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BETTER, FASTER, STRONGER: BUILDING NATIONAL COMPETITIVENESS THROUGH ADVANCED MANUFACTURING

ES 6712: ADVANCED MANUFACTURING INDUSTRY STUDY
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SEMINAR #2

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INTRODUCTION

For decades, globalization has facilitated positive economic ties and development.[1] It also made the US economy vulnerable to disruptions, material shortages, and international competition. As the Biden Administration observed, domestic manufacturing capacity is essential to the reliable availability of the goods, components, and equipment on which America's security, economic prosperity, and international influence rely.[2] Fortunately, Industry 4.0 and Advanced Manufacturing offer opportunities to improve domestic manufacturing capacity. Industry 4.0 is a vision for combining the power of people, machinery, and technology for more efficient production of goods and services that fuel the global economy. Advanced Manufacturing combines data, technical inputs, and process changes necessary to realize that vision.[3]

Since January 2022, Seminar Two of the Eisenhower School has studied the current state of Advanced Manufacturing. The class traveled to various US cities, many of them former industry hubs with broad access to well-paying jobs. With the assistance of federal government initiatives such as Manufacturing USA, innovative educators and researchers, and forward-thinking businesspeople, many of those cities are reinventing themselves as leaders of new American enterprise.[4] Seminar Two assessed from those stakeholder engagements that Advanced

[1] Anne Effland, Mary Anne Normile, and John Wainio, "World Trade Organization and Globalization Help Facilitate Growth in Agricultural Trade," June 1, 2008, https://www.ers.usda.gov/amber-waves/2008/june/world-trade-organization-and-globalization-help-facilitate-growth-in-agricultural-trade/.

[2] The White House, "The Biden-Harris Plan to Revitalize American Manufacturing and Secure Critical Supply Chains in 2022," Statements and Releases, February 24, 2022, https://www.whitehouse.gov/briefing-room/statements-releases/2022/02/24/the-biden-harris-plan-to-revitalize-american-manufacturing-and-secure-critical-supply-chains-in-2022/.

[3] US Department of Commerce, "Advanced Manufacturing Technology Services/Industry 4.0," National Institute of Standards and Technology: Manufacturing Extension Partnership, June 18, 2020, https://www.nist.gov/mep/advanced-manufacturing-technology-servicesindustry-40.

[4] Manufacturing USA, "History," Manufacturing USA: About, n.d., https://www.manufacturingusa.com/pages/history.

Manufacturing enables more agile production and facilitates rapid mobilization but requires a skilled and capable workforce to implement fully. *If strategically resourced and utilized, Advanced Manufacturing processes have the potential to amplify the capability, effectiveness, and responsiveness of the US manufacturing sector and, by extension, US economic competitiveness. The US government should remove barriers to the industry's broad and competitive adoption of Advanced Manufacturing processes to preserve national prosperity, security, and global influence. More transparent and results-oriented collaboration between government, academia, and industry is also necessary to facilitate Advanced Manufacturing adoption at the scope and scale appropriate for American manufacturers of various sizes.*

We researched the increased productivity that broader adoption of Advanced Manufacturing can facilitate. The class then considered potential structural and conduct changes that might influence the performance of companies utilizing Advanced Manufacturing processes, thus leveraging or exacerbating the opportunities and threats associated with the broader manufacturing sector. Using Michael Porter's Diamond Theory of National Advantage, the class analyzed the competitive edge that America might gain from Advanced Manufacturing's wider adoption, particularly relative to countries like China. Finally, we pooled our findings into a holistic analysis of strengths, weaknesses, opportunities, and threats to inform policy options. Ultimately, this paper reflects Seminar Two's findings and associated policy recommendations.

STRATEGIC ENVIRONMENT

Two significant trends shape the strategic environment in which US manufacturing operates: China’s rise as a manufacturing powerhouse and US corporations’ decision to outsource increasing amounts of formerly domestic production. Higher labor costs and the

decline of vocational education have pushed low-end manufacturing to places where cheap, skilled labor is plentiful. Lower shipping costs made it more profitable for US corporations to spread their supply chains across multiple countries (see Appendix B). Manufacturing remaining in the United States is typically high-tech or has sensitive national security implications.

COVID-19's onset, continuous pandemic management, Russia's invasion of Ukraine, and persistent and growing inflation are causing US manufacturers to reevaluate the sustainability of the current dynamic. For instance, Chinese lockdowns of manufacturing and port facilities under their "zero-COVID" policy severely threaten the just-in-time availability of the goods and raw material supplies that feed US domestic production.[5] Western efforts to deter Russian expansionism have disrupted global energy markets and driven up production and goods transportation prices. Finally, rising inflation forced the Federal Reserve to raise interest rates, increasing capital costs for US producers and subsequently increasing prices for customers.[6]

Advanced Manufacturing offers relief from these mounting pressures with processes and technologies that reduce production costs and make it cheaper to build closer to home. Companies and governments alike stand to prove their future competitive advantages with these processes. Strategic competition with China, which uses both open and covert tactics to shift global economic norms in its favor, heightens the urgency of the United States' leading the international conversation on Advanced Manufacturing. That competition also places mastery of Advanced Manufacturing at the center of US economic and, subsequently, national security, amplifying the criticality of America winning the Advanced Manufacturing race.

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[5] Ana Swanson and Keith Bradsher, "Supply Chain Woes Could Worsen as China Imposes New Covid Lockdowns," *The New York Times*, January 16, 2022, sec. Business, https://www.nytimes.com/2022/01/16/business/economy/china-supply-chain-covid-lockdowns.html.

[6] Rachel Siegel and Abha Bhattarai, "Fed Hikes Rates by Half a Percentage Point in Fight against Inflation," *Washington Post*, accessed May 17, 2022, https://www.washingtonpost.com/us-policy/2022/05/04/fed-rate-hike-inflation-may/.

STAKEHOLDER INTERESTS

The US adoption of Advanced Manufacturing relies on various stakeholders participating in activities such as basic research, applied research, prototypes, and production applications. Stakeholders include state and federal government, manufacturing companies, and academic institutions with vested interests in Advanced Manufacturing adoption. Proactive, results-oriented stakeholder engagements are essential to perpetuating process, knowledge sharing, and valuable experience to make relevant, transparent, and effective Advanced Manufacturing policy.

The federal government (and their state counterparts) has an overarching interest in a healthy manufacturing sector that contributes to American national security and economic growth. Accordingly, the federal government has sponsored or incentivized research and development to prove Advanced Manufacturing's capacity. The multiple federal agencies involved in that effort include the Department of Defense (DoD), Department of Energy (DoE), National Science Foundation, the Department of Commerce (DoC), as well as regulatory bodies. The DoC plays a particularly crucial role: in its stewardship of consortia, such as Manufacturing USA, Manufacturing Extension Partnerships (MEP), and university collaborations, DoC convenes the subject matter expertise needed to identify reforms and requirements that US policy and regulation can support.

The interests of another critical stakeholder—US industry—are not entirely dissimilar from those of the federal government: both seek to survive the competition and grow their market share. Similarly, both play a role in speeding or slowing the development and deployment of Advanced Manufacturing technology. Unlike the federal government, though, industry leaders' interests lie in shareholder confidence and creating value at acceptable levels of risk.

Industry views are vital to identifying technology, certification, and process gaps. Thus, while American industry has adopted elements of Advanced Manufacturing in recent decades, industry leaders await additional proof of concept, clear certification standards, and the reliable availability of base material and components to justify the expense that broader Advanced Manufacturing adoption will entail.

Academia, including university and private research institutions, is interested in the thought leadership and reputational benefits of rigorously analyzing the world and driving American innovation. Because it values knowledge regardless of the commercial benefits, academia provides a healthy counterbalance to the industry's near-singular focus on profit generation. Academia should thus be considered an essential stakeholder in identifying Advanced Manufacturing technologies and processes most likely to improve the United States' competitive advantage. Already, several universities and research institutions contribute the brainpower of their students, the extensive practical experience of their faculty, and the openness of their institutional culture to Manufacturing USA.

However, US stakeholders are not interacting in a vacuum. Friendly and competitive foreign counterparts are also interested in the greater economic productivity and international influence that comparative and absolute advantages in Advanced Manufacturing can deliver. Near-peers in Europe and Asia are establishing national targets for Advanced Manufacturing adoption and investing in public-private research partnerships. European and Asian corporate conglomerates such as ABB, Mitsubishi, and Siemens are among the companies that produce much of the software and machinery required to run the world's Advanced Manufacturing-enabled factories. Meanwhile, adversaries such as China have funneled copious state funds into crucial Advanced Manufacturing technologies, domestic production, and military-civil fusion

projects, increasing their overall national industrial capacity.[7] Additionally, the *China 2035* project seeks to set and control global standards for new technology.[8] If China achieves this goal, it will wield significant global influence over future Advanced Manufacturing technological functions and applications.

Therefore, US stakeholders' cooperation could result in a net gain or loss to the US competitive advantage depending on their focus, sense of urgency, and unity of purpose. If American manufacturing is to regain and maintain its global edge, the federal government must help align the structure and conduct of stakeholders and industries that stand to gain the most from adopting Advanced Manufacturing processes so that they may realize the performance improvements that will sustain that focus.

ANALYSIS OF STRUCTURE, CONDUCT, AND PERFORMANCE

To discern the policies that might accelerate broader Advanced Manufacturing adoption, the class used the Structure-Conduct-Performance (S-C-P) framework to evaluate the current condition of general US manufacturing. Advanced Manufacturing is not a single industry but the use and application of technological design and production processes. Therefore, the class used the S-C-P framework to analyze the *sector's* structure, performance, and the conduct of illustrative firms within the sector. Furthermore, since the S-C-P framework applies to industries, not processes, tables in Appendix D include S-C-P analyses of three specified industries that supply varied services and software offerings for Advanced Manufacturing solutions. The

[7] Karen Sutter, "'Made in China 2025' Industrial Policies: Issues for Congress," August 11, 2020, 3, https://crsreports.congress.gov/product/pdf/IF/IF10964.

[8] Carolyn Bartholomew and Robin Cleveland, "2021 Report to Congress of the U.S.-China Economic and Security Review Commission," n.d., 551, https://www.uscc.gov/sites/default/files/2021-11/2021_Annual_Report_to_Congress.pdf.

seminar offers these three industries as a representative sample to account for supply dynamics that will fuel or slow the broader adoption of Advanced Manufacturing in the United States.

The US manufacturing sector is diverse and "comprises establishments engaged in the mechanical, physical, or chemical transformation of materials, substances, or components into new products."[9] Manufacturing companies operate in industries listed under North American Industry Classification System (NAICS) codes starting with 31, 32, and 33, correlating to 446 manufacturing activities, including plastics, metal, and transportation equipment manufacturing, among others.[10] Given the broad array of firms that constitute the sector, it is difficult to characterize its structure in broad strokes accurately. In some sub-sectors, competition is high. Additionally, the market structure is generally a monopolistic competition with a low concentration ratio, and major companies occupy less than 2% of the market share.[11] Ninety-nine percent of the sector firms are small and mid-size enterprises (SMEs) that employ fewer than 500 employees. However, all manufacturers are vulnerable to a dearth of willing, skilled workers—a trend aggravated by the global movement toward Advanced Manufacturing.[12]

Generally speaking, a key influence on the market structure is the growth rate of market demand. One of the main demand determinants within the US manufacturing sector is federal fiscal and monetary policy. In some sub-sectors, barriers to entry are medium.[13] New entrants

[9] U.S. Bureau of Labor Statistics, "Manufacturing: NAICS 31-33," U.S. Bureau of Labor Statistics, May 6, 2022, https://www.bls.gov/iag/tgs/iag31-33.htm.

[10] NAICS Association, "31-33 Manufacturing," NAICS Code Description, 2018, https://www.naics.com/naics-code-description/?code=31-33; https://www.naics.com/code-search/?naicstrms=manufacturing&v=2017.

[11] Jared Ristoff, "Manufacturing in the US" (IBIS World, September 2021), 25, www.ibisworld.com.

[12] Manufacturing USA, "Manufacturing Workforce Development," <https://www.manufacturingusa.com/key-iniatives/manufacturing-workforce-development>

[13] Ristoff, "Manufacturing in the US," 7.

face high capital costs and difficulty securing access to distribution channels.[14] SMEs also compete with multinational conglomerates with extensive research and development budgets and high market shares in other subsectors.[15] Additionally, NAICS codes 31-33 only generate profit margins of less than ten percent, limiting the amount of capital businesses can reinvest into Advanced Manufacturing processes.[16]

The business conduct influenced by sector structure shows that firms are looking to differentiate product and service offerings based on non-price factors. More explicitly, manufacturers look to utilize the most effective and efficient production methods to reduce costs and maximize their profits.[17]

The structure and conduct yield the sector's performance. Overall, performance indicators, including contribution to economic welfare and productivity, show positive but slow growth.[18] As of the fourth quarter of 2021, the sector generated 11.3% of real Gross Domestic Product (GDP), or approximately $2.71 trillion, the highest in three years.[19] Nevertheless, the manufacturing sector's labor productivity is sluggish, with the Bureau of Labor Statistics reporting a 0.7% annual percent change in productivity from the first quarter of 2021.[20] Regarding the workforce, US manufacturing currently provides 12.7 million jobs, down 56,000

[14] Ristoff, 31. Distribution channels refer to both the logistics and sales of the manufactured goods. Some items are shipped from warehouses, showrooms, or built to customer requirements. IBIS suggests vertical integration of distribution channels will increase in the industry.

[15] Ristoff, 31.

[16] Ristoff, 7.

[17] Jared Ristoff, "Design, Editing & Rendering Software Publishing in the US" (IBIS World, December 2021), 12, www.IBISWorld.com.

[18] "Deloitte and the Manufacturing Institute: Big Gains in Perceptions of US Manufacturing As Innovative, Critical and High Tech – Press Release," Deloitte United States, accessed May 9, 2022, https://www2.deloitte.com/us/en/pages/about-deloitte/articles/press-releases/deloitte-and-the-manufacturing-institute-big-gains-in-perceptions-of-us-manufacturing-as-innovative-critical-high-tech.html.

[19] "Facts About Manufacturing," NAM, accessed May 11, 2022, https://www.nam.org/facts-about-manufacturing/.

[20] "Table 3. Manufacturing Sector: Labor Productivity, Hourly Compensation, and Unit Labor Costs, Seasonally Adjusted - 2022 Q01 Results," accessed May 12, 2022, https://www.bls.gov/news.release/prod2.t03.htm.

compared to February 2020.[21] Additionally, industry experts predict a need for 4 million manufacturing jobs by 2030, further expecting that 2.1 million of those jobs will remain unfilled due to a lack of interest in the career field.[22] Despite slow growth and reduced domestic employment, there is great potential to address these struggles through policy recommendations that drive structural change and affect business conduct, which will ultimately feed into the operational health of US manufacturing and increase growth potential.

PORTER'S DIAMOND MODEL ANALYSIS OF NATIONAL ADVANTAGE

Renowned economist Michael Porter identified the "Determinants of National Competitive Advantage," also known as "Porter's Diamond," as a mechanism to evaluate a nation's innovation and productivity and, thus, its potential for economic growth through application to a specific industry.[23] The evaluative determinants include industry strategy, structure, and rivalry; factor conditions; demand conditions; and related and supporting industries.[24] Government influence also impacts how a nation gains an advantage through its determinants. Analysis of Advanced Manufacturing in China and the United States highlights similarities and differences contributing to the two countries' unique economic capabilities (See Appendix E for a graphical Porter's Diamond analysis of each nation).

