Addressing Supply Chain and Manufacturing Challenges and Opportunities

Proceedings of a Workshop Series—in Brief

The COVID-19 pandemic escalated supply chain vulnerabilities that affect almost every sector of the economy. Experts across government, industry, and academia have raised alarms for decades about the need to increase domestic investment and policy support to maintain a competitive edge in manufacturing and supply chain security. The Biden Administration's 100-day review of U.S. supply chain vulnerabilities in four critical industries concluded that more secure and resilient supply chains are essential for national security, economic security, and technological leadership.[1] Identifying key vulnerabilities and developing responses to them will require the mobilization of diverse actors across the U.S. research enterprise.

In October and November 2021, the Government-University-Industry Research Roundtable (GUIRR) of the National Academies of Sciences, Engineering, and Medicine convened a number of virtual workshops for its membership and invited guests to discuss opportunities for enhancing U.S. approaches to addressing manufacturing and supply chain resilience, security, and sustainability challenges through partnerships and cross-sector collaboration. In convening experts and leaders from across sectors and disciplines, GUIRR provided a forum for dialogue on policy priorities for consideration by leaders across the research enterprise.

This document summarizes the presentations and discussions at the four workshops in four sections. The first section covers a workshop held on October 13, 2021; the second section covers a workshop held on October 20, 2021; the third section covers a workshop held on October 26, 2021; and the fourth section covers a workshop held on November 4, 2021.[2]

MAINTAINING COMPETITIVENESS AND ECONOMIC SECURITY IN CRITICAL INDUSTRIES

In opening the series, GUIRR industry co-chair and past president of the MITRE Corporation, **Al Grasso**, stressed the linkages between supply chain weaknesses and U.S. innovation and manufacturing capacity. He noted the share of U.S. production of semiconductor chips—which are essential to the operation of almost any electronic

[1] Building Resilient Supply Chains, Revitalizing American Manufacturing, and Fostering Broad-Based Growth," The White House, June 2021, https://www.whitehouse.gov/wp-content/uploads/2021/06/100-day-supply-chain-review-report.pdf.

[2] Resources from the workshops, including participants lists and presenters' slides, can be found online: https://www.nationalacademies.org/our-work/addressing-supply-chain-and-manufacturing-challenges-and-opportunities-workshop-series.

device—slipped from 37 percent of the global total to 12 percent over the last 20 years. Semiconductor manufacturing, he suggested, may also serve as a lens through which to view U.S. competitiveness in other critical industries.

Erica Fuchs (Carnegie Mellon University) placed the current situation into historic context. Over the last half century, she said, the world has shifted from U.S. economic and scientific dominance. China is now the largest producer and second largest market in the world. Within the United States, economic inequality has increased, while social mobility has declined. The country's institutional and intellectual foundations are insufficient to deal with these multiple challenges, she asserted, and proposals to deal with them conflict with each other. There is little agreement on what defines a critical technology, and much less on how to link criteria defining critical technologies to coordinated investment and policies strategies.

According to Fuchs, what is missing are "data and analytic tools that can support the government in designing critical technology, supply chain, and infrastructure strategies that realize win-win alternatives for its multiple objectives in national security, economic prosperity, and social welfare."[3] For example, equitably building the infrastructure of the future can increase jobs in underserved areas, improve social welfare, and boost industrial resilience and productivity. Despite the potential, she said she knows of no research that quantifies trade-offs and "win-wins" across the full range of national objectives. Existing agencies have singular missions (e.g., energy, transportation, or defense), but without a national landscape view, the impacts and tradeoffs of strategic technology policy objectives on labor, the environment, equity, and prosperity are more difficult to appraise.[4]

Fuchs called for a "nimble agency" that can research and fund initiatives to fill the gaps and serve as a catalyst. She also identified three needs that her proposal for a National Technology Strategy Agency could fulfill: (1) real-time situational awareness of domestic and global technological production capabilities; (2) prevention of supply chain bottlenecks in the United States and globally; and (3) selection of priorities and creation of policies and reforms across agencies' missions.[5] To gain from such a multi-objective understanding of the entire innovation ecosystem, expertise from many disciplines within academia and industry must be brought to bear to, she added, and public-private and academic partnerships are needed to tap into leading expertise to build these capabilities. "I want to reinforce that we have no way right now to think across missions. We can do it informally, but we need an agency or group to break through single-mission thinking," she concluded.

In the discussion, Grasso noted that a common—and sometimes problematic—suggestion to solving a complex problem is to create a new government agency or program that demands a whole-of-government approach that is difficult to coordinate. He noted his appreciation for the focus of Fuch's proposed agency, but asked if it would be possible to leverage existing agencies' capabilities around the same focus. Fuchs acknowledged the challenges identified by Grasso, but reiterated that thinking across singular missions—on topics outside of security, jobs, and transportation—will remain complicated without an entity to bring the expertise and capability to the table to inform these strategic policy decisions.

Quantum technology serves as an example of how the United States can position itself in critical industries, said **Celia Merzbacher** (Quantum Economic Development Consortium [QED-C]).[6] Both the Trump and Biden Administrations have identified the quantum industry

[3] National Technology Strategy: Critical Technologies, Infrastructure, and Supply Chains. https://engineering.cmu.edu/natl-tech-strategy/index.html.

