&D	research and development
STAPLE	Stopping Trained in America Ph.D.s from Leaving the Economy
STEM	science, technology, engineering, and mathematics

U.S. GOVERNMENT ACCOUNTABILITY OFFICE
441 G St. N.W.
Washington, DC 20548

July 26, 2022

Congressional Addressees

Semiconductors, also called microchips or chips, are tiny electronic devices that are critical to nearly all industries.[1] A global semiconductor shortage that began in 2020 continues to affect a range of U.S. industries. For example, an auto industry representative linked the shortage to the production of 3 million fewer cars in North America during 2021. This low supply of new cars led to an 11.8 percent price increase for new cars and 37.3 percent price increase for used cars. The White House reported that the shortage may have reduced the U.S. gross domestic product by one full percentage point in 2021.[2] In addition to having an economic impact, the shortage has exposed long-term risks in the semiconductor supply chain. These risks include workforce gaps, opaque supplier networks, and potential choke points resulting from the concentration of raw materials and manufacturing facilities in a limited number of regions globally.

The United States leads some segments of the semiconductor supply chain, including the production of semiconductor manufacturing equipment and chip design. According to one report, U.S. companies make up 39 percent of the total market share within the global semiconductor supply chain.[3] However, one industry association reported that the U.S. share of global manufacturing capacity for some types of

[1]The term semiconductor refers to a material that has electrical conductivity greater than an insulator, but less than a conductor. In this report we use a common definition of the term to refer to computer chips and integrated circuits. Intel, *Semiconductors and Intel: An Introduction*, https://www.intel.com/content/www/us/en/architecture-and-technology/semiconductors-primer.html; Congressional Research Service, *Semiconductors: U.S. Industry, Global Competition, and Federal Policy,* R46581 (Oct. 26, 2020).

[2]White House, *Fact Sheet: Biden-Harris Administration Bringing Semiconductor Manufacturing Back to America*, (Jan. 21, 2022), accessed June 23, 2022, https://www.whitehouse.gov/briefing-room/statements-releases/2022/01/21/fact-sheet-biden-harris-administration-bringing-semiconductor-manufacturing-back-to-america-2/.

[3]Within this context, the semiconductor supply chain includes the following: research and development, production, production inputs, and distribution for end-use. Saif Khan, Alexander Mann, and Dahlia Peterson, *The Semiconductor Supply Chain: Assessing National Competitiveness* (Center for Security and Emerging Technology, January 2021) 8, https://cset.georgetown.edu/publication/the-semiconductor-supply-chain/.

semiconductor production declined from 37 percent in 1990 to 12 percent in 2022.[4] A previous study found that the decline in U.S. ability to manufacture the next generation of advanced technologies, such as semiconductors, poses a significant long-term economic risk to the United States' ability to generate economic growth through innovation leadership.[5]

U.S. policymakers have expressed concerns about the nation's declining share of global semiconductor production and its lack of advanced semiconductor production capabilities. To address these concerns, the U.S. House and Senate passed bills (in February 2022 and June 2021, respectively) that would, among other things, appropriate over $50 billion in public funding to incentivize semiconductor companies to build manufacturing facilities in the United States.[6] These bills also contain provisions for GAO to report on the global semiconductor shortage and its impact on U.S. manufacturing. We expect to issue a full report on the topic in early 2023.

This report summarizes selected experts' views on policy options that could reduce semiconductor supply chain risks and help mitigate future semiconductor shortages in the United States. In this report, we do not identify which options are being implemented by agencies or are currently being considered in pending legislation. In our forthcoming report, we plan to assess the types of actions the federal government is taking to address semiconductor supply chain risks and describe how agencies are implementing recent legislative requirements.

To gather experts' views on policy options, we selected and interviewed 17 experts with cross-cutting subject matter knowledge related to the semiconductor supply chain. The experts we interviewed included

[4]Semiconductor Industry Association, 2021 State of the U.S. Semiconductor Industry https://www.semiconductors.org/wp-content/uploads/2021/09/2021-SIA-State-of-the-Industry-Report.pdf. We did not independently verify the data and analysis included in this report.

[5]William B. Bonvillian and Peter L. Singer, *Advanced Manufacturing: The New American Innovation Policies* (Cambridge, MA: MIT Press, 2017), 51.

[6]The two bills, United States Innovation and Competition Act of 2021, S.1260, 117th Cong. § 1002 (a)(2) (2021) and America COMPETES Act of 2022, H.R.4521, 117th Cong. § 1002(a)(2) (2022), would appropriate funding for the Creating Helpful Incentives to Produce Semiconductors for America Act (CHIPS Act), (included in the William M. (Mac) Thornberry National Defense Authorization Act for Fiscal Year 2021 (NDAA FY2021), Pub. L. No. 116-283, div. A, tit. XCIX, §§ 9901-9908, 134 Stat. 3388, 4843 (2021) (codified at 15 U.S.C. §§ 4651-4658).

industry executives, government officials, and representatives from academia and nonprofits. We identified the experts by reviewing relevant publications, congressional testimonies, and academic and industry presentations. We also conducted an extensive literature review. Based on that review, we compiled a list of over 70 potential policy options in five categories: research and development (R&D), supply chain strengthening, workforce development, manufacturing capacity, and trade and international coordination. We then interviewed the experts about their views on which policy options had the greatest potential to mitigate supply chain risks. See appendix I for more information on our scope and methodology.

We conducted our work from March 2022 to July 2022 in accordance with all sections of GAO's Quality Assurance Framework that are relevant to our objectives. The framework requires that we plan and perform the engagement to obtain sufficient and appropriate evidence to meet our stated objectives and to discuss any limitations in our work. We believe that the information and data obtained, and the analysis conducted, provide a reasonable basis for any findings and conclusions in this product.

Background

Semiconductors, or chips, are generally smaller than a postage stamp and are composed of billions of components that store, move, and process data. All of these functions are made possible by the unique properties of semiconducting materials that allow for the precise control of the flow of electrical current. Numerous products use semiconductors for many purposes, including to run software applications and to provide data storage and communication capabilities for countless products, such as mobile phones, gaming systems, aircraft avionics, industrial machinery, and military equipment and weapons.

Semiconductors are primarily produced from silicon wafers, but can also be made from gallium arsenide, gallium nitride, and silicon carbide wafers for certain uses. Producing semiconductors requires various chemicals, gases, and different types of manufacturing equipment. Three broad steps are involved in the production of semiconductors: (1) design; (2) manufacturing; and (3) assembly, testing, and packaging. Historically, companies known as integrated device manufacturers performed all three steps in-house. However, with the increased complexity of design and manufacturing, many companies began specializing in different steps of the process. Some companies began focusing on chip design and started contracting with other companies to manufacture their designs. The stage of assembly, testing, and packaging the devices is either done at the

manufacturing site or outsourced to another company that specializes in this step.[7]

When considering the types of semiconductors produced today, one key distinction is the maturity of the technology used to manufacture them. As technology evolves, semiconductor manufacturing techniques place increasing amounts of information processing power in physically smaller spaces. These more advanced chips (known as "leading-edge chips") are used to build highly complex processors that are used in applications such as artificial intelligence and machine learning.[8] "Legacy chips" on the other hand, are semiconductors made with older technology that are still used today for many applications.

The semiconductor supply chain—from R&D to design, production, and eventual incorporation into end products purchased by customers—is extremely complex and geographically dispersed. Most companies are based in China, Europe, Japan, South Korea, Taiwan, and the United States. Because companies across the globe specialize in specific steps, the semiconductor production process often spans multiple countries. Components may cross international borders as many as 70 times before reaching the final consumer.[9] The entire process can take up to 100 days, of which 12 days are used for transit between supply chain steps.[10] See fig. 1 for an example of a global semiconductor production process.