Government Impact

The government component of Porter's Diamond highlights crucial differences in the United States versus Chinese governance approaches. The United States relies on its capitalistic,

[21] "Facts About Manufacturing."
[22] "Facts About Manufacturing."
[23] Michael Porter, "The Competitive Advantage of Nations," *Harvard Business Review*, May 1990.
[24] Porter, 78–83.

free-market economy to drive competitiveness and economic growth.[25] Free market-driven ingenuity offers innovation advantages with some cohesiveness disadvantages compared to China's state-controlled approach to choosing national champions based on political and social priorities rather than economic motivations.[26] The US system also protects intellectual property, rewards productivity, and self-selects winners based on performance. However, reduced government control also means shareholder equity drives the US economic system, often resulting in companies prioritizing maximizing profits over reinvesting in industrial base health.[27] Ultimately, the US governance approach creates an open and meritorious innovation ecosystem—a global counterweight to China's controlled approach.

China's primary determinant of national productivity is the Chinese Communist Party's (CCP) influence and control over every aspect of its centrally planned economy and its close integration between public and private enterprises. In 2021, the US-China Economic and Security Review Commission identified the following key players in China's military-industrial ecosystem: central government agencies, defense conglomerates, national academies, universities, and research institutes, demonstration bases, industrial parks, and incubators.[28] These centrally-organized stakeholders exist to realize the CCP's "Made in China 2025" strategy, which identifies manufacturing, including Advanced Manufacturing, as the "principal pillar of the national economy, the foundation of the country, a tool of transformation, and basis of

[25] Stephen Brent, "Misunderstanding Investment in the United States and China," *American Affairs* 4, no. 4 (Winter 2020), https://americanaffairsjournal.org/2020/11/misunderstanding-investment-in-the-united-states-and-china/.

[26] Laura He, "China's Biggest Private Companies are in Chaos. It is All Part of Beijing's Plan," CNN Business, August 4, 2021. <https://www.cnn.com/2021/08/04/tech/china-crackdown-tech-education-mic-intl-hnk/index.html>

[27] Brent, "Misunderstanding Investment in the United States and China."

[28] Bartholomew and Cleveland, "2021 Report to Congress of the U.S.-China Economic and Security Review Commission," chaps. 2, Section 4, "Key Actors in China's Military-Industrial Ecosystem," pp. 272-276.

prosperity."[29] This military-industrial ecosystem, combined with the CCP's emphasis on manufacturing, creates a favorable, vertically integrated environment.

Strategy, Structure, and Rivalry

Key strategy, structure, and rivalry elements include public versus private organizations, ease of industry entry and exit, domestic rivalry, and mobilization capacity. The United States fosters strong domestic competition in its consumer marketplace. However, this competition dwindles in manufacturing, where decades of offshore production reduced US capacity. Flexibility in production, speed, decreased inventory, and tooling costs are some of the advantages that Advanced Manufacturing offers and, if broadly adopted, can help the United States as the global leader in high-tech manufacturing.[30] However, this requires strong domestic competition first, especially at the SME level. US policies enabling small-business growth, experimentation, and information sharing are critical. SMEs need assistance moving from legacy systems to Industry 4.0 technology, including tax breaks, grants, low-cost loans, and access to resources and expertise to guide them and incentivize technological adoption.

China does not face the same incentivization challenges. The CCP identifies areas in which China seeks to grow and, using a variety of public and private corporations, creates solutions to satisfy its demands. The same is true for the CCP's ability to mobilize national production on demand. Ultimately, the CCP's willingness to direct China's economy by exerting control over Chinese corporations is a national advantage, allowing the CCP to constrain strategy, structure, and rivalry to CCP-defined terms.

[29] China State Council, "Made in China 2025," July 7, 2015, http://www.cittc.it/wp-content/uploads/2017/07/IoT-ONE-Made-in-China-2025.pdf.

[30] John F. Sargent Jr. and R. X. Schwartz, "3D Printing: Overview, Impacts, and the Federal Role" (Washington, DC: Congressional Research Service, August 2, 2019), https://crsreports.congress.gov/product/pdf/R/R44828.

Factor Conditions

Porter's factor conditions include infrastructure, education, innovation, and culture. From a cultural perspective, the United States is generating momentum by initiating a national conversation on the need to strengthen US manufacturing capacity, infrastructure, and supply chains. President Biden's Interim National Security Strategy guidance directs building supply chain resilience four times. Executive Order 14017 mandated a 100-day review of supply chain weakness.[31] The Biden Administration has signed an infrastructure package into law, and there is widespread acknowledgment that investments in infrastructure are necessary to maintain US competitiveness. The United States also has a risk-taking culture and a vibrant innovation ecosystem that supports new technologies. The capitalistic, free-market approach of the United States should drive long-term advancement and innovation. However, other US factor conditions will limit the fielding of Advanced Manufacturing technologies until the US reconciles those factors with market demand. These include the lack of a skilled workforce, high labor costs, and challenging regulatory and bureaucratic processes. Policy in this area should focus on harvesting existing networks of expertise, like Manufacturing Innovation Institutes (MIIs), research and development centers, national labs, and academia, improving workforce readiness, and easing regulatory barriers.

In contrast, China's focus on corporate espionage attempts to compensate for lacking innovation created by cultural and societal reverence for collectivism at the expense of individual needs, thereby limiting creativity. China's willingness to use aggressive corporate espionage allows the country to monitor market conditions and act as a fast follower as others innovate new

[31] "Executive Order on America's Supply Chains," The White House, February 24, 2021, https://www.whitehouse.gov/briefing-room/presidential-actions/2021/02/24/executive-order-on-americas-supply-chains/.

technologies. China's workforce is also transitioning from low-skilled to more educated. However, the overwhelming majority of the Chinese population (almost 85%) still has not attained an education level above high school.[32] Finally, China excels at creating industry clusters that enable quick vertical integration. An excellent example of this is the city of Shenzhen, where reportedly, an idea can become a functioning prototype in one day.[33]

Demand Conditions

The United States can gain a competitive advantage by exploiting demand conditions. Demand conditions involve increasing productivity and value creation based on market requirements. The United States retains the largest global GDP per capita, a sophisticated consumer base, and large manufacturers looking for efficiency. The United States can apply these advantages to Advanced Manufacturing, assuming the government overcomes the challenge of fighting economic uncertainty. Sometimes firms delay large capital investments due to unknowns in future demand, especially in the manufacturing sector, where companies may wait years to appropriate funding.[34] The US government can use policy to flatten risk curves and incentivize investment in technologies like Advanced Manufacturing.

Demand conditions are also a determinant in which China excels due to its economic controls. The direct CCP-government-industry link facilitates the party's control over production, sustainment, and budget trends to benefit its economic growth. For instance, the CCP requires that every company with more than fifty employees maintain a CCP representative on

[32] Fuller Wang, Yuanpu Huang, "The Talent Dividend Driving China's Advanced Manufacturing" (20 September 2021) accessed at https://equalocean.com/analysis/2021092016642, pp. 2-3.

[33] Abhijit Dutta, "They built this city, Shenzhen 40 years after," HT Media, December 13, 2018, (2 pp.). https://nduezproxy.idm.oclc.org/login?url=https://advance.lexis.com/api/permalink/62a77b58-d8d2-4511-a5cc-65eed63099dc/?context=1516831

[34] Mrinal Menon and Jeff Decker, "Why the Defense Industry Could Be the Most Transformative Market for Startups," *Fast Company*, May 10, 2021, https://www.fastcompany.com/90634168/why-the-defense-industry-could-be-the-most-transformative-market-for-startups.

payroll, furthering the government's ability to direct companies according to CCP mandates.[35] In essence, the CCP sets demand conditions for the Chinese economy.

Related and Supporting Industries

The United States benefits from many related and supporting industries that contribute to the strength of its industrial base. The United States is also home to several distinct technology clusters—the leading example is Silicon Valley. These clusters create an ecosystem where ideas, information, capital, and products rapidly change hands.[36] Such interactions boost innovation and productivity. The United States also directly feeds (through public-private partnerships) manufacturing clusters in places like Michigan, Illinois, Ohio, and Pennsylvania, ready for Advanced Manufacturing. Manufacturing industry connections to the software industry in the US provide an advantage in developing data-driven technologies; digital design, IIoT, and additive manufacturing all rely on software integration. Policy in this area should ultimately support clusters. Policymakers should consider directing funding to areas where complementary markets exist, such as the Rust Belt, or where specific industries like the automotive or aerospace industries have historical and active roots.

Related and supporting industries are another determinant at which China excels. China has created economic parks and built cities around explicit manufacturing initiatives and institutes through government control. Like the MIIs, China also created institutes dedicated to public-private partnerships, such as national academies and research institutes.[37] Finally, China

[35] Glaser, Bonnie S. (testimony), "Made in China 2025 and the Future of American Industry," U.S. Senate Committee on Small Business and Entrepreneurship, February 12, 2019, pp. 58. https://www.govinfo.gov/content/pkg/CHRG-116shrg35699/pdf/CHRG-116shrg35699.pdf

[36] Robert M. Grant, "Chapter 12: 'Global Strategy and the Multinational Corporation,'" in *Contemporary Strategy Analysis*, 9th Edition, 2016, 317.

[37] *2021 Report to Congress of the U.S.-China Economic and Security Review Commission*, November 2021, Chapter 2, Section 4, "Key Actors in China's Military-Industrial Ecosystem," pp. 273.

uses control over market technologies to its advantage by requiring firms to share technology as a condition for establishing a presence in the country.

Russia

The seminar's analysis of strategic competition also included Russia. However, Russia's February 2022 invasion of Ukraine revealed the consequences of its near-singular focus on energy production and its failure to invest in defense and organic industrial base modernization effectively. These decisions stymied the country's capital investment, education, research, and development contributions to its manufacturing capacity, which are required to rival the United States or China in developing and fielding new manufacturing technologies. While the war in Ukraine might end, it is unlikely that Russia will have the bandwidth to compete in the Advanced Manufacturing space anytime soon.

Summary

Porter's Diamond highlights valuable insights into potential Advanced Manufacturing policy interventions. The US manufacturing workforce has diminished, but technology clusters around the country are reviving commercially viable and workforce-sustaining possibilities. Additionally, manufacturers seeking to work with the government face long-lead times and uncertainty in contracts and funding, but Executive Order 14005 and current supply chain crises have fueled a national conversation on the urgent need for US manufacturing improvements.[38] Finally, manufacturers require access to capital, examples of success, and expertise to break down barriers to adoption, and the United States maintains a rich network of institutions, research centers, universities, and national laboratories ready to aid manufacturers. These areas

[38] "Executive Order 14005: Ensuring the Future Is Made in All of America by All of America's Workers" (The Office of the President, The White House, January 28, 2021), https://www.federalregister.gov/documents/2021/01/28/2021-02038/ensuring-the-future-is-made-in-all-of-america-by-all-of-americas-workers.

present opportunities for policy action made apparent through a comparative analysis highlighting strengths, weaknesses, opportunities, and threats.

COMPARATIVE ANALYSIS OF STRENGTHS, WEAKNESSES, OPPORTUNITIES, AND THREATS

The seminar used the S-C-P and Porter's Diamond comparisons of the United States and China to determine the strengths, weaknesses, opportunities, and threats (SWOT) associated with the decision or failure to pursue the adoption of Advanced Manufacturing. In his US and China Net Assessment, Burke Chair in Strategy at the Center for Strategic and International Studies, Anthony Cordesman, describes the competition underway as "a game of three-dimensional chess where there are no fixed rules, no limit to the number of boards where the game is played, and no clear limits to the number of state and non-state actors that can join the game and move on their own."[39] From this perspective, we see the battle to master and leverage Advanced Manufacturing as another "game board" in the broader US-China strategic competition. However, this specific game board is connected to—and supports—other game boards associated with the instruments of national power: economic support, military capability, and diplomatic strength.

Strengths

The US and China's primary strengths are their economic systems and their governments' ability to tap into them to drive economic growth. Neither system is without faults, and both are prone to missing opportunities due to dogmatic adherence to underlying principles. On the one hand, the free market of the US, which incentivizes short-term gains and innovation, has been the engine of economic growth since World War II. It is a system that prizes efficiency and attempts

[39] Anthony H Cordesman, "Chinese Strategy and Military Forces in 202," n.d., 191.

to allow market forces to determine the vector and velocity of change. On the other hand, China's centrally planned economy is more directive. The variety of five-year plans in various technological areas, the *China 2035* project, and the Made in China 2025 strategy (and subsequent national vision documents) steer investment.

Interestingly, both economies appear to learn from the other: the United States has created MIIs to facilitate the development of emergent technology that aligns with organically developed industrial clusters. For its part, the CCP allows a degree of regional autonomy in making investment decisions to capitalize on the knowledge of the market. The challenge for both countries will be to align their economic models to global demand conditions as technologies mature.

Beyond the strengths that each country leverages based on their economic models, both the United States and China have other structural strengths that contribute to their ability to implement Advanced Manufacturing. For the United States, many of the strengths enable a business environment that accepts and rewards risk-taking. These strengths include the rule of law, protection of intellectual property rights, a robust innovation ecosystem, a strong university system, and a government that contributes to—but does not direct—research activities. The United States also benefits from its stewardship of the liberal international order and a strong community of like-minded partners and allies.

China's strengths, on the other hand, are associated with an authoritative, centralized direction of the political and economic life of the country, a culture that subordinates individual interests to the larger whole, the civil-military fusion of investment, and centralized asset control—everything from communications spectrum to raw materials used in supply chains. The "Made in China 2025" plan, which seeks to "escalate market share of Chinese suppliers in the

domestic market up to 70%, is an example of the centralization that has pushed financial resources and political support to China's monopolization of the international manufacturing marketplace."[40]

Weaknesses

US strategic weaknesses that impact Advanced Manufacturing adoption result from the impact of globalization on domestic production and years of infrastructure neglect. These meta-factors have contributed to a domestic workforce ill-equipped to support current manufacturing levels and will struggle to participate in an Advanced Manufacturing-dominated future. Currently, 83% of US manufacturers struggle to attract and retain a skilled workforce.[41] Along with shortfalls in skills associated with data management, digital design, and higher-level manufacturing support (e.g., robotics), US manufacturing faces numerous structural challenges.[42] Conversely, China excels in aligning whole-of-government and whole-of-nation efforts to achieve national objectives. Meanwhile, the US government has thus far struggled to incentivize the workforce development and other investments needed for Advanced Manufacturing processes to thrive.