[4] For more detail on Fuch's proposal for a National Technology Strategy see: "What a National Technology Strategy Is—and Why the United States Needs One," *Issues in Science and Technology*, September 9, 2021. https://issues.org/national-technology-strategy-agency-fuchs/.

[5] Fuchs noted her views are more fully described in a recent policy brief and Congressional testimony: E. Fuchs and V. Karplus. 2021, September 10. A New Approach to Coordinate U.S. Critical Supply Chains in Crisis. https://docs.google.com/document/d/115tiyxuu4LQyKzRCPf9GzJmeM-V0ur4d8B5W3_AD3_es/edit; E. Fuchs. 2021, June 9.

Testimony before the House Subcommittee on Research and Technology, Hearing on Building Regional Innovation Economies. https://science.house.gov/imo/media/doc/Fuchs%20Testimony.pdf.

[6] For more information about QED-C, see https://quantumconsortium.org/.

as one of the critical industries of the future. The federal government is making significant investments in basic research in quantum information science and technology, or QIST. "And the private sector is making big bets without the government as an early customer," she said.

Merzbacher noted global investments in quantum are significant, as indicated through several metrics. A recent report by the Basic Energy Sciences Advisory Committee based on publication metrics concluded that, "China's progress is surging and Europe leads in quantum information sciences, while U.S. research output is flattening or falling behind."[7] As another metric, QED-C looked at patents by field, company, and country over the past 10 years—where a patent is filed can indicate where the applicants think the principal market exists. Among the top 19 companies in quantum computing, most are North American-based, and the largest number of quantum computing patents are filed in the United States.[8]

By contrast, for quantum communications patents, companies from China and Japan dominate, and the largest number of quantum communications patents are filed in China, followed by the United States and Japan.

Quantum is not a single technology with a single technology readiness level (TRL), she stressed. Some areas are at very early TRLs, while others are relatively mature—for example, quantum memory, quantum repeaters, and quantum networks are still considered early stage (TRL 1), while quantum key distribution is considered relatively mature (TRL 6).[9] Similarly, no single standard applies to all QIST; standards are being developed around the world by multiple organizations for many different aspects of quantum (Figure 1). Merzbacher urged the critical need for the United States to build robust partnerships with other countries, since innovation is happening globally.

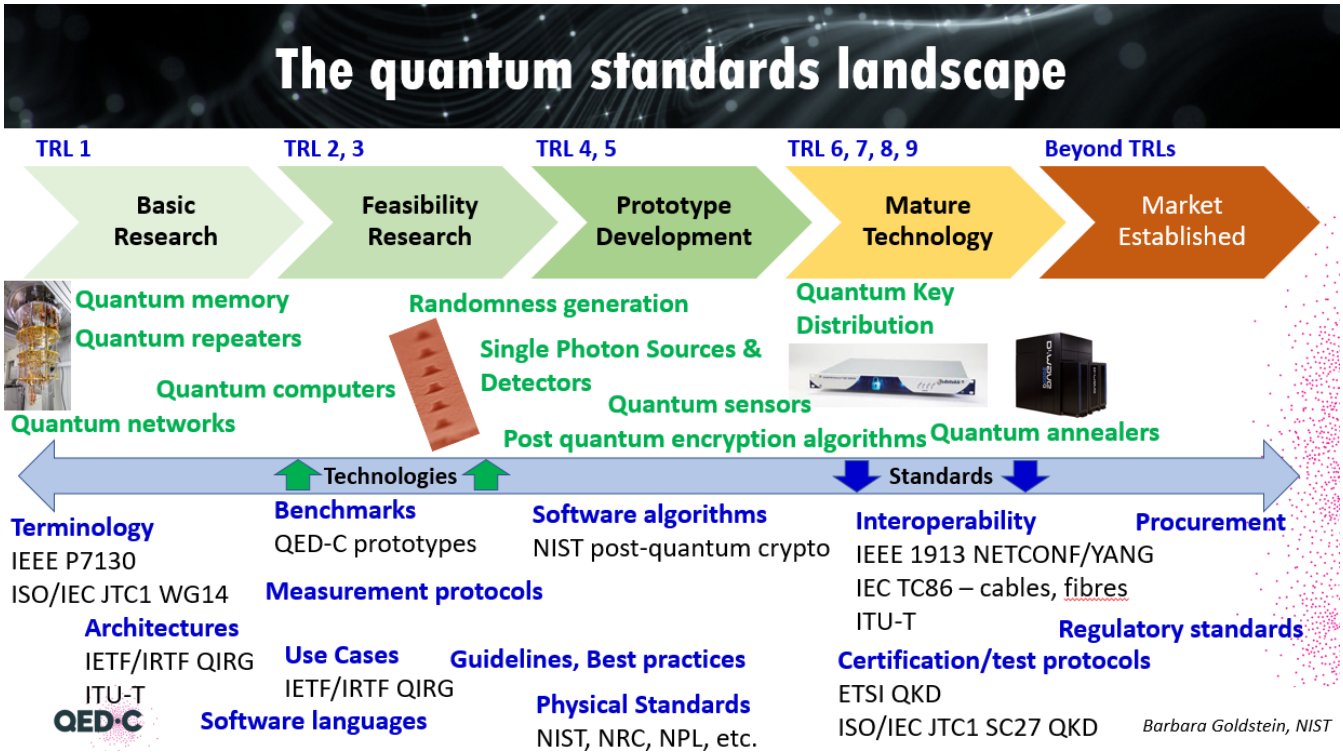

FIGURE 1 The quantum standards landscape.
SOURCE: Barbara Goldstein, NIST; presented by Celia Merzbacher, Quantum Economic Development Consortium, at a workshop of the Government-University-Industry Research Roundtable on "Maintaining Competitiveness and Economic Security in Critical Industries, held October 13, 2021.

