

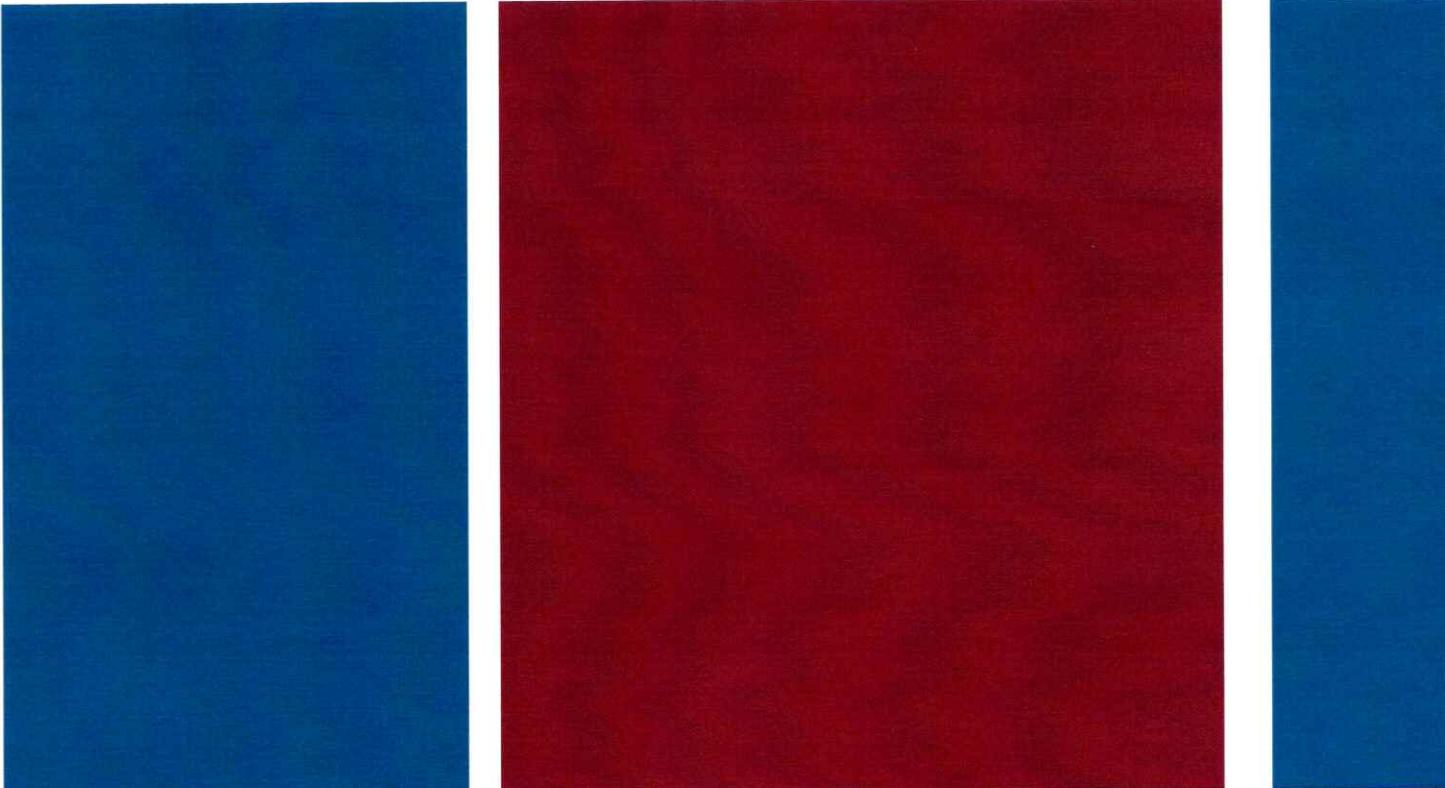
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Advanced Manufacturing

A Strategy to Support Advanced Security



Industry Study; Advanced Manufacturing
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Table of Contents

Executive Summary

Introduction 1

Manufacturing Matters
Advanced Manufacturing Matters More
Roadmap for Winning the Race

Overview of U.S. Manufacturing 5

Factory of the Future

The United States and the Competition 8

Assessing the United States
China
European Union
Singapore
Russia

Challenges to Advanced Manufacturing Adoption 12

Inadequate Federal Research and Development
Gaps in Cybersecurity and Intellectual Property
Lack of Long-Term Capital
Skilled Workforce
The Ineffective Role of Government to Date
The Department of Defense Acquisitions Process
A Closer Look: Obstacles to the Adoption of Advanced Manufacturing

Recommendations 17

Returning Manufacturing to the U.S. Playing Field
Developing and Deploying Advanced Manufacturing
Encouraging Innovative Firms to Enter the Market
Human Capital and Talent Management

Appendices 24

DOD's Role in Supporting Advanced Manufacturing
Recommendations by Agency
Overview of Chart of Recommendations

List of Abbreviations

Additive – Additive Manufacturing

AI – Artificial Intelligence

ASD – Assistant Secretary of Defense

CAD – Computer Aided Design

CLIN – Contract Line Items

DIB – Defense Industrial Base

DLA – Defense Logistics Agency

DoC – Department of Commerce

DoD – Department of Defense

DPA – Defense Production Act

FoF – Factory of the Future

GDP – Gross Domestic Product

IACMI – Institute for Advanced Composites Manufacturing Innovation

IP – Intellectual Property

IT – Information Technology

NIST – National Institute of Standards and Technology

OSD – Office of the Secretary of Defense

R&D – Research and Development

STEM – Science, Technology, Engineering, and Mathematics

USPTO - U.S. Patent and Trademark Office

EXECUTIVE SUMMARY

The recently released National Security Strategy notes manufacturing is both an economic and national security imperative. Manufacturing is a key contributor to U.S. prosperity, impacting jobs, research and development, and new weapons systems.

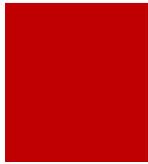
The state of U.S. manufacturing is at once both impressive and troubling. U.S. manufacturers remain on the cutting-edge of technology, but the last fifteen years have been devastating to the health of the sector and its workforce. This is a significant national security challenge.

To remain a leading global power, U.S. policy must redirect the macroeconomic trends that have made other manufacturing destinations more attractive than the United States. To lead the world's next industrial revolution, the United States needs to create a welcoming environment for advanced manufacturing, one that includes a collection of technologies like digitization, artificial intelligence, automation, big data analytics, and additive manufacturing.