In contrast, several weaknesses may impact China's ability to evolve its manufacturing capabilities. Experts expect China's population to peak at 1.407 billion in 2024, followed by a period of accelerating population loss.[43] Fewer births equal fewer workers. China must also contend with significant splits in its existing workforce (e.g., urban vs. rural, educated vs. non-educated, etc.). China's insularity compounds these divisions; future aging workforce issues are

[40] China State Council, "Made in China 2025."
[41] "Deloitte and the Manufacturing Institute."
[42] "Deloitte and the Manufacturing Institute."
[43] Wang Guangzhou and Wang Jun, "Economic and Social Impact of China's Aging Population and Public Policy Response," *China Economist* 16, no. 1 (February 2021): 1, https://doi.org/10.19602/j.chinaeconomist.2021.01.05.

unlikely to be mitigated by adjusting immigrant inflows. Through its Belt and Road Initiative, China has already begun to outsource elements of its lower-end manufacturing.[44] Beyond demographics, the centralization at the heart of the Chinese economic model may omit vital technological innovations in favor of the government's prescribed plan of action. Ultimately, the conditions fostering innovation flourish in free societies.[45]

Opportunities

The United States has awoken to the challenges presented by its diminished manufacturing capability. Furthermore, populist concerns regarding the health of these jobs and the middle class have impacted legislative priorities.[46] In response, federal and state governments built a network of Manufacturing Innovation Institutes and Manufacturing Extension Partnerships designed to facilitate the research and preparation for firms of all sizes to compete in a globalized, digitized economy. Finally, globalization has caused the costs of raw materials and labor to increase in once highly competitive markets compared to the United States. These realities, coupled with customer needs that favor customization and small batch ordering, give US industry opportunities to better align manufacturing capacity with market demands.

China's opportunities rest on its ability to leverage its economic strength to influence regional and global actors. The Belt and Road Initiative creates a platform for China to gain and control international sources of raw materials, including rare and critical minerals. Additionally,

[44] "China's 'One Belt, One Road' Initiative: Economic Issues" (Washington, DC: Congressional Research Service, January 22, 2021), https://crsreports.congress.gov/product/pdf/IF/IF11735; Saibal Dasgupta, "Outsourcing Appears to Be China's Workaround for US Tariffs," *Voice of America*, January 26, 2019, https://www.voanews.com/a/east-asia-pacific_outsourcing-appears-be-chinas-workaround-us-tariffs/6172681.html.

[45] Matt Ridley, *How Innovation Works : And Why It Flourishes in Freedom.*, First U.S. edition. (Harper, an imprint of HarperCollinsPublishers, 2020).

[46] National Science and Technology Council, "Strategy for American Leadership in Advanced Manufacturing: A Report by the Subcommittee on Advanced Manufacturing Committee on Technology," October 2018, https://trumpwhitehouse.archives.gov/wp-content/uploads/2018/10/Advanced-Manufacturing-Strategic-Plan-2018.pdf.

the initiative allows China to seize real estate through predatory tactics from countries through "lend-to-own" deals or debt trap transactions.[47] China is also poised to take advantage of global cyber vulnerabilities: the country still lags in indigenous innovation but is skilled in cybertheft. It can use this capacity and its forced technology transfer provisions to maintain at least a fast-follower position vis-a-vis other nations' manufacturing capability. Finally, recent global events present an opportunity for China to promote its yuan (renminbi) as an alternative to the US dollar as a global reserve currency.[48] Specifically, the recent US-led economic retaliation against Russia for its invasion of Ukraine has proven the United States' ability to control any country's access to the global financial system and may spark interest among authoritarian countries to actively push an alternative to the US dollar, severely undermining US influence over the international financial order if realized.

Threats

The two biggest threats the United States faces concerning Advanced Manufacturing adoption are infrastructure vulnerabilities and economic instability. As previously mentioned, China's ability to exploit cyber vulnerabilities is a significant threat to the US, given America's patchworked, decentralized, and voluntary approach to cyber security. Data is the lifeblood of Advanced Manufacturing, making data integrity a prerequisite for any company or country's success. Additionally, the US faces concerns over its economic health, and the Federal Reserve recently increased the national interest rate in response to persistent inflation.[49] The rising cost of

[47] Jordan Calinoff and David Gordon, "Port Investments in the Belt and Road Initiative: Is Beijing Grabbing Strategic Assets?," *Survival (00396338)* 62, no. 4 (August 2020): 59–80, https://doi.org/10.1080/00396338.2020.1792134.

[48] "DS549: China - Certain Measures on the Transfer of Technology" (The World Trade Organization, June 1, 2018), 549, https://www.wto.org/english/tratop_e/dispu_e/cases_e/ds549_e.htm.

[49] Marc Labonte, "Inflation in the Wake of COVID-19," *Congressional Research Service*, accessed May 9, 2022, https://crsreports.congress.gov/product/pdf/R/R46890.

borrowing increases risks associated with annual budget deficits and risks that firms assume when making capital investments in Advanced Manufacturing technologies.

China faces potential backlash to the predatory actions it has used to expand its sphere of influence. Further, its continued economic growth has thus far relied on an infusion of state funds, which relies on a continued international commitment to manufacturing in or buying from China. If most participants in the Belt and Road Initiative or markets for China's export-driven economy close, Chinese economic growth will slow. China's challenge is, therefore, to pursue a strategy of global economic pre-eminence without alienating the partners and customers that power its domestic economy.

POLICY RECOMMENDATIONS

The amalgamation of strategic considerations, S-C-P, Porter's Diamond, and SWOT analysis frame the current Advanced Manufacturing environment and inform several policy recommendations. The seminar broadly assesses that adopting Advanced Manufacturing techniques will increase US economic productivity, enhance US national security, and bolster the United States' continued leadership of the international economy. The class also learned that many manufacturers, especially SMEs, are hesitant to invest the capital necessary to transform their production lines. Consequently, the seminar identified a series of policy recommendations intended to mitigate those risks and encourage adoption. However, the long-term viability of these policy recommendations hinges on two overarching realities.

First, policy implementation relies on funding through congressional appropriations, Executive Branch prioritization, or US corporate allocations. These funds are not charitable contributions, though—they have tangible impacts on US GDP. Each dollar invested in

manufacturing returns $2.68 in economic growth. Each manufacturing job creates four non-manufacturing jobs.[50] The boost in economic output and employment creation increases tax collected by the federal government without tax increases.[51] Therefore, the narrative associated with implementing our policy recommendations must consistently couple near-term resourcing costs with long-term economic gains.

Second, legislation sends a more consistent demand signal for industry structure and conduct than Executive Orders. Congress has passed funded legislation for Advanced Manufacturing adoption, which still requires obligation.[52] The COMPETES ACT, BUILD BACK BETTER ACT, CHIPS ACT, and CARES ACT are examples. While Executive Orders provide flexibility, legislation is the long-term path to predictable resourcing and prioritization necessary to generate industry demand that aids Advanced Manufacturing adoption on an annual basis like the National Defense Authorization Act does for national defense.

With these realities in mind, the seminar offers several policy recommendations grouped into four primary areas, none mutually exclusive: reducing risk by proliferating use cases, developing the workforce, creating standards, and promoting international collaboration. Appendix G offers additional details.

Tell the Story: Reduce Risk and Proliferate Advanced Manufacturing Use Cases

The United States needs to reduce Advanced Manufacturing adoption risk and incentivize adoption. China executes this through state funding and direction. In a free market, adoption requires market demand, not government direction, but the US government can foster demand by

[50] "Facts About Manufacturing."

[51] Andrew Lundeen, "Economic Growth Drives the Level of Tax Revenue," *Tax Foundation* (blog), October 15, 2014, https://taxfoundation.org/economic-growth-drives-level-tax-revenue/.

[52] Nate Rattner Pramuk Jacob, "The U.S. Has Spent Most of Its Covid Relief Funding, but There Are Still Billions Left to Dole Out," CNBC, December 9, 2021, https://www.cnbc.com/2021/12/09/covid-relief-bills-us-has-spent-most-of-coronavirus-aid-money.html.

assuaging risk and promulgating early successes. The threat of rising interest rates will further reduce corporations' propensity to invest in Advanced Manufacturing technologies, highlighting the necessity to have the government incentivize adoption. Ultimately, success breeds success: if corporations see the business case for how Advanced Manufacturing processes can reduce cost and increase quality, more will assume the risk of process adoption. Risk reduction and subsequent use case proliferation require complementary actions by the Executive Branch, Legislative Branch, regulatory agencies, and non-regulatory bodies.

The US government should pursue four initiatives toward reducing risk and proliferating use cases. First, the Executive Office of the President should update Executive Order 14005, "Ensuring the Future Is Made in All of America by All of America's Workers," to create a unifying Advanced Manufacturing vision to include direction for overarching mechanisms (e.g., government liaisons, digital platforms, and annual symposiums) necessary to drive collaboration and highlight successful use cases across the manufacturing ecosystem.[53] Doing so will establish a necessary manufacturing narrative for the 21st Century. Next, the seminar recommends investing $1 million per year for each MII and MEP ($66 million per year) over five years, funded through the 2022 America COMPETES ACT, to develop Advanced Manufacturing deployment kits highlighting technological successes. A unified vision coupled with deployment kits will allow MII and MEPs to showcase possibilities across industry and academia, inspiring adoption.

Additionally, the DoD can help drive Advanced Manufacturing adoption by updating its 2016 Source Selection Guide to promote the inclusion of contractors that utilize Advanced Manufacturing processes, with an initial target for 5% of work in the contract using Advanced

[53] "Executive Order 14005: Ensuring the Future Is Made in All of America by All of America's Workers."

Manufacturing, with a goal of 35% by 2035. Finally, the DoD, DoE, and DoC should establish pilot programs with appropriate academic and innovation institutes for commercial access to testbed facilities to test processes and materials manufactured using Advanced Manufacturing techniques. The US government should fund these pilot programs through current department budgets for MIIs, the DoD's Federally Funded Research and Development Centers, and University Affiliated Research Centers.

Identify and Codify Standards

Standards instill confidence in innovation: they give manufacturers a consistent production target and customers the assurance that products will perform as reliably and safely as those made using traditional manufacturing processes. Consequently, the US needs to identify and codify Advanced Manufacturing standards to de-risk adoption of technologies by firms and enable manufacturing resiliency. Codifying standards will rectify the weakness of lack of usable formats across manufacturers while mitigating the cybersecurity threat.

Four actions will accelerate codification. First, the National Institute for Standards and Technology (NIST) should develop and maintain a materials database with certified metallurgic properties to accelerate the adoption of additive manufacturing in collaboration with industry consortia. Next, the Office of the Secretary of Defense for Manufacturing Technology and DoD Departments should invest through MIIs to modernize the Organic Industrial Base, develop and maintain Digital Twin standards, and publish a workbook detailing standards used on legacy machinery to demonstrate the value propositions for scaled adoption. Further, the DoD must develop a definition of Tech Data Packages (TDP) for digital twin and additive manufacturing, mandating use in solicitations (DoD non-commercial). As a corollary, DoD should also invest in the necessary infrastructure to improve the storage and consumption of TDPs. Finally, the

Federal Acquisitions Regulations (FAR) Council must expand Cybersecurity Maturity Model Certification (CMMC) applicability across all government acquisitions by modifying the FAR. Simultaneously, the DoC should develop a roadmap for baseline minimum cyber security for the rest of the manufacturing base. Such actions would bring more manufacturing firms under the umbrella of CMMC and define a path forward for other manufacturing firms. The departments can utilize Infrastructure Investment and Jobs Act funding to update the infrastructure for databases and cybersecurity requirements. Costs associated with CMMC compliance will be mitigated through MIIs fielding the cyber marketplace to simplify the process and identify low-cost options that meet requirements. The US government should also resource this policy through corporate cost-sharing with companies whose interests align with developing standards to ensure American manufacturing remains competitive.

Develop a Capable Workforce

A skilled workforce is essential to the industry growth necessary to mitigate the threat of Chinese competition but does not exist in sufficient strength to sustain the transition to Advanced Manufacturing.[54] The US must address the historical narrative of manufacturing as a dull, dirty, and dangerous occupation and close the workforce deficit to realize Advanced Manufacturing productivity. All sixteen Manufacturing USA institutes implemented workforce development initiatives to increase workforce participation and skills in advanced manufacturing. The federal government can amplify these initiatives by fostering the greater alignment of national strategy, publicizing the benefits of manufacturing jobs, synergizing the activities of MEPs, and reforming immigration policy.[55]

[54] "Will Advanced Manufacturing Close the Workforce Gap? - SecureAmerica Institute," accessed May 12, 2022, https://secureamerica.us/will-advanced-manufacturing-close-the-workforce-gap/.

[55] "Manufacturing Workforce Development," Manufacturing USA, accessed May 12, 2022, https://www.manufacturingusa.com/key-iniatives/manufacturing-workforce-development.

Specific actions to this end should include the Economic Development Agency (EDA) providing grants to community colleges to create Advanced Manufacturing training and education facilities. Additionally, EDA should market Advanced Manufacturing as an exciting employment opportunity vital to national security through the Ad Council. The US government could fund these efforts through unobligated portions of the $1.5 billion CARES Act.[56] Additionally, the US government should focus EDA investments, NIST MEP, and Manufacturing USA engagements by leveraging Defense Critical Supply Chain Task Force reports to identify struggling manufacturing areas before they go offshore or out of business, insulating critical manufacturing sectors from unfair trade practices. The America COMPETES Act provides funding to research such strategic concerns.[57] Finally, Congress should increase the cap on H1-B visas from 85,000 to 500,000 over the next five years while also fast-tracking applications for Advanced Manufacturing focused degrees.[58] This action should occur in conjunction with prioritizing foreign graduates of US academic institutions for clear paths to citizenship. At the end of the five years, the Department of Commerce will report to Congress on the program's success and assess the impact on US Citizen jobs.

Collaborate with Allies and Partners

International cooperation on standards and process improvements is vital to gain an advantage in strategic competition. China seeks to overtake the United States in influencing the

[56] EDA Office of Public Affairs and Communications, "U.S. Department of Commerce Invests $1.1 Million in CARES Act Recovery Assistance to Support the Growth of Advanced Manufacturing, Life Sciences and Technology Sectors in Fall River, Massachusetts," accessed May 11, 2022, https://eda.gov/news/press-releases/2021/07/22/fall-river-ma.htm.

[57] "Policy Briefing: Passed by the House, the America COMPETES Act Would Boost Research Funding," accessed May 11, 2022, https://www.asce.org/publications-and-news/civil-engineering-source/civil-engineering-magazine/article/2022/02/passed-by-the-house-the-america-competes-act-would-boost-research-funding.

[58] "H-1B Specialty Occupations, DOD Cooperative Research and Development Project Workers, and Fashion Models | USCIS," February 25, 2022, https://www.uscis.gov/working-in-the-united-states/h-1b-specialty-occupations.

international approach to Advanced Manufacturing adoption, standardization, and use. US partners and allies can effectively counter China's ambitious goals by leading standards development and ensuring Advanced Manufacturing standards are high-quality, transferable, and useable by manufacturers worldwide. The United States can foster international standards, norms, and approaches that favor US business success while assuaging US national security concerns through diplomatic engagement, foreign assistance, and technical collaboration.

Specifically, the United States should take several actions led by DoS with support from the interagency, given the diplomatic overtones. First, the United States should aggressively pursue US participation in international standards negotiations leveraging touchpoints between government standards-setting organizations and critical non-profit organizations, including the American Society for Testing and Materials International.[59] Additionally, the United States needs to increase information sharing to synchronize Advanced Manufacturing priorities toward processes benefiting strategic competition. Information sharing should occur in conjunction with increased resource collaboration between the United States and its allies and partners to bolster the cooperative development of accessible, US-preferred Advanced Manufacturing processes. Finally, the US should foster partnerships between US MIIs and analogous foreign government institutions to maximize the distribution of Advanced Manufacturing processes across alliances and partnerships that benefit strategic competition without imposing additional US funding requirements.

[59] "ASTM International," accessed May 18, 2022, https://webstore.ansi.org/sdo/astm?msclkid=d50d648c13d719f84b19060ffc2a6a3b&utm_source=bing&utm_medium=cpc&utm_campaign=Standards-US&utm_term=astm%20international&utm_content=ASTM.