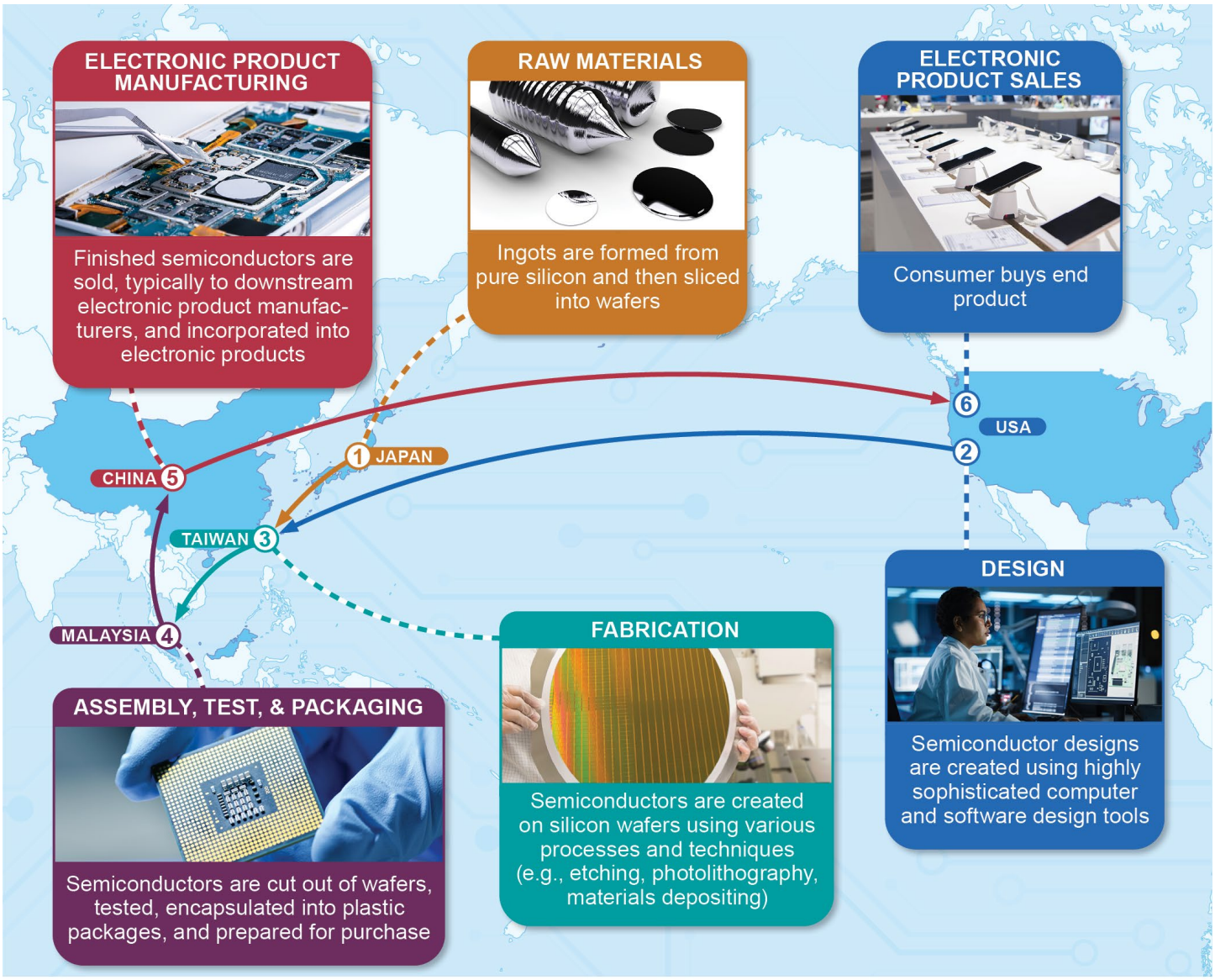
[7]Such third-party companies are known as outsourced semiconductor assembly and test (OSAT) companies. More than 80 percent of the world's top 20 OSAT companies are headquartered in Taiwan, the United States, and China.

[8]McKinsey & Company, *Semiconductor Design and Manufacturing: Achieving Leading-edge Capabilities* (Aug. 20, 2020) https://www.mckinsey.com/industries/advanced-electronics/our-insights/semiconductor-design-and-manufacturing-achieving-leading-edge-capabilities.

[9]Accenture and Global Semiconductor Alliance, Globality and Complexity of the Semiconductor Ecosystem (Feb. 2020) https://www.accenture.com/_acnmedia/PDF-119/Accenture-Globality-Semiconductor-Industry.pdf#zoom=50.

[10]The White House, *Building Resilient Supply Chains, Revitalizing American Manufacturing, and Fostering Broad-Based Growth: 100-Day Reviews under Executive Order 14017* (June 2021) http://www.whitehouse.gov/wp-content/uploads/2021/06/100-day-supply-chain-review-report.pdf.

Figure 1: Illustration of a Global Semiconductor Production Process



Source: Congressional Research Service, *Semiconductors: U.S. Industry, Global Competition and Federal Policy,* R46581 (Oct. 26, 2020) which was adapted from information provided by the Semiconductor Industry Association (information), GAO analysis (presentation), and Gorodenkoff/I'm Thongchai/frog/22091967/bodnarphoto/stock.adobe.com (photos) | GAO-22-105923

The structure of this highly complex, interdependent global supply chain is subject to numerous risks including geopolitical, technological, economic, environmental, and security-related concerns. One of these risks is the existence of critical chokepoints in the supply chain caused by the reliance on a limited number of suppliers for a single production step

or for critical materials and equipment. For example, one Netherlands-based company is the only global supplier for specialized lithography equipment needed to manufacture the most advanced semiconductors.[11] In addition, most leading-edge chips are manufactured in Taiwan. Climate-related factors can add another layer of risk to these chokepoints. For example, in 2021, Taiwan experienced its worst drought in over half a century, causing leading semiconductor manufacturers to depend on water trucks to maintain production.

Another risk is the volatile nature of international crises. For example, the COVID-19 pandemic caused a spike in demand for consumer electronics and at the same time it resulted in manufacturing facility closures, which contributed to the current global semiconductor shortage. Additionally, the war in Ukraine is expected to cause a decrease in the supply of neon gas, which mostly comes from Ukraine and Russia and is a critical component in the semiconductor manufacturing process.[12]

Compared to other nations who provide considerable government incentives to their semiconductor industries, the U.S. government currently plays a limited role in providing such incentives to support domestic semiconductor production. According to a joint industry report, incentives provided by other national governments can make up to 40 to 70 percent of the cost advantage these countries have over the U.S. semiconductor industry. For example, China reportedly provided $33 billion worth of subsidies in 2020. China also offers incentives such as land, grants, and preferential loan and tax rates.[13] Other countries in Asia, such as Taiwan and South Korea, have given strategic focus to their semiconductor industries and support domestic manufacturing by providing tax credits, grants, and other government incentives.[14]

[11]Extreme ultraviolet (EUV) lithography is the process used to install transistors on the most advanced chips.

[12]About 70 percent of the world's neon come from Ukraine and Russia. GAO, *Advanced Technologies: Strengthened Federal Approach Needed to Help Identify and Mitigate Supply Risks for Critical Raw Materials,* GAO-16-699 (Washington, D.C.: Sept. 7, 2016).

[13]Antonio Varas, Raj Varadarjan, Jimmy Goodrich, and Falan Yinug. "Government Incentives and U.S. Competitiveness in Semiconductor Manufacturing." *Boston Consulting Group and the Semiconductor Industry Association.* September 2020.

[14]Varas, Varadarjan, Goodrich, and Yinug. "Government Incentives"

The recent semiconductor shortage has prompted U.S. lawmakers to create legislation aimed at addressing challenges to increasing domestic semiconductor production. On January 1, 2021, Congress enacted the Creating Helpful Incentives to Produce Semiconductors for America Act (CHIPS Act), as part of the William M. (Mac) Thornberry National Defense Authorization Act for Fiscal Year 2021 (NDAA FY2021). The CHIPS Act authorized the federal government to conduct a number of activities, including providing financial assistance to incentivize investment in facilities and equipment in the United States for semiconductor fabrication, assembly, testing, advanced packaging, or R&D.[15] The CHIPS Act also authorizes the establishment of both a National Semiconductor Technology Center to conduct research and prototyping of advanced semiconductor technology and a National Advanced Packaging Manufacturing Program.

In addition to the activities authorized by the CHIPS Act, there are a variety of ways in which federal agencies are working to address semiconductor supply chain issues. In February 2021, the administration issued Executive Order No. 14,017 on "America's Supply Chains," which called for federal agencies to conduct reviews of supply chain risks in several areas, including semiconductors.[16] In response to the Executive Order, the Department of Commerce (Commerce) played a convening role by bringing industry representatives together to obtain information and encourage increased transparency throughout the supply chain. In 2021, Commerce's Bureau of Industry and Security issued two notices requesting information related to semiconductors, and one notice about the information communications technology supply chain, which is facing ripple effects due to the global semiconductor shortage.[17] This data collection effort allowed Commerce to report on the impacts of the shortage on a range of industries. Specifically, this report found that consumer inventories for difficult to acquire semiconductor products decreased from 2019 to 2021, falling from 40 days to less than 5 days. It

[15]NDAA FY2021, Pub. L. No. 116-283, div. A, tit. XCIX, §§9901-9908, 134 Stat. 3388, 4843 (2021) (codified at 15 U.S.C. §§ 4651-4658).