[7] BESAC Subcommittee on International Benchmarking. Can the U.S. Compete in Basic Energy Sciences? Critical Research and Strategies. https://science.osti.gov/-/media/bes/pdf/reports/2021/International_Benchmarking-Report.pdf.
[8] The analysis is published on the QED-C blog: https://quantumconsortium.org/blog/trends-in-quantum-computing-patents/, and https://quantumconsortium.org/blog/quantum-patents-part-2/.
[9] Barbara Goldstein, "The Dream of a Common Language: International Standards for the Quantum Economy," presentation on Harmonization of Terminology in Standards for Quantum Technology, June 23, 2021. https://www.itu.int/en/ITU-T/webinars/20210623/Documents/Goldstein%20Final.pdf?csf=1&e=GdALdj.

To promote and protect the U.S. quantum industry, Merzbacher suggested being targeted in use of export controls; investing in basic research to addresses gaps; supporting access and use of private quantum computing and other quantum systems; welcoming top researchers worldwide to come to the United States; and working with international partners, such as through the Tokyo Statement on Quantum Cooperation.[10] Within the United States, the quantum innovation ecosystem encompasses a broad range of stakeholders in the public, private, and nonprofit sectors. The quantum supply chain can be strengthened by enhancing R&D capacity, incentivizing private investors, accelerating market growth, helping U.S. firms grow their global business, and supporting U.S. firms' participation in standards setting, she concluded.

Chris Toffales (CTC Aero) discussed enhancing domestic capacity in microelectronics for national security to eliminate reliance on Asian producers, for both commercial and military systems. Toffales discussed a recently completed CTC Aero briefing to the Office of the Undersecretary of Defense for Acquisition and Sustainment focused on the trustworthiness and reliable availability of microelectronics parts. The focus of the briefing was on the Department of Defense, but he noted the issue affects the economy as a whole. Asian countries—particularly China, Taiwan, and Korea—now manufacture 75 percent of the global microelectronics supply, projected to increase to 90 percent by 2030. With this concentration in one region of the world, supply chains could be disrupted for a number of natural or human-caused reasons. Furthermore, most major corporations rely on only one source for production of many of their parts because it is more advantageous financially. The risk is that if that supplier no longer produces the part, it could take 3 to 5 years and billions of dollars to replicate it elsewhere. "These factors heighten the threat of embargos, counterfeiting, sabotage, and supply chain disruptions," he said.

Toffales explained that consumer markets represents 75 percent of the total microelectronics market; DoD and the intelligence agencies represent a very small part of the total market (1 to 2 percent), which makes partnerships with the commercial world necessary to resolve issues and to strengthen national and economic security infrastructure.

In the current ecosystem, Toffales said, intellectual property (IP) design may originate in the United States. However, the IP moves to Asia where a component may be fabricated in one or more countries, shipped to other countries for packaging and testing, and finally assembled for sale to the consumer market. "In such a diverse execution of a supply chain, any one area of breakdown will create the situation we are in today," he stated. It will take large investments and time to bring back to the United States some level of manufacturing capacity to secure the supply chain, and he called for attention to the availability and sustainability of legacy, state-of-the-present, and state-of-the art microelectronics parts.

About 20 percent of the global market requires parts that meet secure and/or safe standards. Toffales urged creation of a new and innovative ecosystem in the United States and with allies to meet these "safe and secure" microelectronics needs. The U.S. Innovation and Competition Act (USICA) proposed funds that for infrastructure, technology innovation, and defense.[11] Properly made investments could result not just in newly built factories, but in developing a national microelectronics infrastructure innovation ecosystem, he suggested. He also urged incenting industry to look at models used in Asia, as well as finding ways to satisfy legacy needs, perhaps through digital technologies and digital twinning.

In the last presentation of the workshop, **Ronni Chatterji** (U.S. Department of Commerce) shared five

[10] Merzbacher cited a report in reference to the discussion on international talent: "The Role of International Talent in Quantum Information Science," Subcommittee on Economic and Security Implications of Quantum Science of the National Science and Technology Council, October 2021. https://www.quantum.gov/wp-content/uploads/2021/10/2021_NSTC_ESIX_INTL_TALENT_QIS.pdf. The Tokyo Statement on Quantum Cooperation was released by the Government of the United States of America and the Government of Japan on the occasion of the signing of a joint statement of cooperation to advance innovative and emerging quantum information science and technology on December 19, 2019. https://www.state.gov/tokyo-statement-on-quantum-cooperation/.

[11] S. 1260 – United States Innovation and Competition Act of 2021. https://www.congress.gov/bill/117th-congress/senate-bill/1260/text.

observations based in part on his participation in the Biden Administration's Supply Chain Disruptions Task Force.[12] First, supply chain policy is a new area for many policy makers. It is taught in business schools, but not in public policy schools and has not been on the radar for most policy makers. He noted the current situation will lay the foundation for development of capabilities and competencies, but there are few historical examples or case studies on which to draw in this moment. He expressed hope, as an academic, that supply chain policy theory will develop as a field of study to determine the role of government. Second, he noted supply chain policy requires different data and tools than the government is used to collecting and using. While the government, particularly within the Department of Commerce, has strength in data collection and analysis, these efforts are not organized in ways to track supply chain resilience and disruption.