COSTS, RISKS, AND GAPS

The following broad discussion outlines cross-cutting costs, risks, and gaps associated with the proposed policy recommendations with mitigation considerations, where appropriate. For a more detailed breakdown of costs, risks, and gaps associated with recommendations, see Appendix G.

Costs

Generally speaking, the seminar formulated policy recommendations designed to avoid expansive Congressional appropriations with the potential exception of workforce development. If America wants to maintain economic leadership writ-large, it must find creative means for resourcing wide-ranging workforce initiatives, including the proposed policy recommendations specific to Advanced Manufacturing. Recent resourcing efforts, including the Creating Helpful Incentives to Produce Semiconductors for America Act and the proposed Advanced Manufacturing Jobs in America Act, are steps in the right direction.[60] However, the government must couple these efforts with continuously evolving commercial incentives to ensure sustained progress at the manufacturer level. Congressional resourcing also needs to account for the administrative cost of maintaining manufacturing leadership, such as long-term governance of standards compliance. Addressing these administrative costs now will allow the government to manage costs over time rather than allowing unaddressed costs to compound. Beyond these workforce and administrative outlays, government costs to achieve these recommended policies are primarily political and diplomatic.

[60] Michael T. McCaul, "H.R.7178 - 116th Congress (2019-2020): CHIPS for America Act," legislation, June 11, 2020, 2019/2020, https://www.congress.gov/bill/116th-congress/house-bill/7178; Jacky Rosen, "S.121 - 117th Congress (2021-2022): Advanced Manufacturing Jobs in America Act," legislation, January 28, 2021, 2021/2022, https://www.congress.gov/bill/117th-congress/senate-bill/121.

The most significant cost challenges beyond government remain with manufacturers. Ultimately, adopting Advanced Manufacturing processes in a free-market economy requires manufacturer buy-in. High up-front costs with a limited near-term return on investment for small and medium manufacturers will remain a potential impediment. For large commercial firms, sharing technologies necessary to develop the manufacturing ecosystem may reduce profit margins, subsequently disincentivizing participation. Facilitating buy-in will require the US and state governments to offset costs to small-and-medium manufacturers and create environments where commercial industry collaboratively leads itself toward progress without specific government inducement.

Risks

Much like costs, risks to policy implementation fall broadly into government and commercial groupings. From a government standpoint, the most significant risk is political and financial risk stemming from policy and prioritization waffling. Policy priorities and associated programs adjust from administration to administration based on partisan divides, often through short-term mechanisms like Presidential Executive Orders. Advanced Manufacturing progress risks failure without legislation to codify long-term priorities and funding as the manufacturers reliant on sustained support question government commitment. Of course, such legislation also presents the risk of burdening manufacturers with unreasonable compliance requirements, so the development of long-term legislative support to Advanced Manufacturing must strike a balance between leveraging requirements serving accountability versus providing much-needed regulatory and fiscal stability to the manufacturing ecosystem.

On the commercial side, the most significant risk to policy implementation and success is ultimately commercial buy-in and workforce health. Advanced Manufacturing adoption relies on

firm adoption, and commercial firms have unique requirements that inhibit repeatable implementation of Advanced Manufacturing processes at scales creating near-term impacts on the national economy. Adoption progress will require time and tailoring technology to individual firms through methods that sustain manufacturers through near-term challenges to reach long-term gains. Intrinsically tied to sustainment is workforce availability: any policy or strategy for Advanced Manufacturing adoption requires and healthy workforce, as highlighted previously in the report.

Gaps

Any policy recommendation gaps are likely an outcome of constraints on the scale, scope, and time associated with this report's studies. For instance, seminar research focused heavily on commercial and academic Advanced Manufacturing equities, with government engagements centered more on senior leader perspectives, public-private partnerships, and overarching funding mechanisms. As a result, policy recommendations may not comprehensively represent government stakeholder interests, especially at the operational level (e.g., program managers).

Beyond the probability of gaps associated with research constraints, the seminar identified two acute gaps not addressed in policy recommendations. First, the policy recommendations leverage additional support from Manufacturing Innovation Institutes and academia without a thorough understanding of staffing limitations. Consequently, policy implementation should occur in conjunction with a discrete review of institutional capacity to ensure staff availability matches the scope and scale of proposed policy actions. Additionally, the proposed policy recommendations do not close the gap in the materials necessary to sustain Advanced Manufacturing progress, especially when hostile governments monopolize some of

those materials. Much like workforce capacity, Advanced Manufacturing adoption hinges on material availability (e.g., tooling and raw material supply). Therefore, the US government must couple the proposed Advanced Manufacturing policy recommendations with ongoing activities to create resilient and sustainable supply chains.

CONCLUSION

Advanced Manufacturing processes will amplify the US manufacturing sector's capability, competitiveness, and responsiveness. Policy implementation will remove barriers to industry's broader, competitive adoption of Advanced Manufacturing processes by streamlining efficient partnerships between government, academia, and industry and facilitating Advanced Manufacturing adoption at respective scopes and scales appropriate for American manufacturers of various sizes. Ultimately, successful Advanced Manufacturing implementation will bolster US economic competitiveness necessary to preserve national prosperity, security, and global influence.

APPENDIX A: UKRAINE

As of May 2022, over 5.4 million Ukrainian refugees have fled the violence and destruction unleashed on their homeland while uniting the western world in opposition to Russian aggression.[61] Rebuilding Ukraine is a global effort supported by funding through the International Monetary Fund (IMF), The World Bank, Foreign Direct Investment (FDI), and public-private partnerships engaged with Ukraine that will help jump-start the most important rebuild in Europe since the Marshall Plan after World War II and the Balkans in the 1990s.[62] Advanced manufacturing and multiple industries can help accelerate Ukraine's rebuild.

Advanced Manufacturing, including 3D rendering, printing, and factory of the future concept, has the potential to alleviate human suffering now while revolutionizing Ukrainian manufacturing and agricultural sectors for economic viability and future stability. Advanced manufacturing could build shelters for refugees while they wait to return to Ukraine in the near term. Additionally, providing healthcare is critical to reducing human suffering. Deploying pharmacy on-demand and micro-dosing systems to displaced person camps provides medication to a vulnerable population preserving the health of Ukraine's human capital necessary to rebuild the country. Over the long term, the destruction of Ukraine's manufacturing capability provides a blank slate to overlay industry 4.0 and factory of the future initiatives to improve productivity while building Europe's next economic and manufacturing powerhouse.

Reducing Human Suffering

Refugees are some of the most vulnerable people globally, faced with poor living conditions and inadequate housing and health care access.[63] 3D printing can potentially alleviate suffering while reducing waste that often comes with a call for donations. Setting up 3D printing sites along refugee routes and near camps can meet the needs of the vulnerable quickly, reducing the strain on local transportation systems and reducing warehousing requirements. Focusing printing on-demand capabilities on delivering shelters, basic life support needs (e.g., utensils, water containers), and pharmaceutical and medical supplies provide refugees with critical items to maintain health while they wait to return home.

Shelter: India, Europe, and the United States have all successfully printed houses and look to improve the technology.[64] In partnership with Loci Robots, a California company, Azure developed a 3D printing process that prints durable living structures out of repurposed plastic. Azure can print the entire structural skeleton, the exterior sheathing, the water control barrier, the exterior finish, the passageways for utilities, and the grounding for interior finishes in about 20 hours.[65] French researchers have printed emergency shelters 3 meters high by 3 meters squared

[61] "Situation Ukraine Refugee Situation," accessed May 1, 2022, https://data2.unhcr.org/en/situations/ukraine.

[62] "War in Ukraine: IMF Approves $1.4bn Emergency Funding," *BBC News*, March 10, 2022, sec. Business, https://www.bbc.com/news/60686413.

[63] "Refugee and Migrant Health," accessed May 6, 2022, https://www.who.int/news-room/fact-sheets/detail/refugee-and-migrant-health.

[64] "These 3 Countries Are 3D-Printing New Homes," World Economic Forum, accessed May 7, 2022, https://www.weforum.org/agenda/2021/05/countries-3d-printing-new-homes/.

[65] "Azure Printed Homes Showcases the World's First 3D Printed Backyard Studio Made From Recycled Plastic Materials," PRWeb, accessed May 6, 2022, https://www.prweb.com/releases/2022/4/prweb18649191.htm.

in 20-30 minutes.[66] For refugee camps, it is possible to create shelters much faster, in an environmentally conscious way, and able to withstand weather changes for longer-term scenarios. Deploying Loci Robots, having the capability to print (additive) and finish (subtractive) shelters in refugee camps near Ukraine, provides training opportunities on the technology.[67] Additionally, it makes it easy to move into Ukraine to support reconstruction after the war.

Essential Items: Shelter is critical for Refugees' health, welfare, and safety. However, Refugees often leave home with only what they can carry on their back. 3D printing of essential items like eating utensils, water containers, cribs for children, and tables provides access to essential life support items while reducing waste from regular donation pipelines. 3D printing allows support agencies to only print what is required, reducing waste and transportation costs for moving donations across the world to the respective Refugee camps.

Pharmaceutical and Dental 3D printing: Access to healthcare and medication is critical to support the health and welfare of a population that has been through extreme stress. Shelter and access to essential items, clean water, and sanitation will be vital in reducing the transmission of disease. Access to pharmaceuticals, especially crucial Active Pharmaceutical Ingredients, is key to maintaining population health. Healthcare providers can assess the patient, insert the order into the electronic health record, and send it directly to the pharmacist, who verifies the dosage. The order then proceeds to the printer for print and test before transfer to the patient as part of their treatment plan.[68] Additionally, 3D printing can treat dental issues by scanning the patient's mouth and printing a dental implant on the spot.

Training Ukrainian Refugees

Globally, 14% of the workforce, over 375 million workers, will need to change jobs or secure new skills by 2030.[69] Ukraine inherited a massive manufacturing infrastructure when the USSR broke up, which is being targeted by Russian forces.[70] Rebuilding Ukraine's manufacturing industry starts with training a workforce able to install the factory of the future technology and the ability to run high-tech robots or work with cobots. Ukraine does have a strong computer software workforce providing a solid foundation for adopting Advanced Manufacturing.[71]

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[66] "3D Printed Emergency Shelter in 30 Mins," 3D Printing Industry, July 15, 2015, https://3dprintingindustry.com/news/french-researchers-3d-print-emergency-shelter-in-30-minutes-53519/.

[67] Advanced Manufacturing Cohort visited Loci Robotics in Knoxville, Tennessee witnessing the testing of their robotic platform used by Azure. For more information on their Azure collaboration visit: https://www.linkedin.com/feed/update/urn:li:activity:6927418129299996672/

[68] "PoD Technology," *On Demand Pharmaceuticals* (blog), accessed April 26, 2022, https://ondemandpharma.com/pod-technology/.

[69] "Reskilling China: Becoming Lifelong Learners | McKinsey," accessed May 5, 2022, https://www.mckinsey.com/featured-insights/china/reskilling-china-transforming-the-worlds-largest-workforce-into-lifelong-learners.

[70] "Economic Development of the Ukraine: Industry," accessed May 7, 2022, https://www.loc.gov/rr/business/ukraine/industry.html; Jack Detsch Gramer Robbie, "Russian Troops Are Taking Putin's Orders to Demilitarize Ukraine Literally," *Foreign Policy* (blog), accessed May 7, 2022, https://foreignpolicy.com/2022/05/04/russia-demilitarize-ukraine-arms-facilities/.

[71] "Ukraine Economy: Population, GDP, Inflation, Business, Trade, FDI, Corruption," accessed May 7, 2022, //www.heritage.org/index/country/ukraine.

Leveraging industry, universities, and innovation institutions worldwide are vital to rebuilding Ukraine's manufacturing base. The United States Manufacturing USA and Germany's Fraunhofer Innovation Institutes can help Ukraine plan and implement Advanced Manufacturing, Internet of Things (IoT), and factory of the future concepts. Initial phases should include training teams from innovation institutes and companies like Siemens, Deloitte, and 3D Systems set up in refugee camp areas to train workers to implement the plan. Such training is critical to ensure Ukraine's human capital return to help rebuild. Training, funding, and a rebuilding roadmap will assure citizens that Ukraine can rise from the ashes of war.

Rebuilding Ukrainian Cities

The use of the IoT metaverse to map out and digitally plan cities creates possibilities to test traffic patterns, the flow of energy, and the placement of essential services deliberately.[72] 3D rendering software can take prewar images and provide 3D printer renderings that allow the printing of historic architecture while also designing new, energy-efficient structures built in days versus years.

Currently, China leads the world in large-scale printing, recently unveiling a 1,640-foot structure.[73] Training refugees now combined with FDI and PPP has the potential to build a western competitor to China in large 3D printing while digitizing Ukraine's industrial base. Furthermore, Ukraine could serve as the global roadmap for industry 4.0 and factory of the future adoption. Ukraine's success could offer proof of principle for other western companies hesitant to adopt Advanced Manufacturing and factories of the future.

Rebuilding Ukrainian Manufacturing and Agriculture Industries

Ukraine has a rich history of manufacturing focused on power generation, machine-building, and food production.[74] Ukraine's Defense Industrial Base also produces aircraft, tank and light armor, and radar systems.[75] Like most developed economies, there are significant opportunities to adopt Advanced Manufacturing to increase economic productivity. 75% of Ukraine had access to the internet before the war.[76] Leveraging SpaceX's Starlink internet services in the near term allows Ukraine to implement digitization efforts in manufacturing and agriculture.[77] Training efforts in the refugee camps can focus on manufacturing sectors across Ukraine, building a digital factory twin before the physical build to include process flow, machine locations, and data control towers to capture data. Following process creation, public-

[72] "Rebuilding Ukraine: 3D Printing and the Metaverse Could Help Create the Cities of Tomorrow," TechNewsWorld, March 21, 2022, https://www.technewsworld.com/story/rebuilding-ukraine-3d-printing-and-the-metaverse-could-help-create-the-cities-of-tomorrow-87455.html.

[73] "China Just Completed the World's Largest 3D-Printed Structure," Futurism, accessed May 7, 2022, https://futurism.com/the-byte/china-worlds-largest-3d-printed-structure.

[74] "Economic Development of the Ukraine: Industry," accessed May 1, 2022, https://www.loc.gov/rr/business/ukraine/industry.html.

[75] "TOP 10 WEAPON SYSTEMS MADE IN UKRAINE - U.S.-Ukraine Business Council (USUBC)," accessed May 2, 2022, https://www.usubc.org/site/aerospace-defense-industry/top-10-weapon-systems-made-in-ukraine.

[76] "Ukraine Economy."

[77] Michael Sheetz, "Elon Musk's SpaceX Sent Thousands of Starlink Satellite Internet Dishes to Ukraine, Company's President Says," CNBC, March 22, 2022, https://www.cnbc.com/2022/03/22/elon-musk-spacex-thousands-of-starlink-satellite-dishes-sent-to-ukraine.html.

private partnerships funded through FDI, IMF, or World Bank recovery initiatives could allow packaging of capabilities combined with 3D printing files to build the factory faster than traditional techniques.