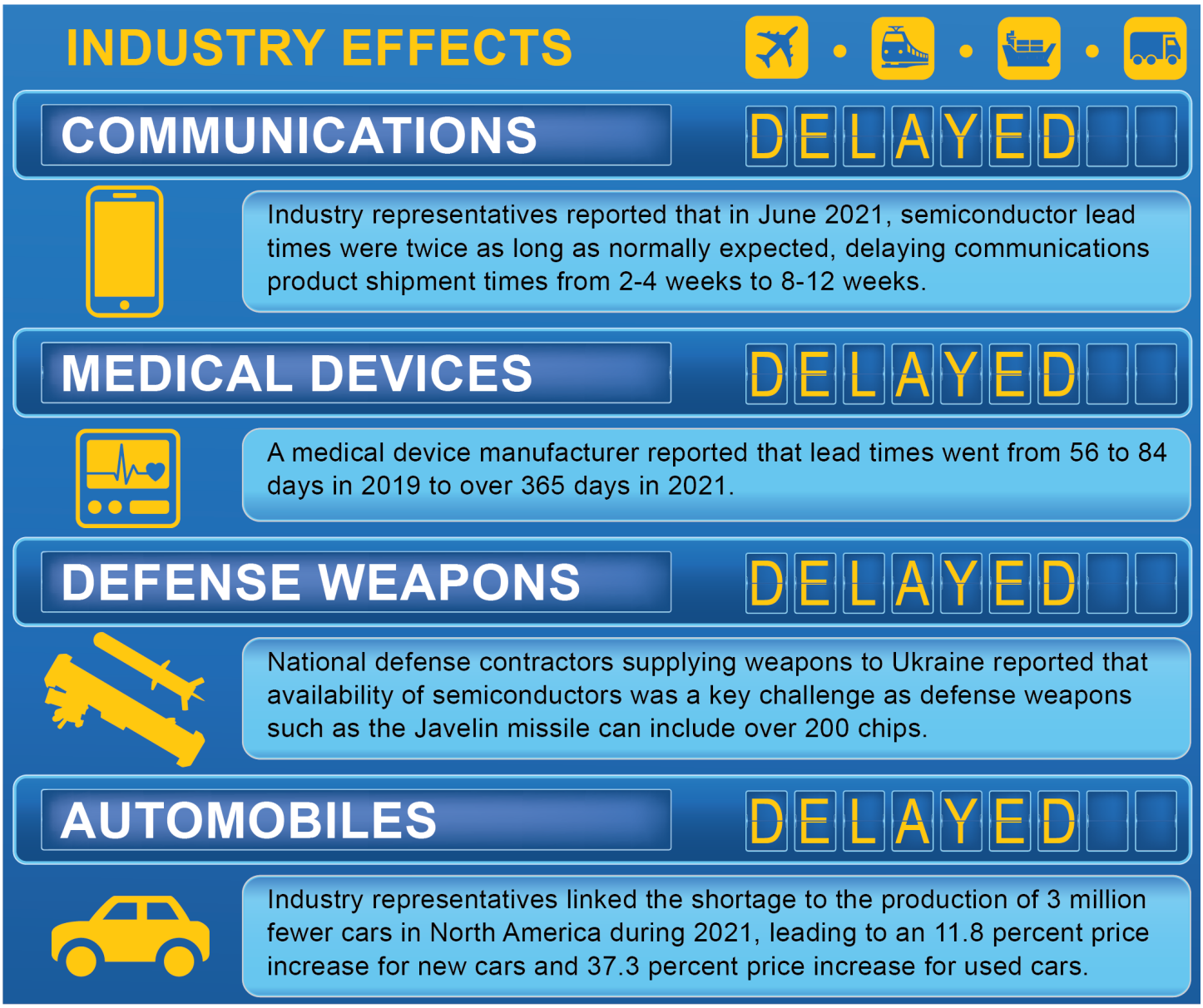
[16]Exec. Order No. 14,017, *America's Supply Chains* (Feb. 24, 2021), 86 Fed. Reg. 11,849 (Mar. 1, 2021).

[17]Risks in the Semiconductor Manufacturing and Advanced Packaging Supply Chain (BIS-2021-0011), 86 Fed. Reg. 14308 (Mar. 15, 2021); Notice of Request for Public Comments on Risks in the Information Communications Technology Supply Chain (BIS-2021-0021), 86 Fed. Reg. 52127 (Sept. 20, 2021); Notice of Request for Public Comments on Risks in the Semiconductor Supply Chain (BIS-2021-0036), 86 Fed. Reg. 53031 (Sept. 24, 2021).

also revealed the types of semiconductors with the most significant mismatch in supply and demand are required by several critical industries, such as medical devices, automotive, and broadband.[18] See fig. 2 for examples of the effects of the semiconductor shortage on selected industries.

[18]Department of Commerce, Results from Semiconductor supply Chain Request for Information, (Washington, DC: Jan. 25, 2022). https://www.commerce.gov/news/blog/2022/01/results-semiconductor-supply-chain-request-information.

Figure 2: Effects of the Semiconductor Shortage



Source: GAO analysis of public reporting (data). maconga, wawx, nuwaba /stock.adobe.com (images) | GAO-22-105923

At the international level, the U.S. Trade Representative, Commerce, and Department of State have worked with international partners to jointly

address technology and trade challenges.[19] At the U.S.-European Union (E.U.) Summit in June 2021, the administration announced the formation of the U.S.-E.U. Trade and Technology Council, which includes a "Working Group on Secure Supply Chains" focused on semiconductors. Our forthcoming report on the global semiconductor shortage and its impacts on manufacturing will provide additional information on federal actions to strengthen semiconductor supply chains.

Experts Identified Federal Actions that Could Reduce Semiconductor Supply Chain Risks to Mitigate Future Shortages

Selected experts we interviewed identified federal actions that they believe could reduce semiconductor supply chain risks to mitigate future shortages. The experts recommended a range of federal policies to address such risks. They also discussed the need for identifying federal priorities and improving interagency collaboration in implementing these policies.

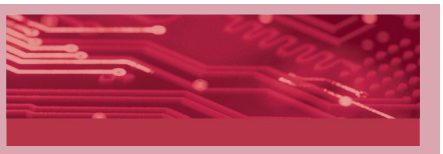
Experts Recommended a Range of Federal Policies to Address Risks to the Semiconductor Supply Chain

The 17 experts we interviewed recommended a range of federal policies to address risks in the semiconductor supply chain. Specifically, we asked the experts to identify which of the over 70 policy options we compiled through our literature review had the greatest potential to reduce supply chain risks and mitigate future shortages. We grouped the policy options into the following five categories: workforce development, supply chain strengthening, R&D, manufacturing capacity, and trade and international coordination. In response, the experts generally emphasized that no single policy option would be sufficient. Instead, the experts recommended implementing a variety of policy options such as addressing immigration reform to meet workforce needs, establishing public-private partnerships, and improving supply chain monitoring. However, some experts were in favor of a more limited role for the federal government and noted the importance of the private sector taking the lead to address semiconductor supply chain risks. Additionally, some experts stated that, while little can be done to solve the current shortage, the federal government could address structural risks over the long term.

[19]We have a forthcoming report reviewing the diplomatic efforts that the U.S. Trade Representative, Commerce, and Department of State have taken in coordination with key trading partners to strengthen supply chains since the onset of the COVID-19 pandemic and any efforts to address challenges faced across sectors.

When reporting the results of our expert interviews, we define "all" as 17 experts, "most" as 14-16 experts, "many" as 10-13 experts, "several" as 6-9 experts, and "some" as 3-5 experts. Our methodology allowed for an open response from the experts to identify which policies from our list of options stood out to them. Therefore, we did not receive comments from every expert on each of the policies. The total number of experts who agreed or disagreed with a particular policy option reflects only those experts who identified the option as either particularly beneficial or particularly unhelpful.

Focusing on Training and Immigration Reform to Address Future Workforce Development Needs



Policy Options to Address Semiconductor Supply Chain Risks

- **Workforce Development**
- Supply Chain Strengthening
- Research and Development
- Manufacturing Capacity
- International Coordination

Source: GAO (information). Shuo/stock.adobe.com (images). | GAO-22-105923

All of the experts interviewed highlighted the importance of workforce policy options. These policy options included training programs and immigration reform to ensure that the semiconductor industry has enough trained workers to meet its needs. In discussing the importance of addressing workforce issues, some experts mentioned that the availability of workers in a particular geographic area played a role in firms' decisions about where to locate their operations. However, while agreeing with the criticality of addressing workforce issues, two experts stated that, to avoid duplicating efforts, the government needs to better understand the current landscape of workforce development in the United States. This includes better understanding which workforce training programs exist, which ones are working, and performance metrics for measuring success.