The race is on to capture the value associated with the deployment of these technologies. Compared to competitor nations, including allies, the U.S. commitment to manufacturing has not been as robust. Senior leaders should consider the implications of new advanced manufacturing technologies on the national economy and national defense. Technologies involved in advanced manufacturing will impact the ability to mobilize both people and equipment. Sustainment and logistics could, for example, be more expeditionary and customized for the warfighter, while maintenance to major platforms could be performed while deployed.

Several challenges stand in the way of the sector's widespread success. Included are inadequate federal research and development funding; gaps in cybersecurity and intellectual property rights protections; a lack of long-term investment to support capital improvements; a skills gap and need to retrain workers for the jobs of the future; the ineffective role of government to date; and shortcomings of the Department of Defense's acquisition process.

The government clearly has a role in supporting the sector's competitiveness. Government should not direct industry, as other countries do with more regularity, but instead use policy to incentivize private industry to invest its own resources in technology development and deployment. This report describes a strategy to rebuild, revitalize, and improve U.S. manufacturing for the great power competition of the 21st century. First, the United States must create an attractive environment for domestic and global manufacturers. Second, it must develop and broadly deploy new advanced manufacturing technologies to increase the existing industrial base's productivity and retain a competitive advantage for U.S. manufacturers. Third, the United States must encourage innovative firms to enter the market, bringing with them disruptive technologies and additional capacity. Finally, it must prepare its greatest resource — the people of the United States — for the jobs of the future.



Introduction

“The future will be written (coded) by clever and bright engineers”

-- An industry representative during a recent field study trip

The United States is in a global race to capture the value of the fourth industrial revolution. To date, the U.S. commitment to win the race has been episodic, inefficient, and largely ineffective. Other countries have invested more resources and sustained a level of support that could result in a shift of global manufacturing power away from the United States, with adverse consequences across industries and for U.S. national security. This report describes the beginnings of a national strategy to reverse this trend, ensuring the United States remains the forerunner of global manufacturing.

A unique relationship exists between manufacturing prowess and economic prosperity, the latter of which allows a nation to resource its national defense. The recently released National Security Strategy and National Defense Strategy make this observation, noting manufacturing is both an economic and national security imperative. The United States’ manufacturing base is at risk of

losing its technological edge as well as its opportunity to lead the future of manufacturing. The solution is three-fold. First, the country must create an attractive environment for both domestic and global manufacturers to produce in the United States. Second, new advanced manufacturing technologies must be deployed broadly to increase the existing industrial base’s productivity. Third, the country must sustain and expand conditions that encourage innovative firms to enter the market, bringing with them disruptive technologies and additional capacity. Cutting across all three objectives is the need to invest in the country’s most valuable resource, its people, by upscaling today’s workforce and ensuring future generations can meet the competitive demands of tomorrow’s manufacturing sector.

Underlying each recommendation is a recognition that given the importance of manufacturing to the economic and national security of the United States,

Advanced Manufacturing Industry Study Group

The Industry Studies Program (ISP) is a cornerstone of the Eisenhower School (ES) curriculum. The Advanced Manufacturing Industry Study (IS) is one of 21 ISPs during the Eisenhower Spring 2018 semester. The Advanced Manufacturing IS seminar students span the Air Force, Army, Marine Corps, Navy, Department of Commerce, Department of State, U.S. Agency for International Development, Battelle Memorial Institute, and International Fellows from Serbia and Kuwait. This paper represents the culmination of individual research from each student; synthesis of course readings and lectures; and domestic and international travel to gain first-hand testimony on issues concerning opportunities and challenges within the Advanced Manufacturing sector. Domestic travel included visits to the Department of Energy National Labs; Department of Defense Research Labs; universities with programs supporting science, innovation and engineering; private sector companies engaged in adopting advanced manufacturing, and member institutions of “Manufacturing USA” in Chicago, Raleigh, Knoxville, Youngstown, and Pittsburgh. International travel allowed seminar participants to gain lessons learned and compare the U.S. with other ecosystems for advanced manufacturing in the United Kingdom, Germany, and Singapore. The purpose of the course was to gain an understanding of the importance of advanced manufacturing to the overall economy and key actions that can be taken to ensure continued competitiveness of the U.S. manufacturing sector, taking into account the U.S. industrial base and the ability to meet U.S. national security objectives. This paper represents the culmination of this effort.

the government must play a key role in facilitating the sector’s competitiveness. The United States will not win the race for 21st century manufacturing by out-centralizing China or mirroring the balanced approach to funding innovation employed by the United Kingdom and Germany. Instead, the United States should create the policy and regulatory conditions necessary to incentivize private sector investment, amplifying the culture and business climate that have promoted U.S. manufacturing leadership for decades. A stronger, more sustained financial commitment will certainly be needed, but equally as important is the need for a whole-of-government strategy that reflects the competitive environment of the modern global economy.

As the United States approaches a manufacturing inflection point, manufacturing itself is undergoing a dramatic transformation. Technological advances in artificial intelligence (AI), robotics, big data, metrology, and materials science are converging to transform the way products are designed and produced along with the way manufacturers interact with consumers and suppliers. Additive manufacturing alone, also known as 3D printing, is poised to change not only how technologies are made, but also their physical properties, unlocking new capabilities in aerospace and other sectors not previously available.

The technologies associated with advanced manufacturing are not the sole domain of the United States and its companies. Competitors are positioning themselves to lead the next wave of global manufacturing. As the world enters its fourth industrial revolution, the United States should

prepare for a long endurance race – one that is winnable with a sustained commitment to science, engineering, and practical investment in the domestic innovation ecosystem. Put simply, when the Soviets launched Sputnik, it was not tariffs and trade barriers that won the space race; it was a whole-of-government commitment to innovation. A similar effort is needed to win the future of manufacturing.¹

Manufacturing Matters

Manufacturing is a key contributor to a nation’s prosperity, to its ability to shape global economic trends, and to its ability to equip its military with the technologies needed to project power.

Manufacturing has important impacts on individuals and communities. Manufacturing jobs have a higher multiplier effect than jobs in other sectors and add \$1.37 per dollar invested to the nation’s gross domestic product (GDP).² Manufacturing also pays more to workers than other fields – particularly those with comparable levels of education. In 2015, for instance, the average manufacturing worker earned 27 percent more than the average U.S. worker with an annual wage and benefits of \$81,289.³ Manufacturing companies contribute to an overwhelming percentage of the country’s research and development (R&D), accounting for roughly 70 percent of U.S. industry R&D despite contributing just 12 percent of the nation’s GDP.⁴ The loss of manufacturing can have a profoundly deleterious impact on communities, government institutions, and social order.