Conclusion

Rebuilding Ukraine is critical to establishing stability in the region. President Zelensky has the world and his people behind him. How quickly Ukraine recovers is crucial to the solvency of the Zelensky government and will help keep Russian malign actions at bay. Advanced manufacturing can reduce human suffering today, supporting displaced persons and refugee camps inside and outside Ukraine. Deploying training teams from the United States and European Union to refugee camps will help Ukrainians rebuild their country using new technology and ideas. Leveraging 3D printing, digitizing the Ukrainian manufacturing and agriculture industry, and implementing the factory of the future could prove the power of combining 3D printing and digitization of the factory. The world's actions over the following months and years will alleviate suffering and determine the recovery of Ukraine, providing a pathway for Ukraine's human capital to return and rebuild for the future.

APPENDIX B: EXPANDED DISCUSSION ON STRATEGIC ENVIRONMENT

The United States, European Union (EU), and China: Manufacturing Moving Different Directions

The world economy has undergone dramatic changes in the last few decades. Supply chain expansion plus manufacturing and raw material globalization transformed national economies. China is the biggest beneficiary of this shift, undergoing an unprecedented economic expansion, as shown in Figure B.1 below, where, from 2000 to 2020, the Chinese economy grew 12.3 times, while the US and EU economies barely managed to double in size.

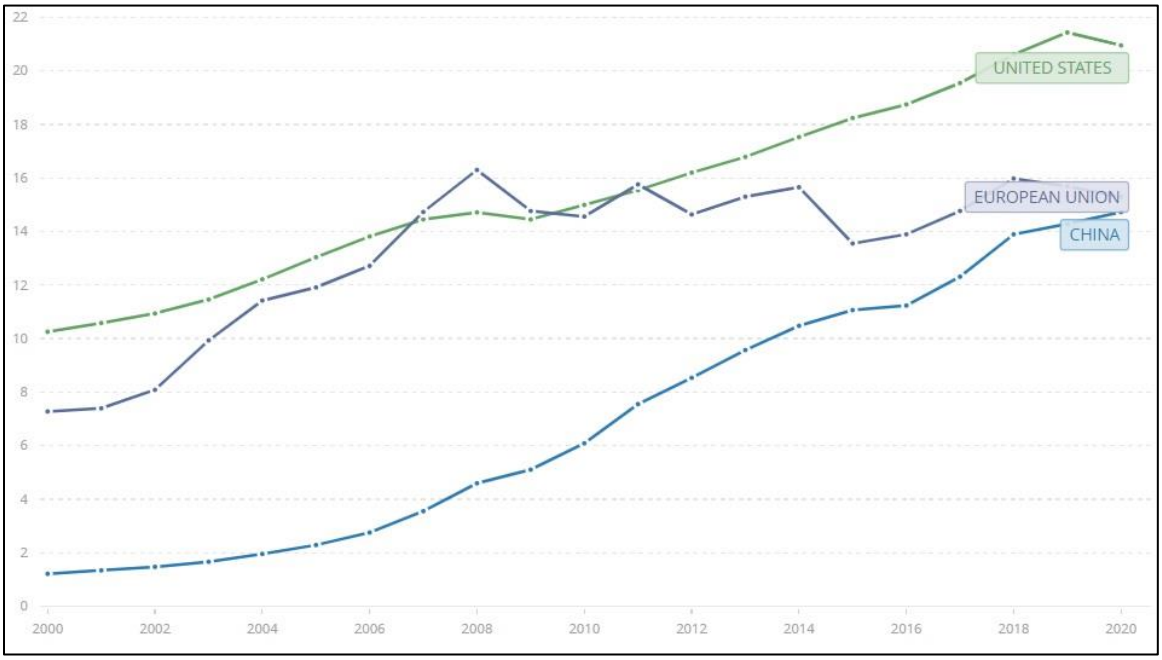

Figure B.1: GDP for China, the US, and the EU 2000-2020 (Current US Dollar)[78]

Manufacturing is the centerpiece of China's supercharged economic growth. China facilitated transformation from an agrarian society to a manufacturing powerhouse through various policies, including state subsidies, cheap labor, forced technology transfer in exchange for Chinese market access, and low-cost capital. Global producers flocked to China to gain from these opportunities and escape rising Western operating costs. Consequently, manufacturing in the US and the European Union remains comparatively flat despite gains in productivity. Figure B.2 below shows the scale of Chinese manufacturing expansion compared to the US and EU.

[78] World Bank, "World Bank Data," n.d., https://data.worldbank.org.

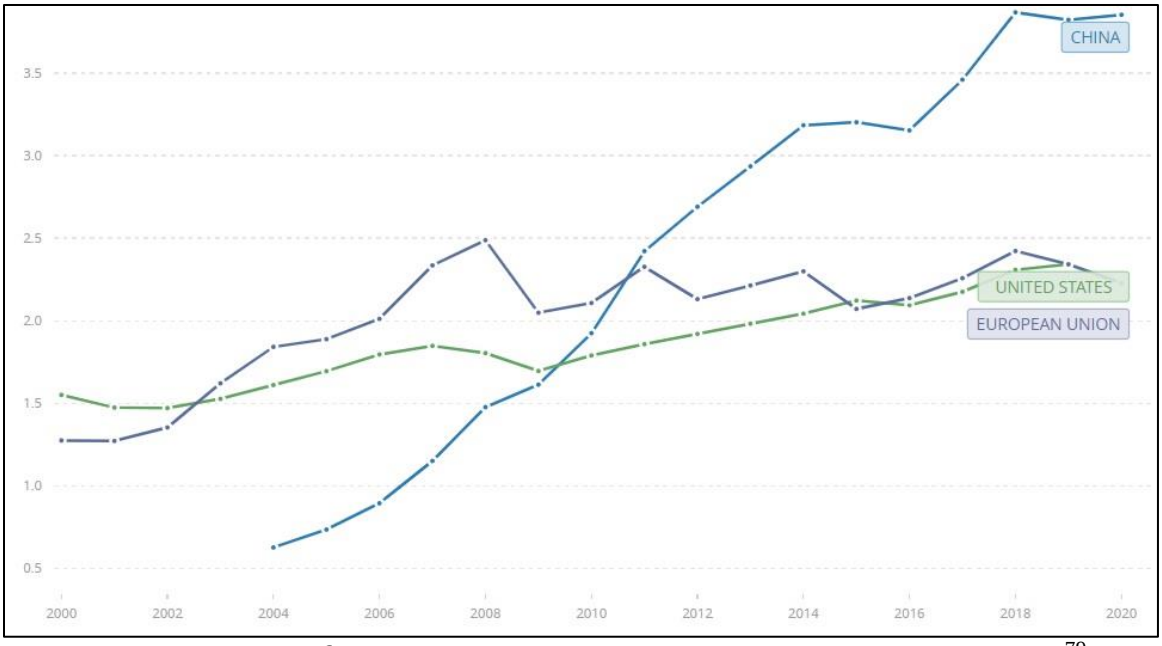

Figure B.2: Manufacturing Value Added 2000-2020 in Trillion US Dollars[79]

Challenges to Manufacturing in the United States

Various factors challenge US manufacturing. The chief challenge is higher labor costs in Western, developed nations with more extensive social safety networks and healthcare programs. Additionally, as manufacturing moved overseas, the emphasis shifted away from manufacturing workforce development and recruitment. Federal funding for high school vocational study programs has dropped 32% since 1985, while the average number of vocational credits students receive has declined by 14%.[80] The shortage of highly skilled machinists and production staff further increased the costs of hiring and retaining these valuable employees. While labor costs and availability are essential, they are not the only factors driving manufacturing supply chain globalization. Larger container and bulk cargo ships with associated port infrastructure growth created an explosion in shipping availability and affordability.

Manufacturing digitization and interconnectivity are another trend speeding supply chain globalization. Systems and parts of systems designed in the digital domain are sent instantly to production houses overseas for manufacture. Companies like Apple have embraced this paradigm, with their iPhone and other products bearing the stamp "Designed by Apple in California. Assembled in China."[81]

Finally, Western production centers face higher regulatory burdens than Chinese producers in areas like worker safety, environmental protection, and quality control from regulators, including the Federal Aviation Administration, Food and Drug Administration, and

[79] World Bank.

[80] Daniel Kreisman and Kevin Strange, "Depth Over Breadth: The Value of Vocational Education in US High Schools," *Education Next* 19, no. 4 (Fall 2019), https://www.educationnext.org/depth-over-breadth-value-vocational-education-u-s-high-schools/.

[81] C Rawson, "Why Apple's Product Are 'Designed in California' but 'Assembed in China,'" engadget, January 22, 2012, https://www.engadget.com/2012-01-22-why-apples-products-are-designed-in-california-but-assembled.html.

Nuclear Regulatory Commission. Further, regulators in "elevated risk" sectors are conservative in their approaches to innovative technology, preferring additional research and evaluation to the rapid adoption of new materials and production techniques.

Economic and Geopolitical Risks Give Domestic Manufacturing Another Look

For years American politicians, educators, and strategists voiced concerns about the steady departure of industrial capability and reduced supply chain control. COVID-19's onset, continuous pandemic management, Russia's invasion of Ukraine, and current economic inflation are reinvigorating actions addressing these concerns.

China's willingness to weaponize trade and participate in unfair trade practices warrants a reexamination of its role in our supply chains. Over several decades, China systematically developed its low-cost manufacturing sector and associated supply chains. Examples include the Chinese buildout of low-cost electrical capacity, dominance in mining rare-earth metals and minerals, and their domestic semiconductor industry present vulnerabilities to competitors. In January 2022, the Biden-Harris administration announced a series of efforts to improve the US position in semiconductor manufacturing while proposed legislation in Congress, such as the America COMPETES Act, looks to support domestic manufacturing and building supply chain resiliency.[82]

Reshoring supply chains lowers risks posed by massive supply disruptions from China's zero-COVID or similar Chinese government policies. The downside of Chinese dominance in manufacturing and raw materials production is increasingly evident as the COVID-19 pandemic unfolds. Recent lockdowns of Shenzhen, Shanghai, and parts of Beijing have put millions out of work within China while threatening production and consumption patterns across the globe.[83] With no sign that Chinese officials will shift away from their zero-COVID policy, China could disrupt supply chains for months or years as viral transmissibility, lethality, and vaccine effectiveness evolve.

The unjustified Russian invasion of Ukraine has provided additional incentives for reconsidering the globalized nature of manufacturing. Russian sanctions on energy and raw materials have contributed to an inflationary environment, placing pressures on consumption and increasing the cost of capital through higher interest rates. There are no signs that inflation is close to coming under control either. According to Greg McBride, chief financial analyst at Bankrate.com, "The Federal Reserve is behind the curve. They must raise interest rates a lot and in a hurry."[84] The bloody nature of the Russian invasion, including the strong evidence of Russian military war crimes, and the economic harm inflicted upon the world make normalized trade relations with the Russian Federation highly unlikely, illustrating the risks inherent in supply chains strongly reliant upon unethically grounded nations.

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[82] "FACT SHEET: Biden-Harris Administration Bringing Semiconductor Manufacturing Back to America," The White House, January 21, 2022, https://www.whitehouse.gov/briefing-room/statements-releases/2022/01/21/fact-sheet-biden-harris-administration-bringing-semiconductor-manufacturing-back-to-america-2/; "Policy Briefing."

[83] Vivian Wang, "'I'm Very Anxious:' China's Lockdowns Leave Millions out of Work," *The New York Times*, May 5, 2022, https://www.nytimes.com/2022/05/05/business/china-shanghai-covid-lockdown-economy.html.

[84] Jessica Dickler, "Here's What the Fed's Half-Point Rate Hike Means for Your Money," *CNBC*, May 4, 2022, https://www.cnbc.com/2022/05/04/heres-what-the-feds-half-point-rate-hike-means-for-your-money.html.

A Rush to Develop and Utilize Advanced Manufacturing

In the face of mounting pressures on American manufacturing arises the potential of new production processes to boost productivity, reduce costs, and limit supply chain risks from economic volatility or geopolitical shocks. Advanced manufacturing processes such as additive manufacturing, digital design and modeling, and more modernized factory production are squarely in the focus of business and government leaders, setting off a race to develop and implement these innovative technologies. China has stood up the Chongqing Institute of Green and Intelligent Technology with the Chinese Academy of Sciences, which "mainly aims at the innovation of additive manufacturing (AM, 3D Printing) technology and the applications in the fields of aerospace, defense industry, automotive, and biomedicine."[85] In the EU, the Fraunhofer-Gesellschaft "is the leading organization for applied research in Europe. Its research activities are conducted by 76 institutes and research institutions at locations throughout Germany."[86] Many Fraunhofer institutes focus on manufacturing, including robotics, additive manufacturing, and digitization. Developing Advanced Manufacturing capabilities and getting them to market will strategically position companies and countries with competitive advantages in the future. America must win the race.

[85] Fraunhofer-Gesellschaft, “Fraunhofer Institutes and Research Units,” Fraunhofer, 2022, https://www.fraunhofer.de/en/institutes.html.

[86] Fraunhofer-Gesellschaft.

APPENDIX C: EXPANDED DISCUSSION ON STAKEHOLDER INTERESTS

The outline below provides a visual depiction of stakeholder roles and interests across the Advanced Manufacturing ecosystem to augment the narrative in the report's main body:

I) Federal Government
  A) Department of Energy
    i) Stakeholder: DoE's Advanced Manufacturing Office (AMO) brings together manufacturers, not-for-profit entities, research organizations, and higher education institutions.
      (a) Oak Ridge National Laboratory (ORNL)
    ii) Interest: Improve manufacturers' energy and material efficiency, productivity, and competitiveness across the industrial sector to promote American energy dominance through affordable and reliable production and use.
  B) Department of Commerce
    i) Stakeholder(s):
      (a) NIST – Office of Advanced Manufacturing: Collaborates with industry, academia, and other government agencies to develop measurement and standards solutions to accelerate the development of the next generation of manufacturing technologies.
      (b) MEP: Enhance the productivity and technological performance of US manufacturing. MEP is a public-private partnership designed from inception as a cost-share program.
      (c) Manufacturing USA institutes support the manufacturing industry through applied research and transfer of technology developed while establishing needed skills and education for the workforce.
        (1) America Makes / Advanced Robotics Manufacturing Institute (ARM) / Institute for Advanced Composites Manufacturing Innovation (IACMI) / MxD / LIFT – American Lightweight Materials Manufacturing Innovation Institute (ALMMII)
    ii) Interest: the mission of these agencies is to mitigate risk in Advanced Manufacturing technology and create the value proposition for commercial and defense industry adoption by connecting people, ideas, and technology to solve industry-relevant Advanced Manufacturing challenges to enhance industrial competitiveness, economic growth and strengthen our national security.
  C) Department of Defense
    i) Stakeholder: DoD requires a mechanism for shaping and developing the domestic design and manufacturing industrial base to support national security needs.[87]
      (a) Office of Assistant Secretary of Defense of Industrial Base Policy (OASD IBP) / Office of the Under Secretary of Defense for Acquisition & Sustainment (OUSD(A&S)) / Technology and Manufacturing Industrial Base, Office of the Under Secretary of Defense for Research and Engineering (OUSD (R&E)) / Organic Industrial Base (i.e., JMTC, Rock Island Arsenal) / Acquisition

[87] "Department of Defense | Manufacturing.Gov." Accessed May 5, 2022. https://www.manufacturing.gov/partners/department-defense.

Innovation Research Center (AIRC) / Systems Engineering Research Centers (SERC)

ii) Interest: Advanced Manufacturing will modernize the national defense systems to improve design and performance and increase materiel readiness to prototype and produce parts to reduce obsolescence rapidly. New emerging technologies promise to deliver continued US economic and national defense dominance.