> "The ultimate supply chain is the chain of human talent, and there is a dire need for the U.S. to encourage a much more robust workforce in manufacturing."— **One Expert's View on the Importance of Workforce Development**

Source: Participant in expert interviews. | GAO-22-105923

- **Science, Technology, Engineering and Mathematics (STEM) training**.[20] Most experts highlighted the value of investing in STEM

[20]GAO has done prior work on STEM and career and technical education. See GAO, *Science, Technology, Engineering, and Mathematics Education: Actions Needed to Better Assess the Federal Investment*, GAO-18-290 (Washington, D.C.: March 23, 2018); GAO, *Science, Technology, Engineering, and Mathematics Education: Assessing the Relationship between Education and the Workforce*, GAO-14-374 (Washington, D.C.: May 8, 2014); GAO, *Science, Technology, Engineering, and Mathematics Education: Strategic Planning Needed to Better Manage Overlapping Programs across Multiple Agencies*; GAO-12-108 (Washington, D.C.: Jan. 20, 2012); and GAO, *Career and Technical Education: Perspectives on Program Strategies and Challenges,* GAO-22-104544 (Washington, D.C.: March 30, 2022).

training, education, or scholarships and provided a number of suggestions for attracting workers and strengthening the workforce, including:

- having additional leading-edge facilities in the United States to draw aspiring students into semiconductor R&D and manufacturing,[21]
- having more prototyping facilities which would enable workers to build hands-on experience and strengthen their technical knowledge, and
- supporting initiatives at the vocational school and community college levels.

- **Immigration reform.** Many experts stated that immigration policy reform would be beneficial because it would allow more of the best and the brightest to work in the United States. However, one expert emphasized the need to also focus on domestic worker training. This expert also said that the Optional Practical Training program is preferable to H-1B programs because the rights of H-1B workers are limited and it is difficult for them to change employers.[22] Another expert expressed strong support for a bill introduced in the 115th Congress, the Stopping Trained in America Ph.D.s from Leaving the Economy (STAPLE) Act of 2017. This act would have authorized certain noncitizens who have earned a Ph.D. degree from a U.S. institution of higher education in a STEM field to be admitted for permanent residence and be exempted from the numerical limits (caps) on H-1B nonimmigrants.[23]

[21]In discussing experts' views with DOD an official noted that building advanced node fabrication facilities is insufficient to attract the required number of STEM graduates to the semiconductor fabrication industry. The official stated that one of the primary challenges that the semiconductor fabrication industry faces is lower starting pay. This incentivizes STEM graduates to seek opportunities in the software sector, which typically offers higher pay.

[22]The Optional Practical Training program provides temporary employment for students who hold an F-1 U.S. visa and is administered through the U.S. Citizenship and Immigration Services within the Department of Homeland Security. The H-1B visa program enables U.S. companies to employ noncitizen workers temporarily in fields that require the utilization of highly specialized knowledge and a bachelor's degree or higher. This program is also administered through the Department of Homeland Security's U.S. Citizenship and Immigration Services.

[23]Stopping Trained in America Ph.D.s from Leaving the Economy (STAPLE) Act of 2017, H.R.2717, 115th Cong. (2017).

Supply Chain Strengthening through Enhanced Security and Conducting More Robust Monitoring

Policy Options to Address Semiconductor Supply Chain Risks

- Workforce Development
- **Supply Chain Strengthening**
- Research and Development
- Manufacturing Capacity
- International Coordination

Source: GAO (information). Shuo/stock.adobe.com (images). | GAO-22-105923

Many experts said that enhancing security and conducting more robust monitoring could help to strengthen the semiconductor supply chain. Experts also recommended federal actions in several other areas to strengthen the supply chain. On the other hand, some experts expressed broad concern about the government's involvement in strengthening the supply chain at all and stated that the private industry was better positioned to do so. In particular, several experts did not believe that the government should be involved in allocating chips to industry.

- **Supply chain security.** Many experts generally noted that policy options to enhance supply chain security were significant. Policy options within this area focus on coordinating technology standards, defining and standardizing new open-source models for semiconductors, establishing programs to understand supply chain risks, and stockpiling critical materials.[24] As a part of supply chain security, several experts noted that there is a federal role for stockpiling domestic supplies along the semiconductor supply chain or stockpiling chips themselves to enhance national security interests. The Department of Defense (DOD) manages the National Defense Stockpile, which stockpiles critical materials, including rare earth minerals, to ensure weapons can be manufactured and national security needs are met. However, in a report issued in response to Executive Order No. 14,017, DOD noted that private sector inventories are thin and the National Defense Stockpile is diminishing—causing vulnerabilities for national preparedness.[25] Alternatively, some experts questioned the value of stockpiling semiconductors because they are customized and cannot always be easily substituted between different products.[26] Another expert pointed out that even with stockpiled supplies, a lack of U.S. domestic

[24]We previously reported on federal efforts to promote U.S. innovation and industrial competitiveness by supporting the development of standards in collaboration with the private sector. See, GAO, *National Institute of Standards and Technology: Additional Review and Coordination Could Help Meet Measurement Service Needs and Strengthen Standards Activities*, GAO-18-445 (Washington, D.C.: July 26, 2018).

[25]Department of Defense, *Securing Defense-Critical Supply Chains: An action plan developed in response to President Biden's Executive Order 14017* (Washington, D.C.: Feb. 2022).

[26]In discussing experts' views with DOD, an official noted that degradation of component performance over the storage period and the environmental requirements to store components are additional reasons that stockpiling semiconductors can be problematic.

manufacturing capacity could limit semiconductor production. Some experts also mentioned the necessity of leveraging the expanded roles of the Cybersecurity and Infrastructure Security Agency to establish and operate programs to help semiconductor manufacturers identify and mitigate risks in their systems.[27]

- **Supply chain monitoring and transparency.** Many experts discussed the importance of implementing policies to monitor the complex semiconductor supply chain, and increase transparency to better understand the companies, suppliers, and countries involved and identify bottle-necks and mitigate shortages. Specifically, several experts said that the federal government should create and support a voluntary and timely data-sharing mechanism for firms that improves visibility into second, third and fourth tier suppliers throughout the semiconductor supply chain. However, some experts indicated that, while developing a voluntary and timely data-sharing mechanism could be beneficial, it would be challenging to implement. Some experts stated that there is an opportunity for the government to improve communication between companies and promote partnerships by convening meetings of company representatives. Other experts discussed the importance of creating a new office within Commerce to specifically focus on monitoring the resilience, diversity, security, and strength of the supply chain. However, one expert who suggested this role for Commerce had concerns about whether it would have enough personnel and expertise to create and staff such an office.

  Some experts stated that the federal government should not require companies to disclose proprietary information when the government is collecting and mapping supply chain data. Two experts suggested that it is possible to map the supply chain architecture without getting to the level of proprietary information. For example, these experts stated that high-level organizational information about the supply chain could be used for collaborative mapping rather than providing specific details about suppliers and customers. This would make the industrial hierarchy transparent without disclosing proprietary information. In discussing experts' views, a Commerce official

[27]The Cybersecurity and Infrastructure Security Agency has new required responsibilities outlined in the NDAA FY2021 that would work to strengthen the semiconductor supply chain, such as 1) establish and operate programs to help owner-operators identify, understand, and mitigate threats, vulnerabilities, and risks to their systems or assets; 2) recommend security measures to owner-operators; and 3) facilitate information sharing regarding physical security and cybersecurity threats. Homeland Security Act of 2002, tit. XXII, subtit. A, § 2215, *amended by* NDAA FY2021, Pub. L. No. 116-283, div. H, tit. XC, §9902, 134 Stat. 3388, 4771, (2021) (to be codified at 6 U.S.C. § 665d(c)(1)-(2)).

disagreed, and stated that Commerce needs access to proprietary information in order to understand the supply chain. One expert also stated that companies should not be able to both claim their supply chain information is proprietary and receive public financial support.

- **Secure access to critical materials.** Several experts discussed the importance of investing in critical materials that are needed for the semiconductor industry. Numerous materials, chemicals, and gases are crucial to the semiconductor manufacturing process. Some of these critical materials are also threatened by potential scarcities, including neon, germanium, helium, high purity solvents, and tantalum, among others.[28] As a part of investing in critical materials, some experts said that the United States should coordinate with key trading partners who already have existing production of raw materials and chemicals that are needed for the production of semiconductors. For example, Japan works to secure critical materials access through direct funding for global exploration and development projects in a number of countries.[29] Two experts also talked about the importance of innovation and materials science research to increase availability of material substrates and one highlighted the importance of decreasing reliance on materials sourced from U.S. adversaries.[30]
- **Building supply chain resiliency.** Several experts generally noted that policies geared towards building supply chain resiliency were important. Such policy options would focus on improving baseline resiliency, developing and requiring resiliency standards, and encouraging partnerships and collaboration. One expert said that building supply chain resiliency was the most critical area for policy focus in order to strengthen the supply chain. Further, one expert noted the importance of taking strategic action to build resiliency to address geopolitical supply chain risks. This expert stated that

[28]Semiconductor Industry Association, *Comments of the Semiconductor Industry Association on the Notice of Request for Information on "Critical and Strategic Materials Supply Chains" 79 Fed. Reg. 42560* (July 24, 2014). (Comments submitted by SIA in response to Office of Science and Technology Policy, Notice, 79 Fed. Reg. 42,560 (July 22, 2014) on Sept. 30, 2014) (Last accessed on June 28, 2022, https://www.semiconductors.org/wp-content/uploads/2018/06/OSTP-comments-on-critical-and-strategic-materials-september-2014.docx.pdf.