Advanced Manufacturing Matters More

Not all manufacturing supports national security and economic well-being in the same way. Advanced manufacturing techniques improve not only the productivity of a country's industrial base, but also its flexibility (See Figure 1). Advanced manufacturing is *not* a sector in-and-of itself. It is a continuation of the trends that have been driving manufacturing toward higher levels of productivity, digitization, and machine learning. In many ways, advanced manufacturing represents the *digitization* of manufacturing methods, both old and new. Advanced manufacturing is the realization of Industry 4.0 or the fourth industrial revolution.⁵ It leverages innovative technologies to create existing products and enables the creation of new products that could not be manufactured in traditional ways. It starts with a digital thread that connects the physical and digital worlds and integrates advanced robotics, additive manufacturing, augmented reality, simulation, horizontal/vertical integration, industrial internet, cloud computing, cyber security, and big data analytics.

Rather than tooling and then retooling when demands change, companies with the latest advanced manufacturing technologies can more easily transition from producing one product to another. In terms of military expediency, this is a distinct advantage and creates new opportunities to mobilize the industrial base faster in times of conflict. It also has the potential to fill supply chain gaps and provide an expeditionary logistics capability.

Today, the United States is home to 1,900⁶ metal casting and 2,400⁷ stamping and forging facilities – each of which could be called upon in a time of conflict to produce war material. These facilities are equipped to support specific, often non-Department of Defense (DoD)-related industries. Retooling them to support a war effort would therefore be costly and time consuming. If more of these facilities used advanced manufacturing technologies, the response time would be quicker. For example, if they were equipped with the latest 3D printing technologies, the production times would be drastically reduced. Producing different systems and components for defense, and producing current systems and components differently, speaks directly to how the nation equips

Figure 1: Why Manufacturing Digitalization Matters and How Countries are Supporting It



Source: Stephen Ezell, "Why Manufacturing Digitalization Matters and How Countries Are Supporting It," *Information Technology and Innovation Foundation (ITIF)* (April 2018): 9.

its armed forces and therefore has implications for force structure and military doctrine.

For decades, the United States has used the private sector to design, develop, manufacture, and maintain its defense and national security platforms. The commercial sector and the national technology and defense industrial base (DIB) are thus inextricably linked, as innovations in one affect the other. Senior leaders should consider the implications of new production techniques on the country's ability to mobilize, as well as the military's force structure and logistics train. The combination of AI, digitization, and automation may even change the types of weapons needed for conflict, as war becomes an integration of the cyber, digital, and physical worlds. For both commercial and defense-related purposes, advanced manufacturing matters.

Roadmap for Winning the Race

This report begins with an assessment of U.S. manufacturing and describes opportunities to incorporate advanced manufacturing technologies to make production smarter, more efficient, sustainable, and local. The following section compares the position of the United States in relation to competitors racing to implement advanced manufacturing technologies in their own countries. The next section lays out the barriers to adoption of advanced manufacturing and the challenges of incorporating new technologies across industries broadly – namely, inadequate or out-of-focus R&D funding, gaps in cybersecurity intellectual property (IP) protection, workforce development, ineffective government support, and

DoD's acquisition processes. The paper concludes with several policy recommendations to ensure the United States maintains an industrial base capable of achieving national economic and security goals well into the future. Taken together, the recommendations outline the beginnings of a national advanced manufacturing strategy – one policy-makers should embrace as others are moving quickly to capture value that could otherwise accrue in the United States.

Overview of U.S. Manufacturing

“The factory of the future will have only two employees, a man and a dog. The man will be there to feed the dog. The dog will be there to keep the man from touching the equipment.”

- Warren G. Bennis

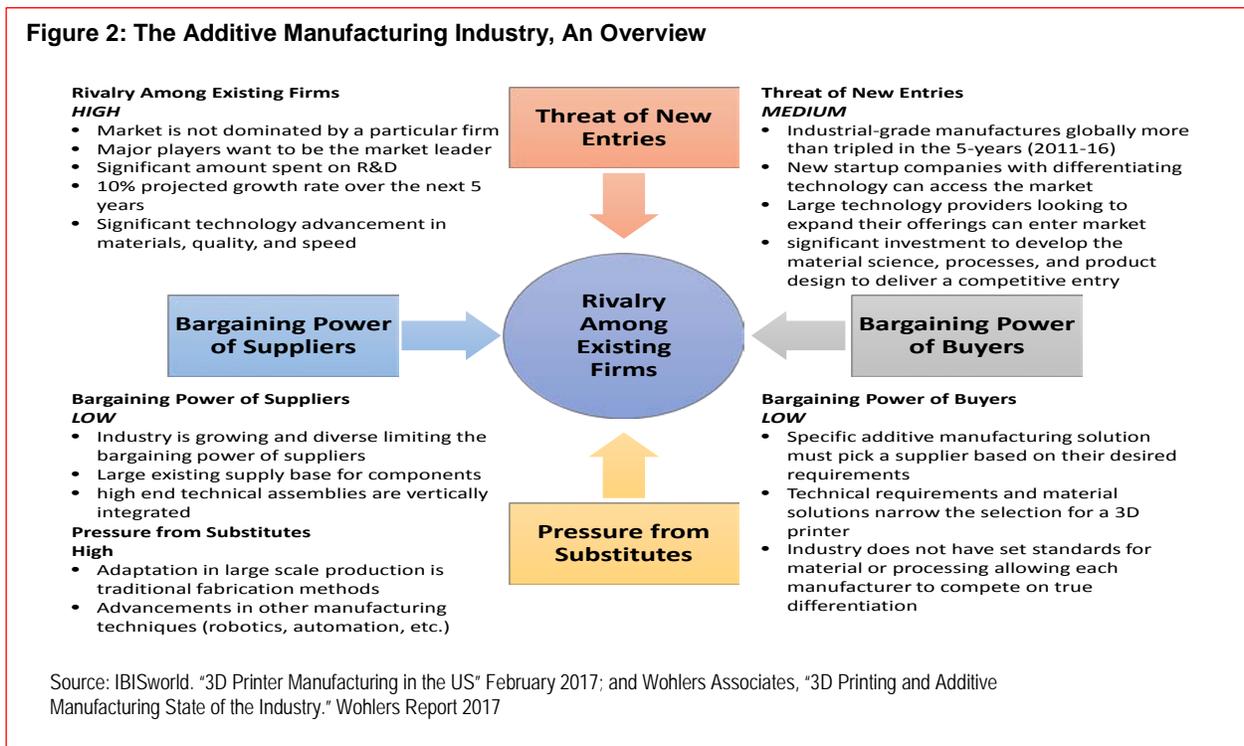
The state of U.S. manufacturing is at once both troubling and impressive. On one hand, the last fifteen years have been devastating to the sector; job losses have been significant across a range of manufacturing industries.⁸ The share of manufacturing output has fallen to 12 percent of the nation’s GDP, down from 25 percent in 1968.⁹ As the World Economic Forum recently noted, “Over the last two decades...the competitiveness of locally manufactured products and the attractiveness of the United States as a manufacturing location have been strongly challenged.”¹⁰