D) Department of Education
   i) Stakeholder: Mission-focused Federal investments in education focusing on grades K-12 and address Advanced Manufacturing through the Carl D. Perkins Career and Technical Education Act.
   ii) Interest: The Department of Education will be critical in expanding the number of skilled workers to meet Advanced Manufacturing sector demands.

E) Office of Science and Technology Policy
   i) Stakeholder: OSTP is a conduit to the President that leads efforts across the Federal Government to develop and implement science and technology policies.
   ii) Interest: Enhance and support Federal investment that supports scaled Advanced Manufacturing adoption to benefit the prosperity and security of the US.

II) Industry

A) Commercial
   i) Stakeholder: Companies recognize Advanced Manufacturing/Industry 4.0 as the future of domestic manufacturing.
      (a) Fast Radius / National Institute of Aviation Research / The Smart Factory, Wichita, KS / Ford Advanced Manufacturing Center
   ii) Interest: Developing or adopting cutting-edge manufacturing processes to leverage the latest high-tech discoveries, forging a path to Industry 4.0.

B) Defense Industrial Base (DIB)
   i) Stakeholder: DIB will look to drive productivity, manage risks, and protect market share as customer demands shift to focus on Advanced Manufacturing.
      (a) GE Additive / Boeing / Bell Textron / Sciaky, Inc.
   ii) Interest: DIB adapts to changes in demand, supply chain, and other parts of the value chain to deliver capability, integrate systems operation, and meet availability and maintainability, while still delivering shareholder value.

III) Academia

A) Stakeholder: Educational institutions bridge skills gaps by developing curricula and conducting cutting-edge research in Advanced Manufacturing fields.
   i) Texas A&M University's SecureAmerica Institute / National Center for Additive Manufacturing Excellence (NCAME), Auburn University / University Research Centers such as Purdue University, Carnegie Mellon's Manufacturing Futures Institute (MFI), and the University of Tennessee

B) Interest: Universities are competing for federal and local funding to enhance their role as global leaders in the research and development of Advanced Manufacturing.

IV) State and Local Government

A) Stakeholder: Ensuring local and state manufacturing economies thrive.
   i) Elected officials on behalf of the public
   ii) Workforce: Creating job and economic security for the general public enhances U.S. economic security—retaining a robust workforce is imperative.

B) Interest: Job/economic security. From 2000 through 2010, the US's previously stable number of manufacturing jobs plummeted by 5.8 million, from 17M to 12M. As of 2021, manufacturing jobs have marginally increased to 12.5M.[88] It is imperative to retain a robust workforce to enhance US economic security.

V) Allies and Trade Partners

A) Stakeholders: European Union, United Kingdom, Taiwan, Singapore, and Japan, are developing Advanced Manufacturing institutes and transitioning technology into their manufacturing base.

B) Interest: Reducing global supply chain shocks realized during COVID-19. With the global economic crisis, nations are dealing with falling GDPs and looking for opportunities to preserve and grow manufacturing capabilities.

VI) Adversaries: China

A) Stakeholder: Made in China 2025 and China Standards 2035 aim to deliver a dual circulation economy to set and control standards for new technology globally.

B) Interest: The Great Rejuvenation: China 2049 aims to ensure sustained economic growth to rival the strategic competition with the US China's ambitious goals and has developed robust industrial policies to include subsidies, directed technology transfers, and state-financed global mergers and acquisitions.

[88] Elka Torpey, "Got Skills? Think Manufacturing," U.S. Bureau of Labor Statistics, June 2014, https://www.bls.gov/careeroutlook/2014/article/manufacturing.htm; U.S. Bureau of Labor Statistics, "All Employees, Manufacturing" (FRED: Federal Reserve Bank of St Louis, May 2022).

APPENDIX D: EXPANDED ANALYSIS OF STRUCTURE, CONDUCT, AND PERFORMANCE FOR SELECT INDUSTRIES PROVIDING ADVANCED MANUFACTURING SOLUTIONS

Advanced Manufacturing is a process enabling production across multiple industries. Consequently, an S-C-P analysis explicitly focused on Advanced Manufacturing is unrealistic. However, an S-C-P analysis of industries producing and supplying Advanced Manufacturing solutions offers insights into the ramification of policy implementations. To that end, the seminar selected three industries heavily tied to Advanced Manufacturing progress for S-C-P analysis to understand how policy recommendations, especially those impacting Advanced Manufacturing adoption rates, will influence these industries' long-term structure, conduct, and performance.

3D Printing Manufacturing Industry
NAICS: 333248 – All Other Industrial Manufacturing Machinery[89]

Per the US Census Bureau, "this US industry comprises establishments primarily engaged in manufacturing industrial machinery," including additive manufacturing machinery.[90] For this industry analysis, the "3D Printing Manufacturing" industry is defined as the group of firms manufacturing 3D printers. The three primary activities associated with this industry include (1) 3D printer manufacturing, (2) build materials manufacturing, and (3) 3D printer service and maintenance.[91]

The competitive market structure that best describes the additive manufacturing machinery manufacturing industry is monopolistic competition.[92] The following characteristics define this classification: low market share concentration and a high number of firms; high degree of differentiation in product type; and modest barriers to entry.[93] Rivalry among existing competitors is medium as the industry has a low concentration ratio indicating more competition among firms. Higher adoption rates since the introduction of this technology in the 1980s have created market fragmentations, thus yielding small-scale operators to differentiate in 3D printers for specific niche markets, such as medical devices. Market shares are not concentrated, and no single firm dominates or influences total production in the industry; in fact, the two key players in the industry capture less than 10% of the total market share, i.e., Stratasys (4.6% market share) and 3D Systems Corporation (3.4% market share).[94] While there is a low degree of seller concentration, Stratasys and 3D Systems Corporation have competitive edges in the industry, so new entrants will have to invest in developing brand awareness strategies as existing firms benefit from customer loyalty.[95]

The threat of new entrants is medium because the barriers to entry are moderate. One barrier to entry is the cost of capital. Per the IBISWorld Industry Report, "significant financial

[89] United States Census Bureau, "North American Industry Classification System," accessed February 19, 2022, https://www.census.gov/naics/?input=additive+manufacturing&year=2022&details=333248.

[90] United States Census Bureau.

[91] Kevin Kennedy, "3D Printer Manufacturing" (IBIS World, June 2021), 5, www.IBISWorld.com.

[92] Glenn Hubbard and Anthony Patrick O'Brien, *Economics*, 6th ed. (Pearson, 2017), chaps. 3, "Where Prices Come From: The Interaction of Demand and Supply," pg 78 and chapter 12, "Firms in Perfectly Competitive Markets," 408.

[93] Kennedy, "3D Printer Manufacturing," 7.

[94] Kennedy, 29–30.

[95] Kennedy, 28.

investment is required to acquire, maintain and update plants and equipment needed to manufacture 3D printers."[96] Additionally, robust research and development (R&D) budgets and product innovation teams are necessary to differentiate product service offerings and obtain patents.[97] "As the markets for several products become saturated, the importance of innovation (and, therefore, the cost of R&D) is expected to increase and deter new entrants."

Conversely, the price of technology is decreasing while the value is increasing, making this industry very attractive.[98] Rapid technological change has impacted this industry as more manufacturers have become interested in applying Advanced Manufacturing processes to production lines. One determinant of demand has been the buyer's increased R&D account and the desire to expend funds on 3D printers to create prototypes for new products.[99] These buyers consist of commercial businesses, the US Government, and educational institutions. More specifically, the market segmentation for this industry shows that 3D printer products and services are used by many industries, including aerospace, automotive, defense, and various sub-sectors of the manufacturing sector. Manufacturers of consumer product companies (29.0%), technology (23.0%), and industrial manufacturing (21.0%) make up most of the customer base.[100]

The behavior followed by firms within this industry is directly influenced by the market structure. Due to the low market share concentration and moderate competition, firms competing in this industry execute feature-benefit selling strategies to focus on product differentiation rather than price. Firms are choosing to invest in R&D, create value through product designs, target the market to customers in specific industries, and expand product service offerings through "cross-selling." Firms are conducting themselves to help create a competitive edge by aligning R&D spending with marketing strategies to offer the most innovative product and services and by hiring employees with unique skills and functional expertise that give the business a technological advantage. Firms are also leveraging the demand from newer customers in the medical and healthcare markets by branding their 3D printers as solutions to the niche market.[101] Lastly, firms are looking to grab market share by offering the complete range of products and services needed to incorporate 3D printing into a customer's production line. Firms are conducting themselves as one-stop shop solutions that offer multiple products and services to the same customer. In theory, firms will increase the number of products and services sold per customer without spending more to acquire new customers. According to the IBIS Worldwide report, "the largest operators in this industry generate recurring revenue from maintenance, services and materials sales after the initial product sale."[102]

[96] Kennedy, 28.
[97] Kennedy, 28.
[98] Kennedy, 16.
[99] Kennedy, 18.
[100] Kennedy, 19.
[101] Kennedy, 24.
[102] Kennedy, 24.

Design, Editing & Rendering Software Publishing Industry
NAICS: 513210 – Software Publishing[103]

The Design, Editing & Rendering Software Publishing industry develops and distributes design, picture-editing, video-rendering, object-rendering, and audio-editing software. These types of software are widely used in graphic design, architecture, video game development, manufacturing, and media production. The industry also includes companies that develop software add-ons.

The concentration in this industry is medium, with the four largest companies accounting for 82.9% of the total industry revenue in 2021.[104] There are few structural barriers to entry, but brand recognition limits new entrants' success. Beyond the brand name, larger firms can harness other programs that provide more development resources. Smaller firms tailor their products to be compatible with larger companies (i.e., Adobe). The industry has high competition, but their customers reinforce brand allegiance as the software becomes engrained in specific operations. Existing competitors drive new entrants toward small businesses or niche markets that are also nascent.[105]

A limited pool of skilled software developers drives up the wages for this industry, which is a hidden barrier for new entrants in attracting and retaining their workforce. Capital investment is $0.05 per $1.00 of labor cost. The industry is trending toward adopting cloud-based software delivery, or software as a service.[106] This capability has been made possible by increased computing power and servers. The increased demand for additive manufacturing on modeling programs also drives demand for increased internet-based services.[107]

Federal copyright laws also impact this industry. The Sonny Bono Copyright Term Extension Act of 1998 extends US copyrights to 70 years after the author's death and extends protections to software. Additionally, the Digital Millennium Copyright Act of 1998 provides assurances to software developers. The 1997 No Electronic Theft Law also criminalizes computer program infringements without monetary or commercial gain.[108] Funding for this industry is derived from private sources and is not supported by public funding. Venture capitalists and shareholders provide the capital required for growth.

Autodesk's most popular software program is AutoCAD which has applications in architecture, engineering, construction, manufacturing, media, and entertainment industries.[109] Autodesk has acquired over 20 companies in the past six years with the goal of stifling competition, adding new team members, and increasing patents. Additionally, ABB shifted towards software as a service which delays operating profit over time. Autodesk's industry-specific revenue increased over the past five years at an annualized rate of 15.1% to $2.8 billion.[110]

[103] "NAICS CODE 511210," NAICS Association, July 8, 2019, https://www.naics.com/what-is-naics-511210-full-description-and-statistics/.

[104] Ristoff, "Design, Editing & Rendering Software Publishing in the US," 23.

[105] Ristoff, 27.

[106] Ristoff, 36.

[107] Ristoff, 37.

[108] Ristoff, 38–39.

[109] Ristoff, 39.

[110] Ristoff, 28.

Data Processing and Hosting Service Industry
NAICS: 518210 — Data Processing Hosting and Related Services[111]

The Data Processing and Hosting Service industry provides data processing or hosting services. These services include web and application hosting.

The concentration in this industry is low, with the four largest companies accounting for 30.5.9% of the total industry revenue in 2021.[112] Customers are leaving the traditional bunding model to follow individual technology needs by building a diffuse network. The competition between these companies is high, and because data processing and storage are undifferentiated, companies seek less expensive labor in China and India to compete on price.[113] The barriers to entry require a capital investment of server farms that require space, computers, and electricity. Companies often lease server space to offset this barrier.

Capital investment is $0.07 per $1.00 of labor cost.[114] Additionally, companies spend 2.4% of revenue on depreciation.[115] Advances in computer technology rapidly depreciate technical hardware. The primary disruptive threat to this industry is the fast pace of technological change.[116]

Federal privacy legislation also impacts this industry, especially as greater access to personal information becomes available. As the industry globalizes, foreign privacy regulations will also complicate standardization.[117] There is no direct assistance through government subsidies or protection for this industry, although governmental accounts share the industry revenue substantially.[118]

Hewlett Packard Enterprise Company (HPE) was formed in 2015 as the Hewlett Packard (HPQ) split off technology infrastructure, software, and services from the computer and printer side. HPE has lost market share despite its acquisitions over the past five years.[119] HPE believes that its investment in hybrid cloud services will create future growth. Hybrid technologies provide flexibility for public and private on-site cloud data storage.

[111] NAICS Association, "518210 - Data Processing, Hosting, and Related Services," NAICS Code Description, 2018, https://www.naics.com/naics-code-description/?code=518210&v=2017.

[112] Jeremy Moses, "Data Processing & Hosting Services in the US" (IBIS World, April 2021), 23, www.IBISWorld.com.

[113] Moses, 26.

[114] Moses, 31.

[115] Moses, 32.

[116] Moses, 33.

[117] Moses, 34.

[118] Moses, 28.

[119] Moses, 35.