[29]GAO has previously reported on the approaches of selected countries and regions to address critical materials supply issues. See GAO-16-699.

[30]For more information about key challenges affecting efforts to advance critical minerals recovery and substitution in the United States see GAO, *Critical Minerals: Building on Federal Efforts to Advance Recovery and Substitution Could Help Address Supply Risks*, GAO-22-104824 (Washington, D.C.: June 16, 2022).

strategic action to achieve resiliency should focus on addressing larger geopolitical risks, such as ensuring domestic production capability for the most advanced semiconductor technology. Some experts discussed establishing federally required best practices to enhance resiliency but stated this should not involve the government dictating inventory levels for private firms. One expert suggested that the federal government should incentivize companies to change their inventory management practices. On the other hand, another expert stated that holding inventory is not the only way to build resilience. This expert stated that holding inventory is costly and often ineffective if the wrong part is held, and suggested that the federal government should promote producers' agility—their ability to pivot to alternative products or processes or react to abnormal situations.

- **Prioritizing chip supply based on industry needs.** Several experts stated that having the federal government prioritize and allocate chips based on industry needs would not be beneficial. We shared two potential policy options with experts: incentivizing chip production based on market demand analysis and prioritizing semiconductor industry investments for critical manufacturing sectors. Of the experts who did not believe these policies would be beneficial, one stated that the government should not prioritize and allocate chips based on need because it cannot react fast enough. Another expert stated that prioritizing allocation based on certain industries would have limited feasibility, because chips are so specialized. As it relates to prioritization and allocation of chips based on defense needs, two experts stated that mechanisms, such as Title I of the Defense Production Act of 1950, could be effective at reducing supply chain risks for the defense sector during an emergency.[31] However, they did

[31]Title I of the Defense Production Act of 1950 allows the President to require entities to prioritize and accept contracts for materials, services, and facilities as necessary to promote the national defense. 50 U.S.C. § 4511(a) (2018).

not believe that prioritization for defense needs was effective in the long term.

> "Federal efforts to prioritize defense needs can indeed be effective, but it should be kept in mind that while this solves [the problem] for defense needs, it comes at the expense of some other customer that is already dealing with short supply. That customer could be, for instance, a manufacturer of lifesaving medical equipment, of critical infrastructure equipment, or an automobile manufacturer. While such an approach can work in an emergency to prioritize defense needs, in the long run it tends to distort the demand signal even more and makes it difficult for semiconductor companies to determine true demand in order to size their investments."
> — **One Expert's View on Prioritizing Defense Needs**

Source: Participant in expert interviews. | GAO-22-105923

- **Increasing and clarifying the demand signal.** Some experts stated that the federal government could increase the supply of semiconductors by boosting demand through public procurement contracts or implementing private sector spending incentives.[32] One expert stated that, if the federal government promoted the use of more microelectronics in infrastructure projects such as smart grids, clean energy, and high speed rail, it would increase the demand signal for domestic production of semiconductors. One expert additionally stated that supporting secure microelectronics for non-DOD needs would create greater economies of scale for manufacturing secure microelectronics. Two experts also noted that the federal government could bring industry together to create a clearer demand signal. One of these experts pointed out that companies are hesitant to share information with each other and thus the actual demand for semiconductors is difficult to determine. This expert also said that manufacturers are unclear whether the current demand signal is going to last or whether it is cyclical and will be followed by an oversupply in the market. This in turn may hinder decision making about production capacity investments. According to the experts, federal efforts to convene companies and encourage information sharing could provide

[32]In the semiconductor context, "demand-side" dynamics have a causal relationship to manufacturing capacity as well as productivity outcomes. Demand changes can lead to supply changes by "pulling new capacity online or by forcing firms to depreciate and decommission existing capacity." Skanda Amarnath and Alex Williams. "Supplying Demand: The Chips Shortage in Macro Context." *Employing America.* March 4, 2021.

clarity about the current and projected demand.[33] One expert noted that a mechanism for convening companies is for Commerce to call companies together for meetings as it did in 2021, potentially under the auspices of a critical supply chain resilience program.

Bolstering Research and Development to Help the U.S. Maintain Its Technology Leadership

Experts discussed the importance of maintaining U.S. leadership in technology innovation by providing financial incentives for R&D development, and developing public-private partnerships to enable more commercialization. In addition, experts recommended other federal actions to bolster research and development. Experts disagreed on the types of financial incentives that would be most beneficial, and two experts did not support providing financial incentives.

Policy Options to Address Semiconductor Supply Chain Risks

- Workforce Development
- Supply Chain Strengthening
- **Research and Development**
- Manufacturing Capacity
- International Coordination

Source: GAO (information). Shuo/stock.adobe.com (images). | GAO-22-105923

- **Financial incentives for research and development.** Many experts agreed that the federal government should provide greater financial incentives for R&D but disagreed on what types of financial incentives would be most effective[34]. Some experts stated that both indirect subsidies, such as tax benefits, and direct subsidies, such as research grants, should be provided to private companies. Two experts stated that additional R&D tax credits, which would allow industry to drive research efforts, were preferable.[35] However, one expert said that tax incentives make it much harder for the government to target market failures and advocated for companies engaging in a competitive bidding process so the government could provide grants to address market failures. Two experts stated that the government should not invest in applied R&D for semiconductors because companies within the semiconductor ecosystem are very profitable and therefore have the money to invest themselves. Another expert noted the government should place conditions on the funding provided to companies to ensure taxpayer's investment yields a public benefit. For example, the government could prohibit companies from using R&D subsidies for stock buybacks.

[33]GAO has not assessed whether or not this suggestion could implicate antitrust concerns or Title VII of the Defense Production Act of 1950 (50 U.S.C. § 4558).

[34]In discussing experts' views with DOD, an official emphasized that there are multiple DOD applications that require specific microelectronics that are not viable for commercial sector investment, such as strategic radiation hardened microelectronics. The official stated that it is critical that DOD invest in microelectronics R&D to maintain technical superiority of weapons systems.

[35]We previously reported on the use of and opportunities to improve the research tax credit. See GAO, *Tax Policy: The Research Tax Credit's Design and Administration Can be Improved*, GAO-10-136 (Washington, D.C.: Nov. 6, 2009).

- **Public-private partnerships.** Many experts discussed the importance of implementing policy options involving public-private partnerships. Several experts discussed the importance of using public-private partnerships to commercialize innovation and close the gap between research and fabrication (known as the 'lab to fab' gap). One expert suggested that an effective strategy might be to provide incentives for more industry labs which this expert stated was extremely successful in addressing semiconductor R&D needs. Some experts expressed concern about the use of national labs to bridge the 'lab to fab' gap. Specifically, one expert stated that leveraging the national labs to close the 'lab to fab' gap would require a deep understanding of the industry which the labs do not have. Some experts said that industry leadership, with its technical expertise should help address this gap, and one expert emphasized that industry wants to work with the government on these issues. This expert advocated for using an integrated approach that puts industry in a leadership role when creating the new National Science and Technology Council subcommittee on microelectronics leadership and competitiveness and the Industrial Advisory Committee called for in the CHIPS Act.
- **U.S. regional coordination.** Several experts mentioned the importance of implementing policy options that aim to enhance coordination of technology hubs and innovation strategies at the regional level in the United States. Two experts stated that strategic placement of regional sites—manufacturing ecosystems that would benefit from the efficiencies of concentrating manufacturing resources—was crucial. Specifically, one expert said that regional research hubs should be located near manufacturing sites so that the R&D innovation and efforts would benefit from local talent. Another expert said scale (rather than geographic distribution and quantity) should be the priority and therefore, the federal government should establish regional R&D technology hubs in just a few locations.
- **National innovation strategy.** Several experts stated that there is a need to invest in a comprehensive national semiconductor innovation strategy.[36] They said that a national strategy could help to fill the gaps

[36]Similarly, in prior work, experts we spoke to identified developing a strategic approach as a key consideration for maintaining U.S. competitiveness through transformational technological advances. See GAO, *Science and Technology: Considerations for Maintaining U.S. Competitiveness in Quantum Computing, Synthetic Biology, and other Potentially Transformational Research Areas*, GAO-18-656, (Washington, D.C.: Sept. 26, 2018).

in the existing innovation ecosystem and to catalyze expertise to address cross-cutting efforts.[37] Specifically, one expert stated that federal agencies could do more to support innovation while working towards their mission, and said that agencies should have a formalized process to support innovation.[38] This expert also stated that the federal government could do more to drive innovation throughout the nation, including expanding agencies' missions.