While manufacturing’s share of GDP has remained relatively constant,¹¹ this is largely due to a single sector: computers and electronics.¹² As the overall economy experienced long periods of growth (albeit with some cyclicity) and low unemployment over the last 30 years, 90 percent of U.S. manufacturing firms saw their contribution to GDP decline and their productivity growth slow.¹³ Broadly speaking, these are the companies that struggled with low-cost foreign competition – in many cases resulting in lay-offs or outsourcing.

The loss of output is largely the consequence of two trends. First, China’s manufacturing capacity has increased considerably and it recently surpassed the United States in terms of total production.¹⁴ Second, companies have often found it more profitable to outsource their manufacturing to China or other lower-cost destinations than to manufacture in the United States. In part, this mirrors the globalizing nature of world trade and the rising consumerism that characterizes many emerging markets.

One effect of off-shoring has been to split R&D from production. U.S. firms are retaining their U.S.-based R&D, but are utilizing offshore production facilities. This has allowed host countries to benefit from the designs of U.S. innovators, learning through the process of manufacturing how to make similar products without the upfront investment typically required for firms to compete globally. The result is U.S. manufacturers remain on the cutting-edge of technology, but the use of those technologies is increasingly occurring elsewhere.

Figure 2: The Additive Manufacturing Industry, An Overview



On the other hand, the United States remains one of the world’s leading producers across a range of products – the breadth of which is an advantage in a globalized world where consumer and military demands can change quickly. Both the government and private sector firms benefit from the innovation and entrepreneurship that define the U.S. system of venture capital, national labs, and university research. Places like Silicon Valley and Boston, Massachusetts are, for example, leading centers of commercializing new technologies, bringing new ideas and capabilities to U.S. industry and consumers alike.

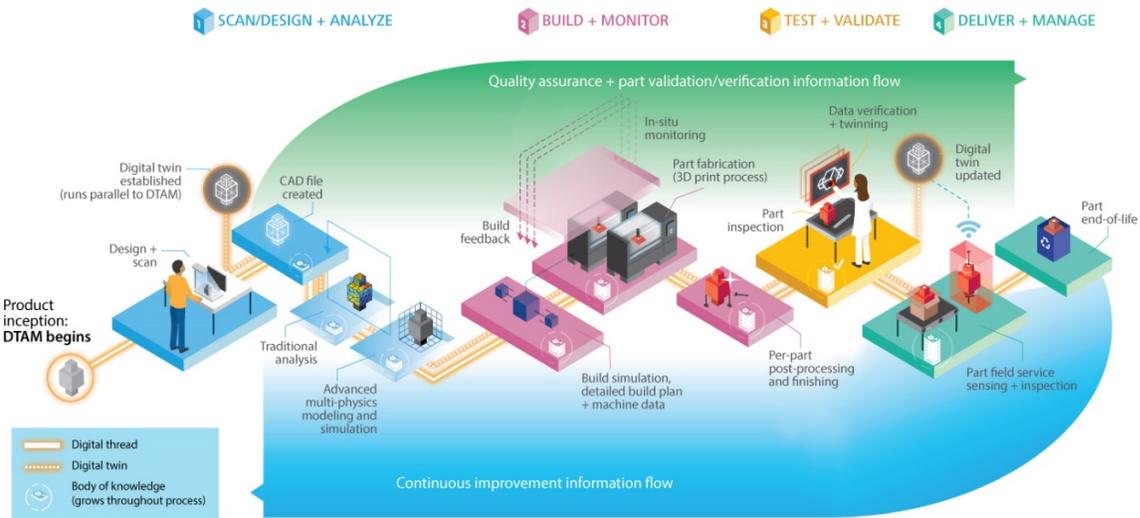
New technologies are changing how and where manufacturing firms compete. Today, any manufacturer, including U.S. manufacturers, can be global from the beginning. They are connected to a globalized world and often find their first sale in Germany, or India, or China before ever marketing their product in the United States. For American consumers, the ability to buy from anywhere has spurred a large trade deficit in manufactured goods, which first occurred in the early 1980s, and has grown steadily thereafter.

Advanced manufacturing offers an opportunity for a paradigm shift that could re-shore U.S. manufacturing and reinvigorate the U.S. industrial base while offering a lifeline to those firms capable

of using technology to increase production, reduce costs, and improve performance. Additive manufacturing, for example, will likely be an important part of the country’s productivity gains in the coming decades, as most firms are already considering how to implement the latest technologies in their facilities.¹⁵ Market share in the sector, however, remains highly competitive and fluid, with new entrants differentiating themselves with unique technologies, software packages, or material capability.¹⁶

The competition for share has been fierce, because the overall investment in the sector (while growing) has remained small. Most firms currently use their R&D budgets to purchase additive and other advanced manufacturing technologies, rather than their much larger capital improvements budget. For smaller firms, the barriers to adoption of new technologies are particularly severe, as they often lack the balance sheet, workforce, or financing options of their larger counterparts. As such, most decisions to use additive technologies – whether by a large or small firm – are still based on the ability to create unique capabilities rather than widespread production or profitability.¹⁷ Figure 2 below depicts Michael Porter’s “five forces” model within the additive manufacturing industry.

Figure 3: One Depiction of the Factory of the Future



Mark J. Cotteleer, Stuart Trouton, and Ed Dobner, "3D Opportunity and the Digital Thread," *Deloitte University Press* (March 3, 2016), <https://www2.deloitte.com/insights/us/en/focus/3d-opportunity/3d-printing-cyber-risk-management.html>, (May 10, 2018) *ibid.*

Factory of the Future

When considering the implications of a manufacturing future, policy makers must consider two important vectors: the future of production and the impact of digital technologies on the entire manufacturing value chain. Industry is making great strides in the precision, speed, size, material properties, and design of advanced technologies. At the same time, there is a convergence of the digital, physical, and cyber worlds that is impacting – and will continue to impact – not only production, but how products and producers interact with consumers.