APPENDIX E: GRAPHICAL PORTER'S DIAMOND MODEL ANALYSIS OF NATIONAL ADVANTAGE

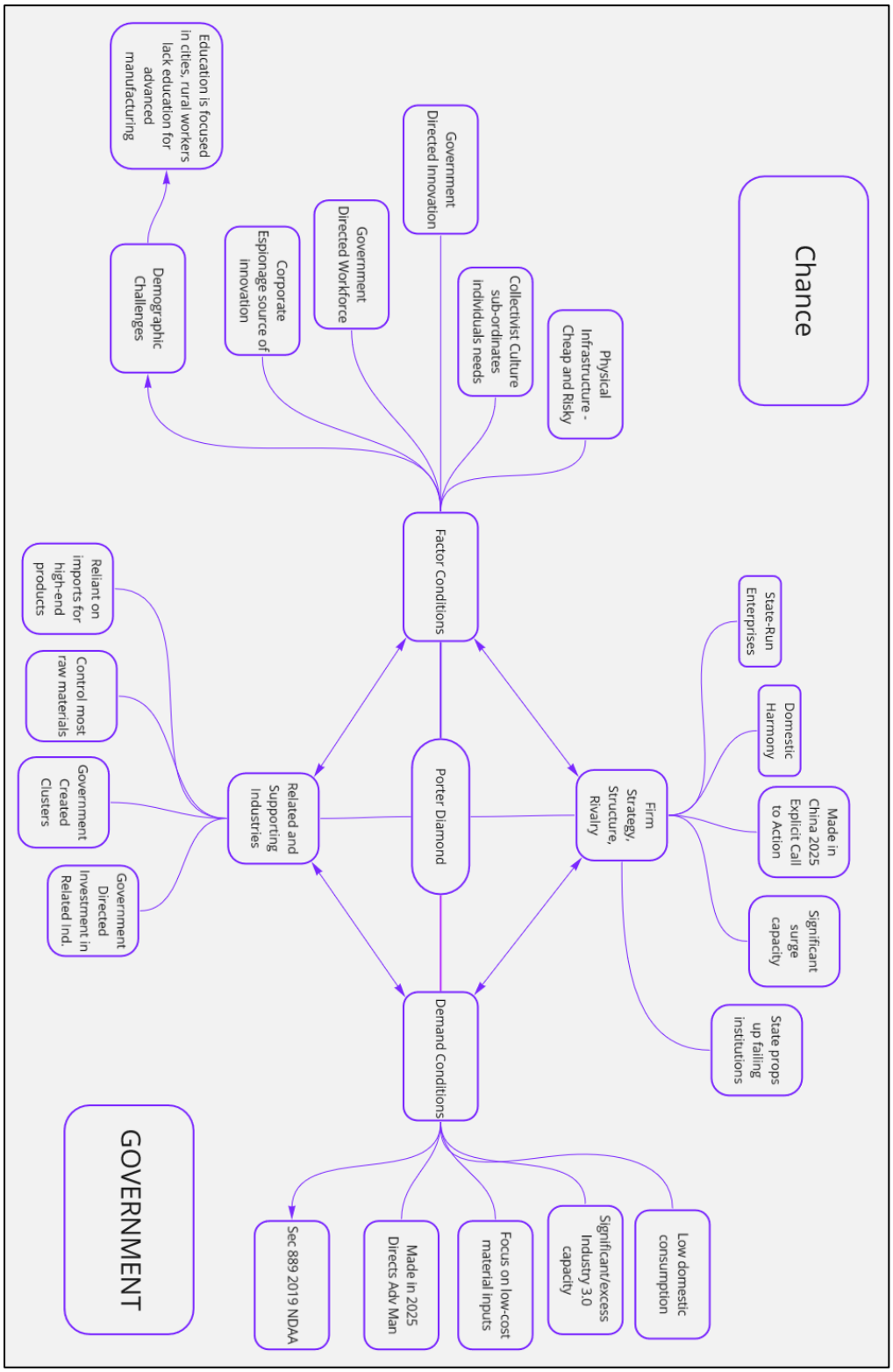

Figure E.1: Porter's Diamond for China

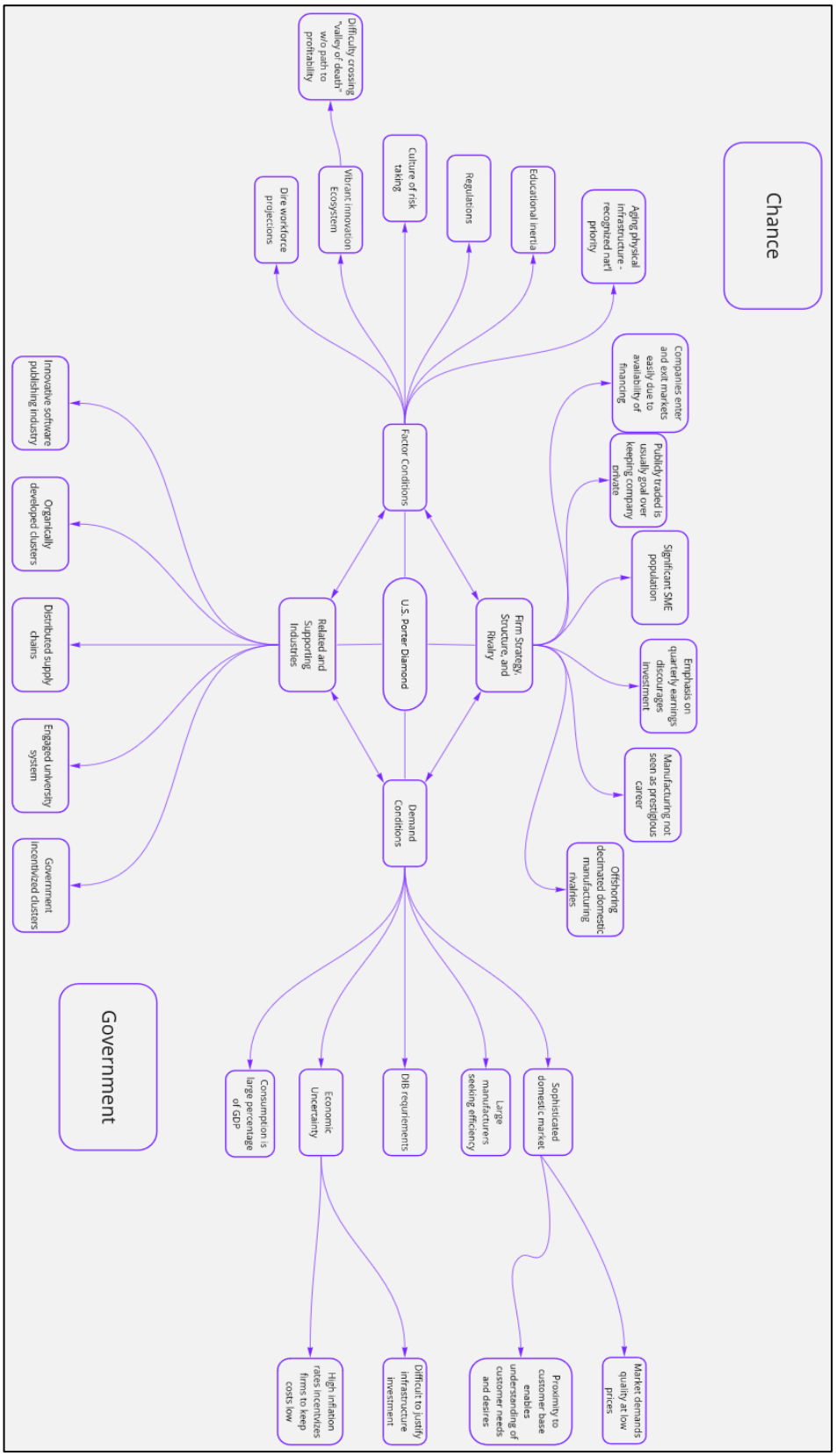

Figure E.2: Porter's Diamond for the US

APPENDIX F: EXPANDED COMPARATIVE ANALYSIS OF STRENGTHS, WEAKNESSES, OPPORTUNITIES, AND THREATS

The tables below provide a breakdown of relevant strengths, weaknesses, opportunities, and threats for the US and China, assessing their ability and readiness to adopt Advanced Manufacturing technologies.

US SWOT

Strengths	**Weaknesses**
Economic performance Innovation ecosystem Culture of risk taking Access to financing SME population Gov't sponsored, generally organically developed clusters Rule of law, IP protection, protect investments Stewardship of the international order Dollar as reserve currency	Aging infrastructure Lack of national narrative Regulatory Environment Requirement for profitability slows adoption Manufacturing not seen as "prestigious" Labor costs / future availability Slow standard development for adv man technologies Demographic trends Increasing economic inequality Dollar as the reserve currency Lack of unifying vision for adv man
Opportunities	**Threats**
Global trade partners and allied nations Changing nature of manufacturing Populist concerns within the electorate seeking to restore US manufacturing Increasing labor costs in other countries (e.g., China) may make manufacturing more attractive in US again Network of MIIs and MEPs	Dependence on national debt Supply chain vulnerabilities Consumption-driven GDP (products/services) Cyber concerns Continued cost pressure on labor China 2035 Standards

A strong culture of innovation permeates the US and inspires the tools necessary to foster technological advances. It finds itself struggling to redefine what manufacturing will look like in the future and to articulate a strategy that will allow the nation to rally behind the necessary structural investments needed to transfer innovative technologies into the private sector. At the same time, economic uncertainty dampens interest in domestic spending.

China SWOT

Strengths	**Weaknesses**
Unity of effort and national focus Collectivist culture – prioritizes community over individual "Made in China 2025" Control supply chains and raw materials Demonstrated significant economic growth Aggressive government subsidization of emerging tech (e.g., green energy) Military-Civil Fusion (MCF) approach Centralized frequency management Centralized Cybersecurity – Great Firewall	Reliance on exports Demographics – urban/rural split, age Government directed innovation, workforce, investment Low domestic consumption Cultural challenges with decentralization National strength dependent on economic superiority
Opportunities	**Threats**
Willingness/ability to engage in corporate espionage – Fast Follower Belt and Road Heavy Gov't / Private Investment Increased Global Influence Currency Manipulation	International Response – NDAA Sec 889 Reliance on imports for high-end products International Response to regional aggression International Opinion of China Transition from manufacturing to services-based economy

China has evolved into a hybrid model of economic governance and leverages the strength of the state to direct investment activities in pursuit of its Made in China 2025 strategy. Having accumulated a significant manufacturing base during the globalization of the '80s and '90s, China is now attempting to morph its economy into higher-end products and increasing the number of services produced. They face significant immediate and long-term demographic challenges and must contend with an international order that increasingly views their actions as anti-competitive, if not predatory.

APPENDIX G: POLICY RECOMMENDATION TRACING

	Diagnosis that defines or explains the nature of the challenge	**Guiding policy** for dealing with the challenge		**Coherent actions that are designed to carry out the guiding policy**	
	Strength / Weakness / Threat / Opportunity	**Interest**	**Policy Recommendation**	**Means**	**Ways (Scope)**
Proliferate Advanced Manufacturing Use Cases	(Threat) Industrial barriers and challenges preventing widespread Advanced Manufacturing adoption, creating dependence on strategic competitors (Weakness) Poor infrastructure, lacking strategic vision, and a gloomy historical narrative undercut adoption of manufacturing technologies. (Strength) Current national conversations are creating momentum toward manufacturing opportunities; US expertise and innovation continue to thrive. (Opportunities) The US' broad network of free market manufacturing entities present an opportunity to turn national momentum into advancements in adoption.	Economic Security and National Security	Foster Advanced Manufacturing market demand and subsequent proliferation by shepherding risk and highlighting successes	Executive Branch (Policy and Strategy development), Legislative (Funding), Government Agencies with regulatory authority for execution (FAA, FDA, NRC, etc.), Non-regulatory bodies for setting standards (NIST), National Laboratories, Manufacturing Innovation Institutes, and Manufacturing Extension Programs	Update Executive Order 14005 to create a unifying Advanced Manufacturing vision to include direction for overarching mechanisms (e.g., government liaisons, digital platforms, and annual symposiums) necessary to drive collaboration and highlight successful use cases across the manufacturing ecosystem. Invest $1M for each MII and MEP ($66M a year) over five years funded through the 2022 America COMPETES ACT to develop and share Advanced Manufacturing deployment kits highlighting technological successes. Update the 2016 DoD Source Selection Guide to promote the inclusion of contractors that utilize Advanced Manufacturing processes (self-certifying that they use these techniques). Initiate DoD pilot program and set an initial target of 5% of all contractors using Advanced Manufacturing processes. Establish a testing pilot program between the DoD, DoE, DoC, and appropriate academic and innovation institutes for commercial access to testbed facilities to test Advanced Manufacturing processes and materials manufactured using Advanced Manufacturing techniques.

Figure G.1 – Policy Tracing: Recommendation Category #1, Part 1

	Coherent actions that are designed to carry out the guiding policy	Other Items Necessary to Frame Narrative	
	Ways (Scope)	**Feasibility / Measures of Success**	**Costs / Gaps / Risk**
Proliferate Advanced Manufacturing Use Cases	Update Executive Order 14005 to create a unifying Advanced Manufacturing vision to include direction for overarching mechanisms (e.g., government liaisons, digital platforms, and annual symposiums) necessary to drive collaboration and highlight successful use cases across the manufacturing ecosystem.	(Feasibility) High - updating current executive order aligns with Advanced Manufacturing language from Biden Administration. (Measures of Success) Increased Advanced Manufacturing adoption rates across the manufacturing ecosystem.	(Cost) Required investment of $1M per year over a 5-year period ($330M total) funded through the 2022 COMPETES Act. (Risk) Temporary establishment of the program if not codified into law as the next Administration may cancel EO.
	Invest $1M for each MII and MEP ($66M a year) over five years funded through the 2022 America COMPETES ACT to develop and share Advanced Manufacturing deployment kits highlighting technological successes.	(Feasibility) High based on funding obligated to DoC through the America COMPETES ACT and strategic documents forthcoming from the White House Science and Technology Office. (Measures of Success) Number of engagements by MII and MEP using the Manufacturing deployment kits. Adoption of Advanced Manufacturing from SMEs over a five-year period once the program is launched.	(Cost) Time and resources to coordinate and develop an interagency solution that modifies existing contracting procedures. (Risk) Doing business with the Government may become more difficult as this creates a new element under the master small business plan. (Gap) Adoption of Advanced Manufacturing by SMEs can be accelerated through incentive offering to large prime contractors.
	Update the 2016 DoD Source Selection Guide to promote the inclusion of contractors that utilize Advanced Manufacturing processes (self-certifying that they use these techniques). Initiate DoD pilot program and set an initial target of 5% of all contractors using Advanced Manufacturing processes.	(Feasibility): High. DoD Source Selection Guide can be updated immediately based on supply chain and manufacturing reports executed by the last two administrations. (Measures of Success): Increase in the number of government contractors utilizing and competing for contracts highlighting Advanced Manufacturing in their processes.	(Cost): Time and resources needed to create necessary oversight measures to manage and consolidate ongoing efforts performed by the MIIs and to foster coordination and information sharing across all MIIs. (Risk): May undermine the benefits provided under the Cluster Theory as new efforts to reduce redundancies may eliminate future institutes' abilities to win awards if institutes are already located in particular clusters where similar Advanced Manufacturing processes are mastered, e.g., AmericaMakes and ARM both serve as collaborative partners in the Additive Manufacturing domain, but are serving in different regions. (Gap): Lack of coordination and information-sharing. Centralized oversight authority may help reduce duplicative efforts and place a better focus on untapped Advanced Manufacturing specialties to increase adoption
	Establish a testing pilot program between the DoD, DoE, DoC, and appropriate academic and innovation institutes for commercial access to testbed facilities to test Advanced Manufacturing processes and materials manufactured using Advanced Manufacturing techniques.	(Feasibility): Moderate to high depending on buy-in and agreement from all sources of federal funding under Manufacturing USA network. The pilot program is to generate agreement. (Measures of Success): The next institutes awarded under the Manufacturing USA network should require a test bed facility that integrates advanced manufactuirng techniques.	(Cost): The triple helix already recieves federal funding. The next MII apporved was funded via the CHIPS act. (Risk): Interagency cooperation, specifically identifying supported and supporting roles with concerns of prioritizaiton and funding. (Gap):SMEs require proven use scenerios to adopt advanced manufacturting processes.