Third, Chatterji recognized supply chain policy as both domestic and international. The semiconductor industry, for example, is a global supply chain involving multiple countries and companies around the world. These interconnections require new models for collaboration. Fourth, supply chains are very diverse. The market structure in each industry is different, which means the playbook is different across industries.

Fifth and finally, he underscored that supply chain resiliency has become a top-level priority and economic concern for the Biden Administration. Executive and legislative actions are aimed at short and long-term solutions, and an entire U.S. government effort is necessary.

Discussion ensued about whether the approaches and proposals for a national technology strategy indicate that the country is moving toward adopting a national industrial policy. Chatterji commented that changes in geopolitical dynamics, climate change vulnerabilities, and supply chain resiliency require policy makers to prioritize and think about connections across and between sectors in different ways. It is also important, he added, to consider the broad range of stakeholders involved in a given industry, to include suppliers, buyers, the financial community, and many others.

[12] See https://www.whitehouse.gov/briefing-room/statements-releases/2021/06/08/fact-sheet-biden-harris-administration-announces-supply-chain-disruptions-task-force-to-address-short-term-supply-chain-discontinuities/.

SUPPLY CHAIN RISK MANAGEMENT: ASSURING SUPPLY CHAIN RELIABILITY AND MITIGATING DEMAND DISRUPTIONS

The second workshop in the series focused on risk management practices to minimize disruptions and reduce vulnerabilities, explained GUIRR co-chair **Laurie Leshin** (Worcester Polytechnic Institute) in facilitating the discussion.

According to **Chris Nissen** (IntelWerks, LLC), nuclear and conventional warfare characterized the post-World War II years, but disruption of systems and technical operations is a principal method of fighting in what he termed the current "asymmetric era." As a result, businesses and governments carry massive unknown operational risks via supply chain vectors. In two reports on supply chain security, Nissen and co-authors asserted that current systems are designed for profit and performance, but without sufficient consideration of risk.[13] Cyber information technologies (IT) are perhaps the most well-known supply chain attack vector, but other vulnerable vectors in a blended operation include humans, used both wittingly and unwittingly; cyber operational technologies (OT), such as the power grid; and the formal supply chain of software, hardware, raw materials, and other goods and services. "You can't look at just one vector because the adversary moves across all of them," he warned.

Risk is based on threats, vulnerabilities, and consequences, which he said are usually approached as three different disciplines. He urged an integrated approach to consider all three, starting with prioritizing the worst potential consequences. In addition, options to protect against risk depend on a product's stage,

[13] C. Nissen et al. 2018. "Deliver Uncompromised: A Strategy for Supply Chain Security and Resilience in Response to the Changing Character of War." Available: https://www.mitre.org/publications/technical-papers/deliver-uncompromised-a-strategy-for-supply-chain-security; C. Nissen et al. 2021. "Beyond Solarwinds: Principles for Securing Software Supply Chains." Available: https://www.mitre.org/sites/default/files/publications/pr-21-0843-beyond-solarwinds-principles-for-securing-software-supply-chains.pdf.

from concept through design, manufacture, integration, deployment, maintenance, and retirement. It is easier to protect at earlier than later stages, he added. Foreign intelligence services have many target selections and collection options, and adversaries often openly state their goals, such as in China's "Made in China 2025" document.[14]

Nissen stressed that managing risk increases value, even if it also increases costs, and he expressed hope that measures are being taken. He related that although he thought OT was the most challenging vector to protect—because of the difficulty in changing out capital investments in machinery and infrastructure—engineering schools are developing new technologies, and companies are doing better monitoring. In any vector or domain, it is necessary to monetize risk by considering an enterprise's degree of risk, cost of mitigation, and risk tolerance (Figure 2).

Christopher Geiger (Lockheed Martin) described four diverse examples that show how Lockheed Martin is increasing resilience in its supply chain: accelerated payments, seabed harvesting, asset tracking, and preparation and response. Underlying these actions, the company strengthened the connection between risk and resiliency in 2017, when enterprise risk management (ERM) and sustainability were placed under the same organizational umbrella. Accelerated payments were a response to the COVID-19 pandemic. Recognizing the vulnerability of suppliers, the company accelerated $2.1 billion in payments to more than 11,250 suppliers, including more than 6,900 small and vulnerable businesses to help keep them in business. Technology was used to comb through the data to identify to whom to advance funds and to continue in a sustained fashion.

A Lockheed Martin subsidiary, UK Seabed Resources, is investing in seabed harvesting to look for rare earth materials on the ocean floor. The benefits may include less impact on biodiversity and on human communities, especially in cases of conflicted, unsafe, or exploitative conditions. In addition, he noted, seabed harvesting of specific materials could lessen supply chain vulnerabilities because production will not depend on any one country.