One vision for the Factory of the Future (FoF) will be a production floor operated by flexible, autonomous vehicles and robots. Both vehicles and robots will utilize machine-to-machine communications, sensors, and wireless technologies to communicate with each other, and will use AI to make decisions in real-time.¹⁸ It will harness both advanced and traditional manufacturing technologies – and do so across a smart ecosystem of networked manufacturing plants, machines, and workers. Robots will be flexible and easily programmed for batch sizes of one but scalable quickly to support mass customization.

The FoF will consist of a network of networks and may utilize block chain technology or digital signatures. This offers the potential for mass

customization and the creation of a digital thread that can be tagged to a manufacturer, a country, or even a particular machine; and can track a product from its inception to its ultimate consumption. In many cases, predictive models will enable the production of a new product *before* the original exceeds its service life and embedded sensors and algorithms within the production machinery will predict when maintenance is needed, removing the divide between manufacturing and services. Work optimization algorithms will manage workloads and assign new work in the process where it is most cost effective.

All of this information – from ideation to consumption—creates “a digital tapestry”¹⁹ comprised of products, machines, and consumers woven together. Such connectivity allows for the development of more functional AI, net-centric manufacturing, and ultimately the delivery of customized, on-demand products. The digital nature should signal—to both government and industry—the imperative to focus efforts on protecting IP and creating a strong cyber security base.

The United States and the Competition

“Bar access to next-generation production. Don’t even sell next generation products in China.”

-- An industry representative

As the next wave of manufacturing technology enters new factory floors across the globe, the experiences of foreign and domestic firms will vary from country to country depending on the enabling environment for investment, innovation, consumer demand, protection of IP, and cybersecurity. Governments around the world have experimented widely with their relationships and approaches to secure domestic production. These approaches range from *laissez faire* free market ideals to state control, and from bilateral to global economic and manufacturing relationships.²⁰

While there is certainly competition between countries to capture the value of the fourth industrial revolution, policy-makers should appreciate that supply chains routinely span national boundaries – a fact that will become more pronounced in the future. No one country can, or should, go it alone. However, there are compelling reasons for the United States to implement a national strategy to ensure its production base is strong enough to achieve its national security objectives.

Prior to 2014, other countries paid significantly more attention than the United States to developing national capacity for advanced manufacturing through varying styles of national policy and initiatives. Figure 4 describes some of the initiatives and investments made by other markets, many beginning decades ago. Notably, most governments have updated their national policies and corresponding funding streams as new developments in advanced manufacturing have occurred. China, Singapore, and the United Kingdom, for example, published detailed action plans in late 2017 and early 2018 specific to additive manufacturing (a subset of advanced manufacturing).

Assessing the United States

The United States is postured for leadership in the implementation of advanced manufacturing technologies. For a myriad of reasons, its competitors are catching up. U.S. firms generally enjoy strong capital flows and a comfort level with digital innovation – two ingredients for outcompeting others. The United States trails China

Figure 4: Relative Investments in Manufacturing Research (2011-2014)

Country	Program and Summary	Investment in U.S. dollars (billions)	Equivalent U.S. Investment (billions)
Germany	Fraunhofer Program. World's most established and premier manufacturing research program; complements Max Plank Institutes (German analog to National Science Foundation).	1.0	3.0
	Spitzencluster. Supports the best or 'leading-edge' German industrial clusters.	0.25	0.75
	Central Innovation Program. Provides grants to small and medium enterprises to finance research and innovation projects.	0.64	1.92
United Kingdom	The Catapult Program. Established seven centers in advanced manufacturing.	0.264	1.6
Australia	Industry and Innovation Program. Collaborations between academic, government and industry researchers to commercialize discoveries; \$500 million over four years.	0.50	5.0
Japan	New Energy and Industrial Technology Development Organization. Promotes R&D for energy and industrial technologies.	1.64	4.89
	Other programs (Kohsetsushi Centers, Technology Advanced Metropolitan Area Association, Kawasaki Business Incubation Center).	0.51	1.45
Taiwan	Industrial Technology Research Institute (ITRI)	0.60	18.9
Finland	Finland Science and Technology Council	0.63	35.5
South Korea	Ministry of Education Science and Technology. Research programs in the 577 initiative target semiconductors, automobiles, machinery, health care and software.	12.8	175.0
Singapore	Future of Manufacturing Program	0.5	25.5
	Other programs (Satellite Industry Development, Collaborative Industry Projects).	0.19	9.7
France	Competitiveness Clusters. Similar to the German Fraunhofer program; 71 competitive clusters in "cutting edge and key technology sectors".	0.75	4.9
China	No government figures. Estimates are 1.7% of GDP, 82.7% of which supports manufacturing sector.	108	222

North American Manufacturing Research Institution of SME, "Advanced Manufacturing Initiatives: A National Imperative," 2015: 3, <https://www.sme.org/hamri-position-paper/>

in overall production and investments in manufacturing-related R&D. Other competitors also are making substantial public investments that are likely to erode the U.S. leadership position, as demonstrated in Figure 5.

To improve competitiveness for U.S. manufacturing, the United States established a network of Manufacturing USA Institutes in 2014 to accelerate the deployment of new technologies and techniques in the U.S. industrial base.²¹ The Institutes brought together the "triple helix" – government, industry, and academia – but because of their time-limited funding and lack of direction, they have not been effective, though they have established a series of connections with industry that may prove beneficial in the future.