Figure G.2 – Policy Tracing: Recommendation Category #1, Part 2

	Diagnosis that defines or explains the nature of the challenge	**Guiding policy** for dealing with the challenge		**Coherent actions that are designed to carry out the guiding policy**	
	Strength / Weakness / Threat / Opportunity	**Interest**	**Policy Recommendation**	**Means**	**Ways (Scope)**
Identify and Codify Standards	(Opportunity) Many actors pursuing standards with need for leadership. (Weaknesses) Complex regulatory environment, slow standard development process. Proprietary environment contributes to desire to not develop standards. Cybersecurity often a late addition. (Strength) American sense of stewardship of international order.	Economic Security and National Security - U.S. interest in establishing and maintaining Advanced Manufacturing standards	Identify and codify advanced manufacturing standards to de-risk and facilitate adoption of technologies by firms and enable manufacturing resiliency.	ANSI & NIST, through engagements with Industry Consortia (e.g., Additive Manufacturing Consortium) use existing processes and governance for materials standards for additive manufacturing materials	Develop/maintain materials database w/certified metallurgic properties. ANSI will delegate standard certifying authority to NIST to develop and deploy a repository for additive manufacturing materials properties and standards. NIST will use existing laboratory infrastructure (Measurement and Science Laboratory, Materials Measurement Laboratory, and Physical Measurement laboratory) to transition newly developed additive materials into approved commercial standards that detail material property, material quality, and material/part qualification methodologies.
				MIIs and OSD ManTech identify candidate OIB locations and modernization activities funded with Congressional appropriations for advanced manufacturing applications	Develop/maintain OIB Digital Twin standards, publish workbook to inform modernization requirements at OIB locations and drive toward digital twin standards for legacy machinery and provide to MIIs
				DoD, MIIs, Industry Consortia (e.g., Additive Manufacturing Consortium and Digital Twin Consortium) and FFRDC come to a consensus on the incorporation of advanced manufacturing specifications in the Technical Data Package (TDP).	Define Technical Data Package for digital twin and additive manufacturing and mandate use in solicitations (DoD non-commercial)
				FAR Council, in conjunction with MIIs, National Cybersecurity Preparedness Consortium, and ANSI, agree on best way forward to protect cyber interests of USG and associated manufacturing industries.	Expand CMMC to FAR and develop commercial roadmap for minimum cyber security baseline for rest of manufacturing base

Figure G.3 – Policy Tracing: Recommendation Category #2, Part 1

	Coherent actions that are designed to carry out the guiding policy	Other Items Necessary to Frame Narrative	
	Ways (Scope)	**Feasibility / Measures of Success**	**Costs / Gaps / Risk**
Identify and Codify Standards	Develop/maintain materials database w/certified metallurgic properties. ANSI will delegate standard certifying authority to NIST to develop and deploy a repository for additive manufacturing materials properties and standards. NIST will use existing laboratory infrastructure (Measurement and Science Laboratory, Materials Measurement Laboratory, and Physical Measurement laboratory) to transition newly developed additive materials into approved commercial standards that detail material property, material quality, and material/part qualification methodologies.	(Feasibility) High - Given experience in maintaining and certifying materials and leveraging existing infrastructure, with industrial participation, NIST can successfully deliver a materials database. (Success) Available, maintainable, accessible materials database. Given the state of additive manufacturing, the database will have to be monitored and updated as new materials are identified.	(Cost) Governance of standards and database management. (Risk) Industry will not voluntarily submit materials for certification to protect intellectual property. Materials certified are viable for use across the additive ecosystem (Gap) Material availability. Certified materials involved in the creation of Critical Safety Items may still require additional testing beyond material certification
	Develop/maintain OIB Digital Twin standards, publish workbook to inform modernization requirements at OIB locations and drive toward digital twin standards for legacy machinery and provide to MIIs	(Feasibility) High - Several OIB modernization efforts are currently underway ex: MxD released RFP for Digital Twin effort at Rock Island on 3 May (Success) Published "Digital Twin Standards" workbook detailing the processes, challenges, and benefits of transitioning legacy non-digital production lines. The workbook will provide US industry use cases for industry-wide consumption to access the value proposition and return on investment of digital conversion.	(Cost) Given the disparate OIB products, the project may require substantial costs and schedule to publish. (Risk) Workbook best practices may contradict with early adopters, impacting those who have already bought into proprietary / not supported standards. Rigorous/Tight Standards may de-incentivize innovation w/o adequate agility to govern to evolve w/new tech. Government workforce may not have requisite workforce to lead and maintain OIB workbook (Gap) OIB Modernization is unique and knowledge may not transfer to the manufacturing base
	Define Technical Data Package for digital twin and additive manufacturing and mandate use in solicitations (DoD non-commercial)	(Feasibility) Moderate - Projects have been underway since 2017 to organize and deliver TDP standards for digital twins and additive manufacturing. However, as data and technology becomes more certain, the framework for defining TDPs will become more clear. (Success) Technical Data Packages developed and distributed through the defense acquisition system.	(Risk) Industry will protect or deny delivery of complete TDP to include digital interfaces and source code. (Gap) Government does not own the infrastructure to verify, accept, maintain, and use digital and additive TDPs deliverables
	Expand CMMC to FAR and develop commercial roadmap for minimum cyber security baseline for rest of manufacturing base	(Feasibility) High, as the FAR mandates compliance in order to participate in USG procurements, however early industry pushback is expected. (Success) FAR updated w/CMMC required, and Commercial Cyber Standards are published.	(Cost) Compliance is complicated and expensive for small and medium businesses (Risk) The cost is not assurance of mitigating all cyber attacks. The request for near terms compliance deviations will extend adoption. High probability industry will lobby for exemptions. Further disincentivizes industry to work with the government. (Gap) The threat of cyber security incidents is currently not being addressed and vulnerabilities will be exploited. (Mitigation) MIIs work to simplify CMMC compliance.

Figure G.4 – Policy Tracing: Recommendation Category #2, Part 2

	Diagnosis that defines or explains the nature of the challenge	**Guiding policy** for dealing with the challenge		**Coherent actions that are designed to carry out the guiding policy**	
	Strength / Weakness / Threat / Opportunity	**Interest**	**Policy Recommendation**	**Means**	**Ways (Scope)**
Develop a Capable Workforce	(Weakness) Companies lack access to a trained workforce required to a) adopt and run their AM factory equipment and systems, b) develop and innovate new solutions to manufacturing challenges, and c) advocate appropriately at the strategic level for AM business use cases that increase the company's profitability. (Opportunity) There are two opportunities--one for the workforce itself (to be recruited, educated, and/or upskilled and thus attain a job/expertise) and one for American industry as a whole, where American's innovative and entrepreneurial spirit can be matched with the tangible skillsets of AM to allow the United States to remain competitive.	Economic Security and National Security	Develop a trained workforce that provides companies access to talent able to execute advanced manufacturing.	Economic Development Administration (DoC) provides grants to community colleges as part of the $1.5B provided through the CARES ACT.	Market the benefits of Advanced Manufacturing not only as an employment opportunity but as a vital element of our national identity and security. The campaign must target high schools, trade schools, and colleges in addition to the general public while providing grants to community colleges to provide training and open access to underrepresented populations.
				Manufacturing Task Force studying region capabilities that drive resources and focus marketing based on manufacturing base. Additionally, look to develop manufacturing clusters in areas where the US does not have capability.	Defense Critical Supply Chain Task Force report identifies areas to shore up American manufacturing. ManufacturingUSA's and NIST MEP interaction with the industry helps drive Economic Development Administration investments.
				Increase the congressional cap on H1-B visas from 85,000 to up to 500,000 over the next five years. Fast track application process for advanced manufacturing-focused degrees.	Prioritize foreign students graduating from U.S. institutions with applicable degrees. Remove restrictions on an annual basis. DoC reports to congress on the success of the program and assesses the impact on US Citizen jobs.

Figure G.5 – Policy Tracing: Recommendation Category #3, Part 1

	Coherent actions that are designed to carry out the guiding policy	Other Items Necessary to Frame Narrative	
	Ways (Scope)	**Feasibility / Measures of Success**	**Costs / Gaps / Risk**
Develop a Capable Workforce	Market the benefits of Advanced Manufacturing not only as an employment opportunity but as a vital element of our national identity and security. The campaign must target high schools, trade schools, and colleges in addition to the general public while providing grants to community colleges to provide training and open access to underrepresented populations.	(Feasibility) High, EDA has allocated money to community colleges. Agencies need to combine marketing plans with access to education. (Success) The number of students enrolling in programs and positive polling on manufacturing jobs.	(Cost) $1-3 Million to upgrade community college Advanced Manufacturing training facilities based on past EDA investments. Use the Ad Council to market Advanced Manufacturing careers. Non Profit is funded by large companies. (Risk) Community Colleges may not have a pipeline to jobs close to their location. Innovation Institutes must facilitate pipeline. (Gap) Fighting perception of Old versus New manufacturing
	Defense Critical Supply Chain Task Force report identifies areas to shore up American manufacturing. ManufacturingUSA's and NIST MEP interaction with the industry helps drive Economic Development Administration investments.	(Feasibility) High, EO directed federal agencies to investigate and report on critical areas of risk to national security. (Success) Task Force risk areas are mitigated while workforce participation rate in advanced manufacturing jobs increases. Increased applications to advanced manufacturing programs.	(Cost) Minimal reports detailing supply chain and manufacturing concerns have already been funded. (Risk) Geopolitical variance could change manufacturing focus areas. Adoption of Advanced Manufacturing or onshoring of manufacturing may not be competitive with foreign sources of supply. (Gap) Critical Supply Chain shortfalls report lacks focus on current US manufacturing capability. Research is required to help identify struggling manufacturing capacity in the US to ensure solvency against unfair trade practices.
	Prioritize foreign students graduating from U.S. institutions with applicable degrees. Remove restrictions on an annual basis. DoC reports to congress on the success of the program and assesses the impact on US Citizen jobs.	(Feasibility) Low-to-medium. Immigration reform is a hot button topic, and would require significant Administration advocacy. (Success) Increasing trend in international participation in Advanced Manufacturing work centers, especially for those international professionals that graduated from U.S. educational institutions and elect to remain in the U.S. instead of repatriating their new skills.	(Cost) Minimal cost to implement in terms of money. Digitization of processes will help streamline processes. (Risk) Political risk is high. Immigration reform has been mentioned in party platforms but is a contentious topic. (Gap) Ensuring allocations go to Advanced Manufacturing and tracking advancement and adoption across the industry.

Figure G.6 – Policy Tracing: Recommendation Category #3, Part 2

	Diagnosis that defines or explains the nature of the challenge	**Guiding policy** for dealing with the challenge		**Coherent actions that are designed to carry out the guiding policy**	
	Strength / Weakness / Threat / Opportunity	**Interest**	**Policy Recommendation**	**Means**	**Ways (Scope)**
Collaborate with Allies and Partners	(Threat) China overtakes the United States in influencing the international approach to advanced manufacturing processes. (Opportunity) The US currently leads the global economic order (e.g., currency, rules, and standards) and has an opportunity to establish the international approach to Advanced Manufacturing.	Economic Security and National Security	Facilitate U.S. leadership of international standards determination and U.S.-preferred adoption of advanced manufacturing processes.	US diplomatic engagement and technical exchanges (e.g., SME & Career Civil Service engagements)	Aggressive U.S. participation in international standards negotiations and proper data use negotiations, such as in the International Standards Organization, the International Electrotechnical Commission, and International Telecommunications Union. Negotiations led by the Office of the U.S. Trade Representative, U.S. Departments of State, Commerce, and Energy.
				Congressional authorization, Executive Branch push, US diplomatic engagement and technical exchanges (e.g., SME & Career Civil Service engagements). Tax write-offs for private firm participation.	Increase commercial information sharing to synchronize Advanced Manufacturing priorities toward processes benefitting US strategic competition. Led by the U.S. Departments of State, Commerce, Energy and Defense in collaboration with Manufacturing Innovation Institutes and Extension Programs.
				US diplomatic engagement, foreign assistance and capacity building, defense appropriations, public-private partnerships.	Increase resource collaboration between US, allies, and partners to bolster cooperative development of accessible, US-preferred Advanced Manufacturing processes. Led by the Office of the U.S. Trade Representative, U.S. Departments of State, Commerce, Energy, and Defense. Partnered with globally-spanned private firms for commercial influence.
				US diplomatic engagement, foreign assistance and capacity building, defense appropriations, public-private partnerships.	Foster partnerships between US MIIs and analogous foreign government institutions to maximize distribution of Advanced Manufacturing processes benefitting US/allied dominance in strategic competition. Led by the U.S. Departments of Commerce, Energy, Defense, and Education (federal & state level education) in collaboration with Manufacturing Innovation Institutes and Extension Programs.

Figure G.7 – Policy Tracing: Recommendation Category #4, Part 1

	Coherent actions that are designed to carry out the guiding policy	Other Items Necessary to Frame Narrative	
	Ways (Scope)	**Feasibility / Measures of Success**	**Costs / Gaps / Risk**
Collaborate with Allies and Partners	Aggressive U.S. participation in international standards negotiations and proper data use negotiations, such as in the International Standards Organization, the International Electrotechnical Commission, and International Telecommunications Union. Negotiations led by the Office of the U.S. Trade Representative, U.S. Departments of State, Commerce, and Energy.	(Feasibility) Moderate given US influence among allies and partners. Expect challenges via economic competition from China. (Success) Wide adoption of US standards through established organizations. Increased collaboration with more stakeholders with international partners.	(Cost) Agency staff time would draw from other priorities. (Risk) Changes of political leadership in partner countries. Partner countries' preference for other standards based on national economic objectives or other constraints. (Gaps) Chinese "donations" of Chinese-standard technical equipment far exceed those that the United States provides, thus China has significant leverage and influence over the United States' target audience.
	Increase commercial information sharing to synchronize Advanced Manufacturing priorities toward processes benefitting US strategic competition. Led by the U.S. Departments of State, Commerce, Energy and Defense in collaboration with Manufacturing Innovation Institutes and Extension Programs.	(Feasibility) Moderate-to-low pending domestic political capital and partisanship influencing policy adoption. (Success) Distinct and open communication channels between private firms across the global manufacturing ecosystem for technology exchange.	(Cost) Potential cost to commercial firms sharing technology. Potential cost to US government through tax incentives, mitigated by long-term growth of GDP. (Risk) Intellectual property violation from partners (Gaps) There is no existing structure for greater info sharing on export controlled material and technology. ITAR restrictions...
	Increase resource collaboration between US, allies, and partners to bolster cooperative development of accessible, US-preferred Advanced Manufacturing processes. Led by the Office of the U.S. Trade Representative, U.S. Departments of State, Commerce, Energy, and Defense. Partnered with globally-spanned private firms for commercial influence.	(Feasibility) Moderate pending domestic political capital and partisanship influencing policy adoption. (Success) Distinct increase in allied and partner's advanced manufacturing-based GDP over multiple years.	(Cost) Increased foreign assistance allocations or further strain on existing foreign assistance allocations. (Risk) Pulling foreign assistance funds from other priorities to fund AdMan cooperation means that pre-existing priorities will not be fully funded/advanced. Limited subject matter expertise in some cutting-edge areas of Advanced Manufacturing might mean fewer people to participate in exchanges. Sharing protected IP might threaten U.S. companies' competitive advantage in certain markets.
	Foster partnerships between US MIIs and analogous foreign government institutions to maximize distribution of Advanced Manufacturing processes benefitting US/allied dominance in strategic competition. Led by the U.S. Departments of Commerce, Energy, Defense, and Education (federal & state level education) in collaboration with Manufacturing Innovation Institutes and Extension Programs.	(Feasibility) Likely given US influence among allies and partners. (Success) Multi-year SME and technician exchanges between multinational institutions.	(Gaps) MIIs and Dept of Education are not currently staffed to facilitate such discussion and cooperation, so would need to be augmented/trained/resourced. (Risk) The EU is pushing for common standards of composition and use among its member states, which sometimes competes with US-preferred common standards. Might alienate partners if the United States pushes too hard to force EU into the US camp.

Figure G.8 – Policy Tracing: Recommendation Category #4, Part 2

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