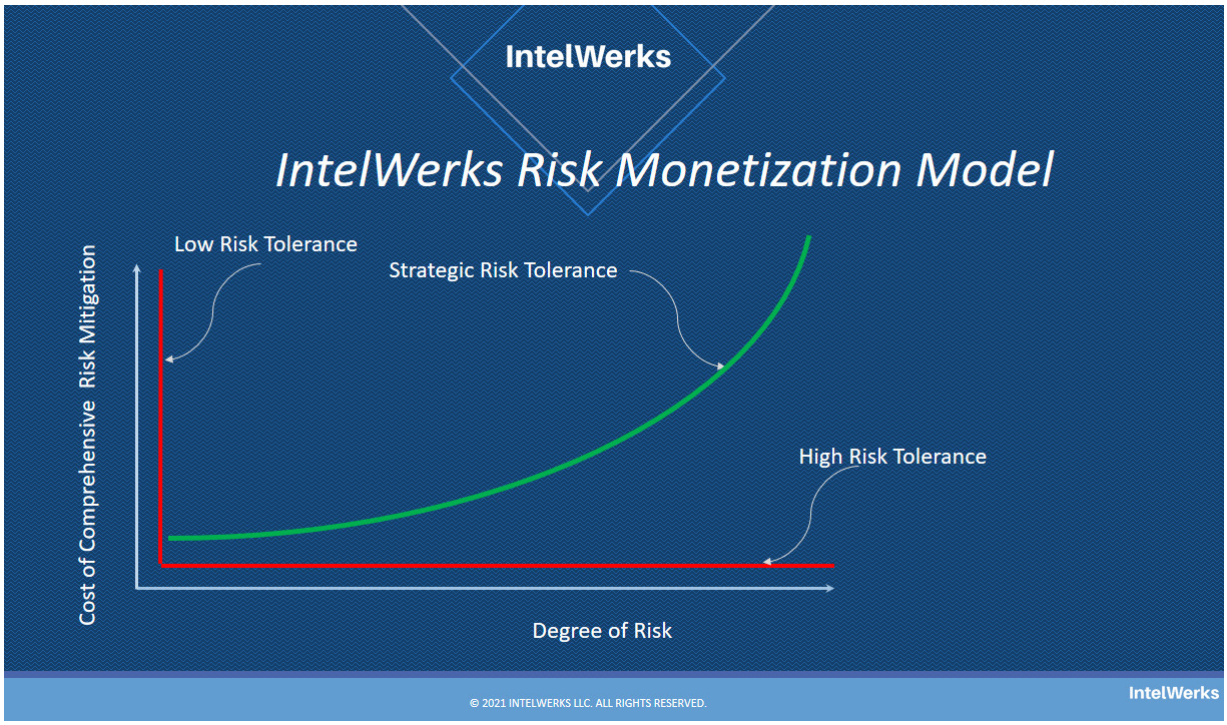

FIGURE 2 Risk monetization model.
SOURCE: Presentation by Chris Nissen, IntelWerks LLC, at a workshop of the Government-University-Industry Research Roundtable on Supply Chain Risk Management: Assuring Supply Reliability and Mitigating Demand Disruptions, held October 20, 2021.

[14] For an English-translated version, see http://english.www.gov.cn/2016special/madeinchina2025/.

"Asset tracking technologies have increased supply chain resilience," he continued. He described TrakG, which tracks potential tampering, temperature, moisture exposure and other important information about items and can be monitored remotely. Another technology, Diamond Unclonable Security Tag (DUST), provides unique serial numbers to items that can inform the circular economy and detect counterfeit parts. The combination of methods allows the supply chain to be more intelligent.

Finally, it is important to prepare for and respond to supply chain threats. Lockheed Martin and other large companies are undertaking climate-related financial disclosures to look at risks from climate change.[15] Recognizing the need to look at risks associated with critical suppliers, Lockheed Martin has expanded this effort from its own 300 sites to thousands of suppliers' sites, with multiple scenarios looking decades into the future.

Leshin pointed out that many of the innovations described began with research activity at labs. Geiger agreed research in both physical and digital innovations is needed. Engineers of the future will need to design for emerging domains. He noted that tying ERM with sustainability helped Lockheed Martin look beyond current goals and put more resources into resiliency, especially in areas that they know they will continue into the future.

Erick Jones described his background in industry, academia, and government in looking at different aspects of the supply chain as preparation for his current role as a Jefferson Science Fellow at the U.S. Department of State. He noted that the Administration has issued several Executive Orders and initially focused on four critical sectors: (1) semiconductors and advanced packaging, (2) critical minerals and materials, (3) electric vehicle batteries, and (4) pharmaceuticals and applied programming interfaces (APIs).[16]

[15] For Lockheed Martin's "Climate Risks and Opportunities," see https://www.lockheedmartin.com/content/dam/lockheed-martin/eo/documents/sustainability/LM%20Climate%20Risk%20and%20Opportunities%20Disclosure%202020.pdf.

[16] Jones mentioned two relevant Executive Orders: E.O. 14001 on public health supply chains and E.O. 14017 on America's supply chains.

The U.S. is developing partnerships in Asia, Europe, and the Americas to mitigate supply disruptions, and he stressed the need for partnerships and for an educated workforce for innovation to solve societal problems. "We are moving into an era based on talent, technology, and common interests," he stated. The talent discussion is about more than college, he added, noting the need for skilled longshoremen, truck drivers, and others. Infrastructure beyond technology is also needed. An impediment to more resilient supply chains is the lack of information sharing, often because private firms want to maintain privacy. He suggested finding ways to share information for system-of-systems modeling.