China

China has the most comprehensive set of national policies for manufacturing generally, advanced manufacturing specifically, and recently, it promulgated an action plan for 3D printing. These plans amplify the efforts articulated in its 2015 joint report from the National Development and Reform Commission and the Ministry of Finance.²² The plan targets ten "key manufacturing industries" and it includes an additive manufacturing revenue growth goal. Several different kinds of financial and fiscal support are in development,²³ and not surprisingly, "Foreign firms will be encouraged to set up research and development centers in China."²⁴

Part of China’s comprehensive, long-term industrial strategy is to pursue global dominance in computing, robotics, AI, nanotechnology, and biotechnology. Its strategy is laid out in the 13th Five-Year Plan, the “Made in China 2025,” and “Internet Plus” initiatives, which exemplify China’s historic state-directed approach to build internationally competitive domestic firms.²⁵ Ultimately, China wants its domestic companies to replace foreign companies as designers and manufacturers of key technology products first at home, then abroad. China aims to accomplish this goal through “state funding, regulations, China-specific standards, localization targets, government procurement, foreign investment restrictions, recruitment of foreign talent, close integration of civilian and military technology development, and, in some cases, industrial espionage.”²⁶

China has the physical manufacturing base to grow its advanced manufacturing sector and to greatly expand its country’s productivity. According to international industry representatives, China recently purchased fifty high tech laser-based 3D printing machines.²⁷ Comparatively, many U.S. manufacturers only purchase one or two a year.²⁸ This indicates China is committed to mass production with advanced manufacturing techniques, and with state support, it is acquiring the foundational elements necessary to achieve its goal. To date, China has not advanced on pace with economic peers though. The primary reason for this lag is China has prioritized “creating on-the-job-know-how,”²⁹ in place of developing the workforce skills and education system infrastructure necessary

to adopt 3D printing or other technologies related to advanced manufacturing.³⁰

To compete effectively in the Chinese market, U.S. companies have learned to adapt to the peculiarities of the market. Large firms often choose to sell their “last generation” technology, recognizing and accepting their IP will be stolen, but having already innovated the next generation of their product. One industry representative aptly advised, “Don’t let China have access to the latest and greatest; let them know what they already know. Bar access to next-generation production. Don’t even sell next generation products in China.”³¹

European Union

Several leading European economies are developing advanced manufacturing technologies. The United Kingdom and Germany, for example, have sustained a level of government investment in the sector an order of magnitude larger than the investment made by the United States. Europe’s advantages in the sector are based on three unique pillars of support which differ dramatically from the United States. First, the United Kingdom’s and Germany’s investment in the sector is based on a model involving a tri-part funding arrangement between private, public, and open competition. Second, the United Kingdom and German governments are less concerned about retaining IP, preferring instead to develop technology for individual companies rather than the collaborative model frequently used in U.S. Government acquisitions. Third, in addition to technology development, most European markets invest

Figure 5: R&D in Manufacturing, 2015
(\$ billions in purchasing power parity)

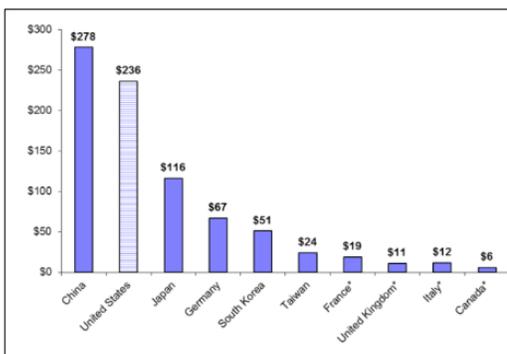
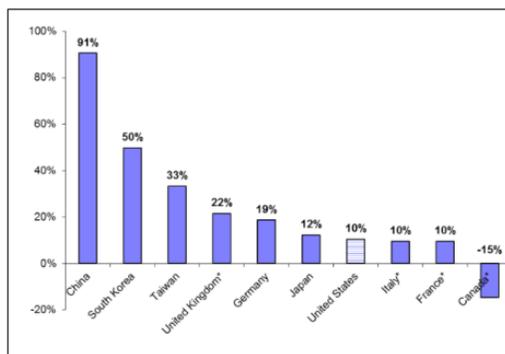


Figure 6: Growth in Manufacturing R&D
(Change at constant purchasing power parity, 2010-2015)



Mark Levinson, (February 21, 2018). *U.S. Manufacturing in International Perspective* (CRS Report No. R42135).

heavily in workforce development, training tomorrow's workers to operate the machines and technologies of the future.

Many European countries have adopted specific additive manufacturing strategies. The United Kingdom, for instance, initiated an additive manufacturing policy for 2018-2025 after a report found it was significantly lagging behind Germany and China in its use and experiments with additive manufacturing.³² Other European countries are leading in digital aspects of additive manufacturing (Belgium), or linking additive manufacturing applications to their historic engineering expertise (Italy and the Netherlands). These countries also have demonstrated a level of government collaboration, both between their national and state governments as well as between political parties, largely absent in the United States. Moreover, unlike the United States, defense needs do not inspire European investment in advanced manufacturing.

The leading European market is Germany. Germany pursues a robust export strategy and annually makes substantial investments in R&D. Its preeminent national and global contribution to both advanced manufacturing and additive manufacturing is its acclaimed Fraunhofer Institutes. Fraunhofer has a long-standing model by which its institutes compete for funding out of a pool that receives equal contributions from the national government, industry, and from technology awards.³³ The model ensures funding is stable enough to encourage long-term research, but also competitive enough to incentivize risk-taking.³⁴

Singapore

In the mid-1960s, few would have predicted Singapore would be a world financial and technology leader. Singapore's success boils down to three factors: its strategic location at the Malacca Strait, its vibrant and welcoming economy, and its "small, efficient and honest" government.³⁵ Singapore strives to be innovative, resilient, and change-tolerant. It welcomes immigration that furthers its specified national economic priorities, it provides social services, and its education system infuses Singaporeans with a belief that the health of the national economy is the key to freedom.³⁶ Because of Singapore's small city-state size, the U.S. cannot directly mimic its top-down model. However, its global technical leadership and

regional economic prowess provide important lessons for larger nations, including the United States, which lacks an influential plan for advanced manufacturing.

Singapore's national policy is to create, fund, and heavily recruit foreign investors and inventors to its innovation clusters, like its National Additive Manufacturing Innovation Cluster, which specifically includes a cluster dedicated to additive manufacturing.³⁷ Top U.S. universities, like Carnegie Mellon University, consider Singapore a leader in the material sciences aspect of additive manufacturing research. Singapore's Economic Development Board selects national policy goals, like advancing additive manufacturing, and nests those national priority goals in cohesive, interconnected ministerial policies—and funding streams—with incredible precision.