Providing Financial Incentives and Streamlining Permitting Processes to Help Increase Domestic Manufacturing Capacity

Policy Options to Address Semiconductor Supply Chain Risks

- Workforce Development
- Supply Chain Strengthening
- Research and Development
- **Manufacturing Capacity**
- International Coordination

Source: GAO (information). Shuo/stock.adobe.com (images). | GAO-22-105923

Many experts we interviewed said providing financial incentives would increase manufacturing capacity, but had varying opinions on the form those financial incentives should take. Several experts also discussed the importance of streamlining manufacturing facility regulations.

- Financial incentives to increase domestic manufacturing capacity. Many experts discussed the importance of providing financial incentives to increase domestic manufacturing capacity. However, experts had a range of opinions around the types of incentives that should be provided and how the incentives should be allocated. For example, two experts stated that financial incentives should be granted in the form of direct subsidies to industry, while two other experts said that the federal government should provide funding to help states and regions compete for companies to establish a manufacturing facility in their area based on the available capabilities.[39] However, not all agreed that financial incentives for

[37]National Strategies or Initiatives are defined as documents or initiatives that are national in scope and provide a broad framework for addressing issues that cut across federal agencies, and often across other levels of government and sectors. GAO, *Managing for Results: Key Considerations for Implementing Interagency Collaborative Mechanisms*, GAO-12-1022 (Washington, D.C.: Sept. 27, 2012).

[38]According to a recent Information Technology & Innovation Foundation report, "…a technology-based view of innovation argues that basic science is just one input, and that good policy means more than supporting investigator-led basic research. It means links with industry. It means funding aligned with key national goals. It means directly supporting industry technology and production efforts. It means supporting engineering, not just science. And it means giving more support to areas of science critical to competitiveness, such as computer science." Robert D. Atkinson. "Why the United States Needs a National Advanced Industry and Technology Agency." *Information Technology & Innovation Foundation.* (June 2021).

[39]In discussing experts' views with DOD, an official stated that there is a need to provide additional incentives beyond grants. The official stated that other types of incentives, such as tax incentives, land grants, and workforce training credits, are necessary to sustain the industry. According to the official, grants to establish manufacturing capacity alone will not make the industry cost effective in the United States if it is cheaper to continue manufacturing in other countries based on the location of existing suppliers.

domestic manufacturing should be provided to industry. For example, one expert expressed concerns, such as the potential for inefficiency or long-term costs stemming from picking specific industries or facilities to subsidize. Another expert stated that the federal government should be careful about arbitrarily selecting certain industries or companies to support. Some experts said that the cost of building a fabrication facility is significantly higher in the United States compared to other countries. Additionally, one expert questioned whether the financial incentives the federal government might provide would make a significant difference given the range of factors that companies consider when making decisions about where to construct a facility. This expert suggested that geopolitical considerations might override any financial incentives offered. Experts also provided views on the financial incentives set forth in the CHIPS Act (see textbox).

Experts' Views on Implementation of the Creating Helpful Incentives to Produce Semiconductors for America Act (CHIPS Act)

Several experts we interviewed provided suggestions related directly to implementation of the CHIPS Act, if funding were to be appropriated.

- **Clear goals for measuring success.** Some experts stated that the federal government should clearly identify its goals in providing financial incentives to semiconductor companies and determine how success will be measured.
- **Leading edge chip production.** Some experts also expressed concern that the federal government may not be able to ensure that the financial incentives set forth in the CHIPS Act would, in fact, bring the most advanced leading-edge chip production to the U.S. They attributed this risk to a combination of factors. Experts said that only a small number of companies have the capacity to produce the most leading-edge chips, so even if funding were appropriated, it would still be problematic if these companies were unable or unwilling to locate leading-edge chip production in the U.S.
- **Holding companies accountable.** Some experts stated that the federal government needs guardrails on future appropriated CHIPS Act funding to ensure companies are held accountable for the financial incentives that they receive. They suggested measures such as transparency requirements, bans on stock buybacks, and limits on CEO salaries.

Source: GAO analysis of expert interviews. | GAO-22-105923

- **Streamlining regulations.** Several experts discussed the importance of addressing manufacturing facility regulations. Specifically, several experts stated that the timeliness of the regulatory review process is an issue and some experts mentioned the need to streamline this process to increase predictability. Two experts called for creating a

"fast track" process at the U.S. Environmental Protection Agency for preconstruction and operating permits related to the Clean Air Act. One expert stated that the United States should form an interagency team to address regulatory barriers that limit semiconductor innovation or inhibit the timely construction of fabrication facilities. However, some experts stated that federal environmental standards should be maintained.

Working with International Partners to Help the U.S. Strengthen Global Supply Chain Resilience

Many experts shared the belief that the United States cannot address supply chain issues on its own and, therefore, recommended several ways the United States should work with international partners to strengthen resilience of the semiconductor supply chain globally.

Policy Options to Address Semiconductor Supply Chain Risks

- Workforce Development
- Supply Chain Strengthening
- Research and Development
- Manufacturing Capacity
- **International Coordination**

Source: GAO (information). Shuo/stock.adobe.com (images). | GAO-22-105923

- **Increasing international coordination.** Many experts discussed the importance of implementing policies to increase coordination with U.S. key trading partners.[40] For example, some experts stated that it was critical to ensure effective cooperation with key trading partners on joint technology development and innovation. Some experts said that the United States should coordinate with international partners to assess and align incentives for semiconductor manufacturing to avoid intensifying a global competition. Specifically, one expert said that with anticipated funding for the CHIPS Act and the potential of European and Japanese subsidies for the semiconductor industry, coordination is essential to avoid competing subsidies. This expert suggested that the use of a standard set of requirements by every country could reduce the possibility of creating competition across locations in order to attract companies.
- **Export controls.** Several experts supported the United States working with its key trading partners to narrowly target and implement export controls to ensure only materials related to national security

[40]The federal agency 100-day supply chain reviews developed under Executive Order 14,017 refer to allies and partners as nations that are not geopolitical competitors with the United States for key products. These reviews, however, do not identify allies and partners. The reviews further state that supply chains used by the United States and its allies and partners could be strengthened if they were moved to friendly shores. For the purposes of this report, we refer to allies and partners as key trading partners. The White House, *Building Resilient Supply Chains, Revitalizing American Manufacturing, and Fostering Broad-Based Growth: 100-Day Reviews under Executive Order 14017* (Washington, D.C.: June 2021) http://www.whitehouse.gov/wp-content/uploads/2021/06/100-day-supply-chain-review-report.pdf.

interests are captured.[41] However, some experts cautioned that export controls could be counterproductive. According to those experts, U.S. companies could be harmed by export controls that prohibit selling in other countries where competitors are able to sell their products. One expert noted that although export controls could cause negative consequences, the benefits of exports controls outweigh the negatives.

- **Updating existing trade agreements.** Several experts discussed the importance of updating existing trade agreements to address the challenges of modern trade, including the protection of intellectual property rights, and the reduction or elimination of tariffs for key technology products including semiconductors. Some of these experts stated that the United States should negotiate new multilateral, bilateral, and regional trade agreements (e.g., Comprehensive and Progressive Agreement for Trans-Pacific Partnership, Trade Facilitation Agreement) to create new markets for U.S. semiconductors.[42]
- **Working with geopolitical competitors.** Some experts discussed the importance of working with countries who might be considered U.S. geopolitical competitors to address supply chain resilience

[41]According to SEMI., "…export controls are powerful national security tools that are best used strategically, in a manner that is integrated in a unified strategy with other tools of national policy, narrowly tailored to address specific national security concerns, and implemented multilaterally with other semiconductor-producing countries. When used instead as a unilateral tool of U.S. industrial policy, any potential short-term benefit to national security is likely to erode over time as the global competitiveness of the controlled industry is ultimately weakened." SEMI, Re: SEMI Comments to Risks in the Semiconductor Manufacturing and Advanced Packaging Supply Chain Notice of Request for Public Comments, 86 R. 14308; RIN 0694–XC073; Docket Number BIS-2021-0011. (Comments submitted by SEMI in response to Bureau of Industry and Security, U.S. Dept. of Commerce, Notice, 86 Fed. Reg. 14,308 (Mar. 15, 2021) on Apr. 5, 2021) (Last accessed on June 29, 2022, https://www.regulations.gov/comment/BIS-2021-0011-0053).