Keying in on this information-sharing need, **Liz Reynolds** (National Economic Council) described the "control tower" model set up by the Department of Health and Human Services to deal with COVID-19-related supplies. The department signed non-disclosure agreements with distributors and set up an early warning system to alert about shortages. There was a ***quid pro quo***—companies sent data to the government, which would aggregate it and provide it back to industry. There might be a similar role for government in other industries, she suggested.

Reynolds recognized that the pandemic exacerbated supply chain problems, but also exposed existing weaknesses. "The Biden Administration has leaned into the idea of a new industrial strategy, with a bolder vision for investments in industrial capabilities," she said. "Supply chains are the red flag to make these investments more salient." The question is how to incent companies to build more resilient supply chains. Many do not have transparency into their own networks, where the weakest link may be a Tier 5 supplier that makes a 10-cent sensor. The 100-Day Reports that came out in June looked at such short-term causes as labor shortages, but also deeper root causes: among them, hollowing out of domestic production linked to innovation, misaligned market incentives that promote short-term vision, geographic concentration of pharmaceutical ingredients and critical minerals, and industrial policies in other countries that have created unfair practices.[17] Reynolds

[17] See https://www.whitehouse.gov/wp-content/uploads/2021/06/100-day-supply-chain-review-report.pdf.

also echoed Jones's call for international cooperation to ensure national and economic security because domestic supply chains will not be totally rebuilt.

Executive agencies and Congress can further the agenda for strengthening supply chains, Reynolds said, by rebuilding capabilities and leapfrogging the United States into a competitive position in such areas as clean energy, advanced manufacturing, and the bioeconomy. She also highlighted a proposal to establish a Supply Chain Resilience Program that would provide monitoring and evaluation across government to anticipate problems in the future, as well as investments in stockpiling, innovation, and a strategic focus on small and medium enterprises (SMEs).

In a final discussion, Nissen pointed out that aspects of the air transportation industry lay within the purview of many agencies and standards, and suggested a parallel with supply chains. Another parallel with the aviation industry is that companies are competitive with another but share data. "You don't have to know every single item being shipped, but there could be classes of products to treat the supply chain like a network," he suggested.

A participant agreed with the need for a long-term vision. Reynolds commented that the power of transportation regulatory bodies including the Surface Transportation Board and the Federal Maritime Commission—designed for environments of the 1950s and 1960s—have been weakened over time. She said she was not advocating for a total regulatory overhaul, but urged the need to keep the public interest in mind when considering the role of government in creating long-term solutions to these challenges. "It's in everyone's interest to get this right," she said. She welcomed ideas from academia and industry.

THE ROLE OF DISRUPTIVE TECHNOLOGIES IN SUPPLY CHAIN RESILIENCE AND SUSTAINABILITY

New technologies and systems can be brought to bear to address supply chain challenges, said Leshin as she introduced a session that focused on cross-sector collaboration to advance research and innovation on supply chain resilience and sustainability—and how the research enterprise can contribute to addressing supply chain challenges.

Georgia-Ann Klutke (National Science Foundation) highlighted previous NSF-supported supply chain research and suggested future directions to catalyze the academic community, clarifying that she was expressing her own views. She based her presentation on a definition of supply chains as complex global networks of relationships among entities that mediate the movement of goods from producers to consumers that involve a large range of organizations, flows, and global economic rules. NSF investments over the past 20 years, mostly on the operational side, have achieved efficiencies and developed longer, more geographically dispersed supply chains, but she pointed out that supply chains have also become more disjointed and opaque. Resiliency has improved to withstand isolated disruptions, such as a fire, but supply chains are more vulnerable to broader disturbances and political risks. Systematic geopolitical vulnerabilities have heightened, and liberal democracies have trended away from government intervention. "There is a need to harmonize private- and public-sector priorities and provide more visibility into networks," she stated.

Klutke identified several areas where research could contribute to solutions: improved supply chain transparency and visibility; fragility built into the cost of supply chains; end-to-end design and optimization, transcending siloed research; continued digitalization and modernization of logistics operations; and secured supply chains from counterfeit and substandard inputs. She also called for bold initiatives to develop a new generation of sustainable, secure supply chains.[18]

"Resilience costs money," Klutke acknowledged. Private companies develop cost-competitive supply chains because otherwise they are at a disadvantage against state-supported organizations. She called for a

[18] Klutke noted she drew on several papers for her presentation: E. Iakovou and C.C. White III. 2020. How to build more secure, resilient, next-gen U.S. supply chains, Brookings Institution, https://www.brookings.edu/techstream/how-to-build-more-secure-resilient-next-gen-u-s-supply-chains/; H. Farrell and A. Newman/ 2020. This is what the future of globalization will look like, *Foreign Policy*, phttps://foreignpolicy.com/2020/07/04/this-is-what-the-future-of-globalization-will-look-like/.

moonshot-type initiative to develop a new generation of sustainable, secure supply chains. NSF wants to re-engage the academic community to think in these directions, she noted.

As an example of university research in supply chain resiliency, **Timothy Sprock** (Applied Research Laboratory for Intelligence and Security [ARLIS], University of Maryland) discussed the socio-technical approach provided by ARLIS to the Department of Defense and intelligence community. Ensuring trustworthy supply chains are one of its five mission areas.