Perhaps because it lacks sufficient natural resources, Singapore has a keen interest in additive manufacturing, viewing it as a key differentiating technology for its unique competitive position. Its innovation clusters support three Singaporean-specified national scientific advancement goals—materials, precision engineering, and additive manufacturing technologies themselves. Singapore robustly funds and trains all levels of its workforce in additive applications in six "focus segments" of its high-tech manufacturing economy: 1) biomedical technology, 2) printed electronics, 3) precision engineering, 4) aerospace, marine offshore, oil & gas, 5) design, building & construction, and 6) clean technology.³⁸

Russia

The United States, and Europe in particular, should not overlook Russia's investment in advanced manufacturing. Russia has the ability to shake up the advanced manufacturing and additive manufacturing markets because it is a major supplier of metals needed to support industrial production across a range of sectors.³⁹ Russia already has proven to the world it has an uncanny ability to interfere in electronic and information technology (IT) systems; this capability should itself create a substantial commercial and national security demand signal for robust IT design and cyber protection for computer aided design (CAD).

Challenges to Advanced Manufacturing Adoption

“There is likely not an appropriate level of appreciation for the importance of cybersecurity within the advanced manufacturing industry broadly.”

-- The assessment of one industry official during a recent meeting

As with any new technology, challenges can impede adoption, delaying or even preventing the technology from reaching its full potential. Advanced manufacturing challenges include inadequate R&D investments, gaps in cybersecurity and IP protection, the lack of long-term capital, a consistent skills gap, the ineffective role of government in supporting the sector, and DoD’s acquisition process. An overview of each challenge follows concluding with a closer look at the barriers to the adoption of 3D printing.

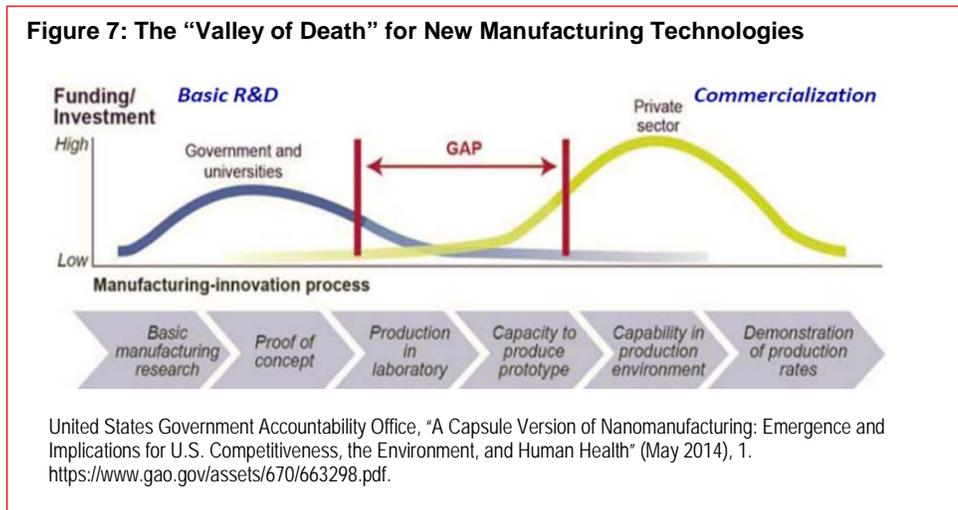
Inadequate Federal Research and Development

The United States has a long history of supporting risk-taking and innovation-led economic growth. Government-funded R&D has made the development of market-creating innovations like fracking technologies, the Internet, biotechnology, and nanotechnology possible.⁴⁰ Despite these successes, the pace and scale of the country’s public investment in future technologies appears to be slowing.⁴¹ Two-thirds of global R&D now occurs abroad, and nine countries now invest more in their R&D relative to their GDP than the United

States.⁴² This has pushed the majority of research into the private sector,⁴³ and while this investment is welcome, the fact most corporations are now global entities means the innovations they develop are increasingly produced elsewhere.

Since almost all basic research into advanced manufacturing is a public-private partnership, the reduction of federal funding means national labs, academia, non-profits, and even the Manufacturing USA Institutes will increasingly need to look elsewhere for financial support. For some organizations, private sector investment is likely to fill the gap, but this investment will predictably be targeted toward firm-specific technologies rather than those to benefit industry as a whole. Other organizations may seek foreign investment thus delivering the fruits of their labor to other countries for their use.

Manufacturing requires a sustained commitment to both innovation and commercialization. Reduced federal R&D efforts into the sector have the potential to set back the country’s transition to a



more advanced industrial base. Reversing this technological deficit will not be the work of a single investment or a short-term policy. It will take years of sustained and committed support, likely spanning multiple presidential administrations.

Gaps in Cybersecurity and Intellectual Property

The digitization of industry makes several concurrent problems more challenging. This includes the deployment of sensors in everything; the development of ever more complex parts; the use of increasingly complex metals and plastics; the connectivity of devices in an insecure cyber world; and the need to monitor equipment throughout its lifecycle. As one industry insider noted, “There is likely *not* an appropriate level of appreciation for the importance of cybersecurity within the advanced manufacturing industry broadly.” A recent study by Deloitte indicated nearly 40 percent of manufacturing companies were affected by cyber incursions, and 38 percent of those impacted indicated cyber breaches resulted in damages in excess of \$1 million.⁴⁴ The consequences of these incidents have grown increasingly significant. Gartner Inc, for example, estimated that the theft of additive manufacturing IP would account for \$100 billion in losses globally by 2018.⁴⁵

While some take the threat seriously, others are pushing the boundaries of connectivity and automation without a clear strategy for resolving cybersecurity threats. As with any interconnected computer network, cyber protections and vulnerability must be managed both at a systems level and within each part. Moreover, the risk of cyber theft or disruption must be balanced against the benefits of tighter integration and machine

learning. Additive manufacturing is one area where it can be especially dangerous, due to additive manufacturing’s reliance on digital files and connectivity, and the impact on multiple parties through the supply chain. For example, fears over excessive downtime have led some manufacturers to neglect updating their machines with the latest cybersecurity software and patches. Some in industry have recognized this challenge and are working to integrate cybersecurity software into existing design applications, but the widespread deployment of these technologies is severely lacking.

Exacerbating the problem are the legal complications associated with a system that is increasingly transnational and reliant on infrastructure, people, and facilities that fall within the jurisdictions of sovereign states.