[42]According to the Semiconductor Industry Association, "More than 80% of U.S. semiconductor industry revenue comes from sales to customers outside the United States, making semiconductors America's fifth-largest export. Access to global markets through trade agreements has enabled U.S.-based companies to secure 47% of the $412 billion global semiconductor market in 2019." Semiconductor Industry Association, *Before the Bureau of Industry and Security, Office of Technology Evaluations, U.S. Department of Commerce In the Matter of Executive Order 14017 of February 24, 2021, America's Supply Chains, In Response to a Notice by Bureau of Industry and Security 86 Fed. Reg. 14308 Risks in the Semiconductor Manufacturing and Advanced Packaging Supply Chain(Mar. 15, 2021) Written Comments from the Semiconductor Industry Association*, (Comments submitted by the Semiconductor Industry Association in response to Bureau of Industry and Security, U.S. Dept. of Commerce, Notice, 86 Fed. Reg. 14,308 (Mar. 15, 2021) on April 5, 2021) (Last accessed on June 29, 2022, https://www.regulations.gov/comment/BIS-2021-0011-0080).

concerns. For example, one expert stated that the United States could collaborate with such nations to share information on supply chain issues using adequate safeguards to protect U.S. national security interests. Another expert stated that other information-sharing could also include open communication between governments about COVID-19 related shutdowns in manufacturing facilities. Other experts discussed the importance of forming partnerships with allies to address concerns about intellectual property theft and other potential threats from U.S. geopolitical competitors.

Experts Discussed the Need for Identifying Federal Priorities and Improving Federal Interagency Collaboration

Identifying Priorities for Federal Actions

Some experts we spoke with discussed the need for understanding the priorities that the federal government seeks to advance through policies to reduce semiconductor supply chain risks to mitigate future shortages. Those experts stated that identifying the most appropriate policy option depends on the federal action being prioritized. Examples of policy priorities that the experts discussed as being related to semiconductor supply chain risks include national security, economic competitiveness, and increased resilience.

- **National security.** The National Science and Technology Council included semiconductors on its February 2022 list of critical and emerging technologies.[43] This list is a subset of advanced technologies that are potentially significant to U.S. national security. As noted in a 2017 report from the President's Council of Advisors on Science and Technology, cutting edge semiconductor technology is critical to defense systems and U.S. military strength, while the

[43]National Science and Technology Council, *Critical and Emerging Technologies List Update* (February 2022).

pervasiveness of semiconductors makes their integrity an important factor in shaping cybersecurity risk.[44]

- **Economic competitiveness.** Advances in science and technology play an increasingly important role in our society and are central to the prevailing issues of our day—including economic competitiveness.[45] Technological innovation is a key driver of economic growth. The President's Council of Advisors on Science and Technology stated that innovation spurred by a robust U.S. semiconductor industry creates a virtuous cycle—by helping U.S. producers stay ahead of competitors, it further strengthens U.S.-based industry, which in turn drives semiconductor innovation.[46]
- **Increased resilience.** As described in Executive Order No. 14,017, more resilient supply chains are secure and diverse—facilitating greater domestic production, a range of supply, built-in redundancies, adequate stockpiles, and safe and secure digital networks. The term supply chain resilience can refer to the ability to prepare for anticipated choke points, adapt to changing conditions, and withstand and recover rapidly from disruptions.[47]

These three policy priorities intersect when it comes to decisions about (1) increasing the production of semiconductors in the U.S. versus increasing the geographic diversity of semiconductor production globally, and (2) focusing U.S. production on advanced leading edge chips versus less-advanced legacy chips. Some experts said that the global semiconductor supply is too reliant on Taiwan for leading edge semiconductors, creating a choke point within the supply chain. Some experts also cautioned that the United States should be concerned about what would happen to its access to semiconductors if China invaded Taiwan. One expert stated that the impact of conflict in Taiwan would be vastly more severe than any other plausible supply chain risk. However,

[44]Executive Office of the President, President's Council of Advisors on Science and Technology, Report to the President, Ensuring Long-Term U.S. Leadership in Semiconductors (January 2017).

[45]GAO, *Trends Affecting Government and Society, United States Government Accountability Office Strategic Plan 2018-2023*, GAO-18-396SP, (Washington, D.C.: Feb. 22, 2018).

[46]Executive Office of the President, President's Council of Advisors on Science and Technology, Report to the President, Ensuring Long-Term U.S. Leadership in Semiconductors (January 2017).

[47]Adapted from GAO's definition of disaster resilience. GAO, *Disaster Resilience Framework: Principles for Analyzing Federal Efforts to Facilitate and Promote Resilience to Natural Disasters*, GAO-20-100SP (Washington, D.C.: Oct. 23, 2019).

the extent to which some experts placed importance on having production in the U.S. versus working with key trading partners to increase production in other locations globally, depended in part on which policy priority is emphasized. For example, one expert said that if national security is emphasized, then increasing production of semiconductors within the United States is important. However, if the economic competitiveness of U.S.-headquartered companies is emphasized, then increasing global geographic diversity may be more desired. Increasing global geographic diversity is also more significant if increased supply chain resilience is emphasized.

Overall, experts had mixed opinions on how much emphasis should be placed on increasing domestic manufacturing relative to taking other actions. Several experts said that geographic diversity is more critical than increasing domestic production capacity in the United States. While some experts stated that it was most important to balance these two options, others said that it depended on which policy priority is emphasized.

Similarly, experts indicated that the question of whether the United States should focus on producing leading edge or legacy chips is shaped by the competing policy priorities of national security and economic competitiveness. Experts noted that one reason to focus on legacy chips is DOD's need to maintain its existing weapons systems. Two experts warned of a potential U.S. reliance on China for purchasing legacy chips. This could pose both national security and economic competitiveness concerns. One of these experts drew a comparison to the current position of the United States in the face of Chinese dominance in solar panel production. Several experts believe that more of the focus should be on leading edge chips. One expert said that a focus on leading edge chips could help the United States to maintain technology leadership. This could increase U.S. economic competitiveness in the future. Another expert said that a focus on leading edge chips was needed to address U.S. reliance on Taiwan. This could improve the resilience of the U.S. supply chain. Many experts stated that federal policies that support increased domestic production should focus both on legacy and leading edge chips. However, determining the balance between leading edge and legacy chips will require careful consideration of the competing policy priorities.

Improving Interagency Collaboration to Help the U.S. Act Strategically

The experts we spoke with noted multiple federal agencies that have activities related to semiconductor supply chains and described ways in which they thought coordination should be more strategic. For example, one expert stated that agencies working on issues related to semiconductors need to collaborate to identify existing work and potential gaps in agency activities where additional action is needed.

Several of the experts stated the need for a single federal entity in charge of coordinating federal efforts to address semiconductor supply chain risks and mitigate future shortages, as well as the need for a national strategy as discussed above. Some experts stated that the coordinating entity should be Commerce. Some experts also provided some specific suggestions on how federal efforts could be coordinated:

- **National or broad industrial strategy.** Some experts stated that the U.S. needs a coordinated national strategy or an industrial policy that encompasses federal activities related to critical and strategic technology sectors, including semiconductors.
- **Data-based approach.** Some experts stated that the federal government needs a data analytics approach to coordinate federal efforts. One expert specified the need for a data-based roadmap for allocating tasks to federal agencies. Two other experts stated that the United States needs a technology analytics office to guide decision-making regarding critical technologies and critical supply chains. One of the experts stated that this office should be integrated into a critical supply chain resilience program.

Some experts, however, were more skeptical of federal coordinating bodies in general or stated that multiple agencies should be responsible for federal efforts. One expert stated that collaborative efforts that are initiated and run at the working level by experts, rather than by coordinating bodies, are effective. That person noted that experts across agencies have pre-existing relationships that support collaboration.[48]

Third Party Views

We provided the experts who participated in our interviews an opportunity to review a draft of this report. Four experts provided technical comments, which we incorporated as appropriate.

[48]GAO has done prior work on interagency collaboration. See GAO-12-1022 and GAO, *Managing for Results: Implementation Approaches Used to Enhance Collaboration in Interagency Groups*, GAO-14-220 (Washington, D.C.: Feb. 14, 2014).

We are sending copies of this report to the appropriate congressional committees and other interested parties. In addition, the report is available at no charge on the GAO website at https://www.gao.gov.

If you or your staff have any questions about this report, please contact Candice N. Wright at (202) 512-6888 or WrightC@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. GAO staff who made key contributions to this report are listed in appendix II.

Candice N. Wright
Director, Science, Technology Assessment, and Analytics

List of Addressees

The Honorable Maria Cantwell
Chair
Committee on Commerce, Science, and Transportation
United States Senate

The Honorable Gary C. Peters
Chairman
The Honorable Rob Portman
Ranking Member
Committee on Homeland Security and Government Affairs
United States Senate

The Honorable Carolyn B. Maloney
Chairwoman
Committee on Oversight and Reform
House of Representatives

The Honorable Eddie Bernice Johnson
Chairwoman
The Honorable Frank D. Lucas
Ranking Member
Committee on Science, Space, and Technology
House of Representatives

The Honorable Haley Stevens
Chairwoman
The Honorable Randy Feenstra
Ranking Member
Subcommittee on Research and Technology
Committee on Science, Space, and Technology
House of Representatives

The Honorable Raphael Warnock
United States Senate

Appendix I: Objectives, Scope, and Methodology

Our objective for this report was to review selected experts' views on policy options that could reduce supply chain risks and help mitigate future semiconductor shortages. To conduct this work, we interviewed experts about their views on a list of policy options that we developed through a literature review.