This research area focuses on uncompromised delivery and sustainment of systems, services, and the workforce, and the intersection of people, technology, and policy. Simply stated, he said, "when you want to buy a thing from a person, how do you trust the thing and the person?" He elaborated that this need begins before the "thing" is made and long after it is in service. A roadmap to supply chain resilience encompasses network engineering and engineering for network efficiency; improved visibility to illuminate structure and events; and moving beyond robustness and toward anti-fragility. This last piece, he said, is where the most amount of new research is needed, because people in the system represent both risks and resilience. His group is developing tabletop exercises to identify vulnerabilities and potential solutions.

In addition to global threats, natural disasters and other disturbances within the United States can affect the supply chain. Sprock said it is important to consider when geofunctional redundancies are needed, and to distinguish the risks associated with allies and those who are not allies. He noted that the literature is starting to consider near-shoring from a political risk management standpoint. "There is work out there about how to solve this problem. It's a question of connecting the pieces to solve the problem correctly," he said.

As president of a company developing solutions in this area, **Joe Lea** (Shift5) described new technologies in transportation as a key component to de-risking the supply chain. While recognizing vulnerabilities related to IT, such as data centers and networks, Shift5 is focused on the OT used in transportation and weapons. A plane, for example, is a collection of sophisticated on-board computers and thus could be part of the overall attack surface, he said. Moreover, most devices are networked together and are remotely connected over RF-based, cellular networks that leave them vulnerable and susceptible to attacks. Unlike the IT world, "the OT side of the house" has a lot to learn, he stated. In OT, the rules of IT apply but there are physical consequences, as shown in the 2021 Colonial Pipeline ransomware attack and other incidents or attempts. Opportunities to mitigate against these risks include to (1) monitor internal networks continuously; (2) ensure cryptographically signed software and firmware updates; (3) develop systems to alert crew and maintenance personnel; and (4) provide full data capture and system access logs.

While most cybersecurity products in the industry focus on Transmission Control Protocol/Internet Protocol (TCP/IP) data, he explained, Shift5 focuses on serial data buses and embedded protocols that can be built into new products or retroactively applied to assets already in the field. "More information-sharing is needed, although historically, organizations that have been attacked have shown reluctance to share information about the attacks," Lea commented.

CREATING NEW MANUFACTURING CAPACITY

Throughout the series, development of U.S. manufacturing capacity, after a long period of decline, was identified as an important long-term solution to addressing supply chain vulnerabilities, noted Grasso. The final session focused on how to increase that capacity, especially through support of small and medium enterprises (SMEs) and public-private partnerships (PPPs).

As stressed by **William Bonvillian** (MIT), unless the underlying manufacturing system is fixed, supply chain problems will persist. In his remarks, Bonvillian drew on four findings. First, signals from manufacturing job losses parallel a decline in productivity levels and a U.S.

innovation gap vis-a-vis international competition.[19] SMEs in particular lag in productivity, he noted, and there are few new entrants because venture capital supports software and biotech, but not manufacturing. Second, production must be seen as part of the innovation system, rather than the current focus on R&D alone as innovation. Third, the tie-in between innovation and production should be deep—if not, both innovation and production will continue to shift from the United States to other countries. Fourth, Germany can offer lessons in how to create a deep manufacturing ecosystem. Bonvillian particularly called attention to the country's Fraunhofer Institutes for training and technology collaboration.

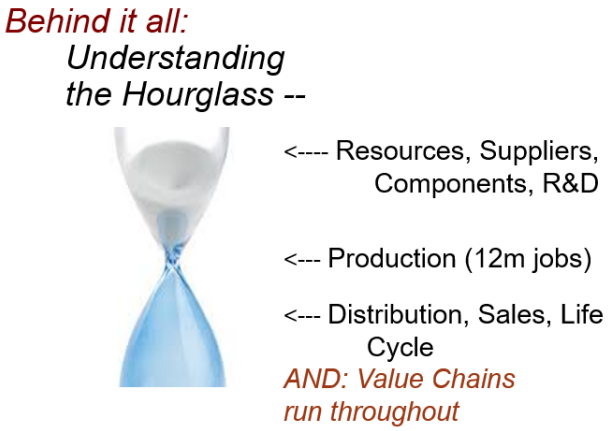

FIGURE 3 An hourglass depicts the key role of production.
SOURCE: Presentation by William Bonvillian, MIT, at a workshop of the Government-University-Industry Research Roundtable on Creating New Manufacturing Capacity, held November 4, 2021.

"Gaps in the U.S. production innovation system have led to social disruption," he continued. Manufacturing employment has dropped in terms of number of jobs, accompanied by stagnating wages. Bonvillian referred to an hourglass as an analogy—at the top of the hourglass resources are devoted to producers, components, and R&D; and at the bottom resources are directed to distribution, sales, and repair (Figure 3). The narrow part of the hourglass, receiving the smallest level of attention and resources, is production. Yet production is what connects the top and bottom of the hourglass, the upstream and downstream value chains with each other. "When you snap the manufacturing moment, you snap the hourglass," he said, which can disrupt the top and bottom of the glass, disrupting supply chains and the entire economy.

As a remedy, Bonvillian proposed applying the innovation system to manufacturing and filling the system's gaps by building new capabilities at the national and regional levels. "New manufacturing paradigms—such as digital production, mass customization, and other new technologies—can create new opportunities," he added. To that end, he urged Biden Administration to expand support for the Advanced Manufacturing Partnership, an industry-university-government collaboration with 16 manufacturing innovation institutes that support technology development, workforce education, and other functions.[20]

Bonvillian said advanced manufacturing provides a way to apply the U.S. innovation system to manufacturing in a more systematic way. Without a manufacturing fix, he concluded, there is no supply chain fix.