To develop the list of policy options, we worked with a GAO research librarian to conduct a literature search that resulted in a review of 198 documents retrieved from academic literature, policy proposals from think tanks, and public responses to federal agencies' requests for information. We identified a total of 371 policy ideas through the literature review, and we combined similar policy ideas to consolidate the list into 77 policy options. Based on our literature review and consultation with internal GAO stakeholders, we categorized the policy options into five policy themes. Below are the five policy themes that we identified:

- Workforce Development–policies designed to strengthen human capital within the semiconductor industry. Policy options within this theme are related to STEM training, education, and scholarships; regional coordination; immigration policy; and recruitment by promoting the semiconductor industry.
- Supply Chain Strengthening–policies designed to mitigate risks in the semiconductor supply chain. Policy options within this theme are related to monitoring the supply chain and increasing transparency, building resiliency, investing in critical materials, stockpiling supplies, and enhancing the security of semiconductors through risk management systems and standards.
- Research and Development–policies designed to advance and support research and development within the semiconductor industry. Policy options within this theme are related to financial incentives, public-private partnerships, regional coordination, national semiconductor innovation strategies, and investments in equipment and programs at universities.
- Manufacturing Capacity–policies designed to increase semiconductor manufacturing capacity. Policy options within this theme are related to financial incentives for domestic capacity, facility regulations, manufacturing regulations, and physical infrastructure investments.
- Trade and International Coordination–policies focused on trade, international coordination, and partnerships within the semiconductor industry. Policy options within this theme are related to trade agreements, coordination with key trading partners, import taxes, and export controls.

We selected experts for interviews based on cross-cutting subject matter knowledge and to obtain a balance of perspectives across the industrial, academic, nonprofit, and government sectors. We initially identified 91 experts with knowledge of semiconductor supply chains through recommendations from representatives of industry associations, the federal government, think tanks, and market research firms and by reviewing relevant publications, congressional testimonies, and academic and industry presentations. We then reviewed publicly available information about experts, including CVs, resumes, and publications, to narrow our list to 39 individuals with demonstrated knowledge about semiconductors and each of the five policy themes that we identified through our literature review. Two GAO analysts independently identified their top 15 experts from the list of 39 individuals based on depth and relevance of the experts' professional experience, as well as the balance of experts' backgrounds and perspectives. The two analysts then conferred on their selections to decide which experts to invite for an interview. We invited 20 experts for interviews, and 17 experts accepted the invitation. We did not ask experts to speak on behalf of the organizations that they represent, but rather on the basis of their personal professional views. Four experts were currently employed in government, six in academia, five in industry, and five in nonprofits (see table 1).

Table 1: Distribution of Interviewed Experts across Sectors

Sector	Current	Prior
Public	4	3
Academia	6	1
Nonprofit	5	4
Industry	5	4
Total	**20**	**12**

Source: GAO analysis of expert background materials. | GAO-22-105923

Note: The sum of current expert experience listed is greater than the number of experts, because some experts were employed in multiple sectors. The sum of prior expert experience listed is less than the number of experts, because some experts were not employed in a different sector in prior jobs.

Prior to the interviews, we asked experts to review the list of policy options that we developed from the literature review. During the interviews, we asked experts to identify which, if any, policy options from our list stood out as having the most potential to reduce supply chain risks and mitigate future shortages. We also asked experts to identify which policy options, if any, are counterproductive to reducing risks and mitigating future shortages. We asked experts to share their perspectives

on the federal role in semiconductor supply chains and on how federal agencies should coordinate in implementing the federal approach to reducing semiconductor supply chain risks. We also asked experts for their views on building a complete semiconductor supply chain within the US, on the importance of domestic versus global semiconductor production capacity, on the need to focus federal efforts on advanced versus legacy semiconductors, and on international coordination of efforts to reduce semiconductor supply chain risks. In some cases, we followed up with experts to get additional information and clarify the comments they made during the interviews.

To analyze the experts' responses to interview questions, we organized and combined expert opinions around the policy themes and specific policy options. We aggregated perspectives that touched on similar policy themes and subthemes, and we documented the number of experts expressing similar opinions as well as the number of experts expressing conflicting or clarifying opinions. We report out on the policy themes that experts brought up most frequently, including both positive and negative opinions. Within the policy themes that were discussed most frequently, we highlight all perspectives on that topic to ensure a holistic and representative presentation of expert views. This means, at times, the views of one or two experts are highlighted in order to reflect the full range of expert views. Additionally, we sometimes highlight the views of one or two experts to reflect unique or clarifying points conveyed by the experts. When reporting the results of our expert interviews, we define "all" as 17 experts, "most" as 14-16 experts, "many" as 10-13 experts, "several" as 6-9 experts, and "some" as 3-5 experts. Our methodology allowed for open response from the experts to identify which policies from our list options stood out to them. Therefore, we did not receive comments from every expert on each of the policies. The total number of experts who agreed or disagreed with a particular policy option reflects only those experts who identified the option as either particularly beneficial or particularly unhelpful. Finally, we provided an opportunity for officials from certain agencies that we identified as having key roles for implementing policy options in certain areas to review and discuss the experts' views. These included officials from the Departments of Commerce and Defense, and the Office of Science and Technology Policy.

We conducted our work from March 2022 to July 2022 in accordance with all sections of GAO's Quality Assurance Framework that are relevant to our objectives. The framework requires that we plan and perform the engagement to obtain sufficient and appropriate evidence to meet our

stated objectives and to discuss any limitations in our work. We believe that the information and data obtained, and the analysis conducted, provide a reasonable basis for any findings and conclusions in this product.

Appendix II: GAO Contact and Staff Acknowledgments

GAO Contact

Candice N. Wright at (202) 512-6888 or WrightC@gao.gov

Staff Acknowledgments

In addition to the contact named above, Christopher Murray (Assistant Director), Darnita Akers (Analyst-in-Charge), Walker Adams, Jenny Chanley, Jehan Chase, Philip Farah, Louise Fickel, Adriane Kline, Briana Lalman, Joe Rando, and Archie Scoville, made key contributions to this report.

GAO's Mission

The Government Accountability Office, the audit, evaluation, and investigative arm of Congress, exists to support Congress in meeting its constitutional responsibilities and to help improve the performance and accountability of the federal government for the American people. GAO examines the use of public funds; evaluates federal programs and policies; and provides analyses, recommendations, and other assistance to help Congress make informed oversight, policy, and funding decisions. GAO's commitment to good government is reflected in its core values of accountability, integrity, and reliability.

Obtaining Copies of GAO Reports and Testimony

The fastest and easiest way to obtain copies of GAO documents at no cost is through our website. Each weekday afternoon, GAO posts on its website newly released reports, testimony, and correspondence. You can also subscribe to GAO's email updates to receive notification of newly posted products.

Order by Phone

The price of each GAO publication reflects GAO's actual cost of production and distribution and depends on the number of pages in the publication and whether the publication is printed in color or black and white. Pricing and ordering information is posted on GAO's website, https://www.gao.gov/ordering.htm.

Place orders by calling (202) 512-6000, toll free (866) 801-7077, or TDD (202) 512-2537.

Orders may be paid for using American Express, Discover Card, MasterCard, Visa, check, or money order. Call for additional information.

Connect with GAO

Connect with GAO on Facebook, Flickr, Twitter, and YouTube.
Subscribe to our RSS Feeds or Email Updates. Listen to our Podcasts.
Visit GAO on the web at https://www.gao.gov.

To Report Fraud, Waste, and Abuse in Federal Programs

Contact FraudNet:

Website: https://www.gao.gov/about/what-gao-does/fraudnet

Automated answering system: (800) 424-5454 or (202) 512-7700

Congressional Relations

A. Nicole Clowers, Managing Director, ClowersA@gao.gov, (202) 512-4400, U.S. Government Accountability Office, 441 G Street NW, Room 7125, Washington, DC 20548

Public Affairs

Chuck Young, Managing Director, youngc1@gao.gov, (202) 512-4800
U.S. Government Accountability Office, 441 G Street NW, Room 7149
Washington, DC 20548

Strategic Planning and External Liaison

Stephen J. Sanford, Managing Director, spel@gao.gov, (202) 512-4707
U.S. Government Accountability Office, 441 G Street NW, Room 7814,
Washington, DC 20548