When asked about the costs of domestic manufacturing, Bonvillian said the United States should not re-enter every sector at scale. Using Germany as an example, he suggested focusing on production of high-quality products that use next-generation technologies. Opportunities where SMEs can compete include as component makers and suppliers, in mass customization, and perhaps in more localized production. "Manufacturing history has focused on scale-up, but new technologies can also scale down with efficiency," he commented. Systemic change takes a long time, he added, which is hard to communicate to policy makers who operate on shorter cycles. But he noted the challenges are apparent in terms of job losses and effects on communities, and he expressed hope that the country can mobilize to increase productivity through innovation.

Rob Ivester (Manufacturing Extension Partnership [MEP]) discussed how MEP supports the kind of growth described by Bonvillian. The MEP National Network is a

[19] Bonvillian referred to manufacturing job losses during the period from 2000–2018.

[20] For more information, see https://www.manufacturingusa.com/pages/history.

public-private partnership that provides proven solutions to manufacturers, with a focus on SMEs. The centers are located in all 50 states and in Puerto Rico. They partner with nonprofits, labs, and government agencies, and each is embedded with the manufacturers in its state. MEP focuses on three, complementary areas: technology, workforce, and supply chain.

SMEs are an increasing share of the manufacturing landscape, Ivester pointed out. In 2019, companies with 500 employees or fewer were almost 99 percent of the manufacturing landscape. Within that total, those with fewer than 20 employees were 68.7 percent of the total, up from 62.3 percent 10 years earlier. In aggregate, SMEs employ 71 percent of manufacturing employees and are 65 percent of the manufacturing payroll.

"An estimated 2.1 million jobs are going unfilled because of lack of a qualified workforce," Ivester said. MEP works to fill that gap through convening, recruitment, and tapping into resources. Opportunities include upskilling programs, better positioning of manufacturing jobs as a good career choice, and increasing the numbers of women and other underrepresented groups in manufacturing jobs. In particular, women make up 46.8 percent of the U.S. labor force, but only 29.5 percent of the manufacturing workforce. About 20 percent of firms have female representation in firm ownership, but only 14.9 percent of manufacturing firms do. This, Ivester said, is a target of opportunity.

As part of the supply chain solution, MEP is working to connect capabilities across the country and help SMEs become more proactive and resilient. For example, MEP has created a structured exercise for companies to quantify the costs and values connected with resiliency.

Mary Isbister (GenMET) illustrated how an SME is affected by supply chain issues and also can contribute to domestic capacity. As president of a 60-person metal fabricating company that makes high-value, complex equipment, she has been involved in leadership roles in several PPPs. Manufacturing has evolved over the 22 years she has been in business, Isbister observed. She identified the three most significant forces impacting U.S. manufacturing, including her own firm: globalization that has resulted in a highly interdependent supply chain; rapidly advancing technology; and, most importantly, changing demographics and attitudes of the workforce.

"We need to anticipate, respond, and adapt to global forces," she stated. When globalization took off in the early 2000s, the United States lost its competitive edge both in process and design innovation. Process innovation is a particular loss, and workforce capacity has declined as people saw those jobs moving overseas. Isbister said she sees the tide turning, in part because of the pandemic, but also because many companies are interested in re-shoring because of supply chain risks and transportation costs. She described rapid advances in manufacturing technology as both enabling and disrupting.

"Manufacturing jobs continue to evolve," she noted. The largest number of jobs used to be for unskilled labor; it now is the smallest segment. Technical competence is most important. Any competitive manufacturer has to have a skilled workforce, she said, and this trend will accelerate. "Talent is the currency of our economy," she said. Educational capacity has to deliver higher quantity and quality of talent.

Isbister described GenMet's activities as an example of how manufacturers must be proactive in building talent. "Imagine what the talent pool would look like if every manufacturer interacted with 350 students per year, participated in one advisory committee, donated one piece of equipment to a high school or technical college, and sponsored one robotics team or school project," she said. She also noted the valuable services from MEP and from the U.S. Manufacturing Institute (MxD), which focuses on digital manufacturing and other content support to SMEs.[21]

Colleges and universities can help prepare the workforce. GenMet supports curriculum development at local community colleges and provides equipment and materials to ensure students are learning with up-

[21] For more information, see https://www.mxdusa.org.

to-date resources. Several days after the workshop, professors from across the country were scheduled to visit GenMet for several days to understand the math and other skills needed in jobs like those at her company. She noted specialized certifications are valuable but warned some are too generic to be useful. U.S. manufacturers can be competitive through process innovation, she stressed. "Low-cost" manufacturing overseas is not necessarily low-cost with transportation and time costs incorporated into the calculations.

Grasso closed the workshop and the series by noting again the timeliness of the discussion and the importance of the work of the three presenters to build U.S. manufacturing capacity. A GUIRR member in the audience remarked, "Many young people in the country seeking meaning—not just cool—careers, and making things is something that can provide a meaningful life in America."

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REVIEWERS: To ensure that it meets institutional standards for quality and objectivity, this Proceedings of a Workshop Series—in Brief was reviewed by **KATHLEEN MCTIGUE**, National Institute of Standards and Technology and **OMKARAM NALAMASU**, Applied Materials. **MARILYN BAKER**, National Academies of Sciences, Engineering, and Medicine, served as the review coordinator.

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