Lack of Long-Term Investment

The lack of long-term investment has significantly reduced demand for advanced manufacturing technologies across a range of industries. The sector’s lifeblood has traditionally been corporate investment, as manufacturers replace older equipment with new technologies that can increase productivity and profits. The appeal of stock buybacks has likely encouraged many of the largest publicly-traded companies to forgo capital investments for the sake of short-term returns. This has limited demand for advanced equipment, including newer technologies like additive machines or robots. In fact, one leading U.S. manufacturing firm noted their purchase of additive technologies required a 17 percent hurdle rate over five years with the first year counted as a wash for having to

test the machine for reliability – making the real hurdle rate closer to 25 percent.⁴⁶ This is significantly higher than the hurdle rate for replacing existing machines with similar, but newer versions. Industry representatives explained that private sector investments in additive technologies and advanced manufacturing are using corporate R&D budgets thereby tapping into a smaller pool of money to purchase the most cutting-edge technology.⁴⁷

The lack of demand-pull and innovative push has created a larger than normal “valley of death.” The “valley of death” (shown in Figure 7) represents the challenge of transitioning new technology from the laboratory to the marketplace. However, the breadth of the “valley of death” is a symptom of a larger problem. Good projects and investable companies are difficult to find, but capital is available when they manifest themselves. The challenge for policy-makers is not to link buyer and seller, large manufacturers and new technology provider, but rather to inspire the former’s demand and the latter’s innovation. This is the opposite of the U.S. Government’s approach in most instances over the last decade. DoD and others have tried to rush into the “valley of death” with new programs and investments – initiatives that have largely been ineffective – when a more nuanced and thoughtful approach to creating demand and catalyzing R&D would have been more effective.

Skilled Workforce

The U.S. manufacturing industry has a significant skills gap. By 2025, an estimated 3.1 million manufacturing jobs will be available, but two million jobs will go unfilled due to willing workers lacking the skills required for the jobs available.⁴⁸ Additionally, tech companies such as Google, Amazon, and Facebook, although large employers, have not added to the country’s productive capacity because they have little if any manufacturing capability.⁴⁹ These companies, and others like them, have not maintained the traditional link between growth and job creation, relying instead on technology to increase productivity and scale.

The structural unemployment challenge of traditional manufacturing is worth addressing, but not at the expense of losing ground in advanced manufacturing. The factories of the future will require less labor-intensive traditional

manufacturing jobs and more jobs tailored to the needs of automation and digital design. Workers will need to be highly skilled and well trained for technical jobs such as CAD designers, computer programmers, robotics engineers, data analytics and technicians. While new jobs are on the horizon, they will not resemble the traditional manufacturing jobs lost to date.

Workforce development can be considered from two angles. First, there are not enough skilled workers to hire into the country’s evolving manufacturing sector. In one “rust belt” community, 16,000 jobs remained unfilled despite a widespread willingness of local manufacturing companies to hire and train employees. Causes of this worker shortage are complicated but include a lack of skills, drug addiction, and an unwillingness to engage in what is considered “dirty” work. The problem is pervasive enough that 75 percent of manufacturers report a lack of skilled workers as the reason they cannot implement new techniques such as additive manufacturing.⁵⁰

Second, the manufacturing sector has lost talent to larger, more attractive firms in other sectors. As one source noted, “For too long we have been exporting talent in manufacturing to other sectors.”⁵¹ And the competition for high-skilled workers is only growing more intense, as manufacturing firms must compete with the likes of Google, Amazon, Apple, and other digital companies for the data scientists, engineers, and innovators of the future.

All echelons of military services will need to consider advanced manufacturing and its second and third order effects, which will impact force structure (types of equipment, types of equipment operators), as well as institutional and operational training. At a strategic level, leaders and sustainment and acquisition professionals will need to learn and incorporate advanced manufacturing, including procuring the necessary data storage requirements and developing appropriate standards and protocols.

The Ineffective Role of Government to Date

For decades, the government has funded basic research, supported technology commercialization, helped with workforce training, and ensured that U.S. companies had access to foreign markets. With

so much effort (and money) invested in supporting manufacturing, it is fair to question whether the resources of the U.S. Government have been used as effectively as possible. DoD, for example, funded nine Manufacturing USA Institutes with \$70 million each over a five-year period, to be matched with non-federal funding from academia and industry. This amounted to roughly 0.0002 percent of DoD's budget over five years. The funding level covered no more than space for industry to convene.

Nevertheless, the institutes did provide some immediate benefit to industry. They helped to de-risk investment in new manufacturing technologies. They facilitated hundreds (and probably thousands) of new contacts between technology providers, manufacturers, and entrepreneurs. As one industry source mentioned, "The institutes do not bring profits or ideas to the company, but they do bring a space to make new contacts."⁵² The Institutes also demonstrated the type of public-private partnerships that have been so effective in other markets.

Industry does not lack places to convene or to collaborate on projects; nor is this a function that requires or deserves government investment. Anecdotally, large companies use the Manufacturing USA Institutes to keep tabs on what others are doing; small companies use them to showcase their technology and meet representatives of larger firms. In fact, the mandate of the Institutes to create group IP has likely reduced the willingness of leading companies to engage with anything more than their marketing budgets. Leading companies do not want to share their latest technology developments – they want someone to buy them.

The five-year funding period for most Manufacturing USA Institutes is coming to an end. Without federal recapitalization of the program, it is likely many of the institutes will face a lack of funding and could even close. While it is appropriate to regularly review each institute, they will likely not be successful without sustained investment and, in some cases, will require a reassessment of business strategy. Emphasis should be placed on providing industry a technical contribution, rather than a place to convene.

The Department of Defense Acquisition Process

DoD is itself a challenge to the proliferation of advanced manufacturing technologies in U.S. industry. For example, defense leaders and acquisition executives face high non-recurring engineering costs to minimize the associated risks of transitioning to additive manufacturing. As a result, two things have occurred. First, the adoption of additive technologies has been extremely limited when compared to the scope of the defense acquisition enterprise (e.g., research and development, major weapon system procurement, lifecycle supply chain). Appendix 1 includes a menu of DoD-specific policy options. Second, DoD's support for advanced manufacturing has not created the level of demand necessary to encourage investment in improving the technology offerings of both machine providers and the manufacturers of parts using advanced techniques, like 3D printing.

A Closer Look: Obstacles to the Adoption of Additive Manufacturing

To provide the revolutionary change they herald, advanced manufacturing technologies must be easier to use, cheaper to deploy, and sophisticated enough to evolve with production needs. Many additive technologies do not yet meet this standard. In fact, during several industry visits, manufacturers complained different printers (and sometimes the same printers) produce variability in parts meant to be the same – a claim disputed by others who suggest repeatability is possible with applied expertise. Either way, additive manufacturing requires some form of product or process certification, standards, and software protocols before widespread adoption will take place.

Affordability - High-quality additive machines that can produce metal parts are still expensive and require significant effort to maintain. These machines can cost more than a million dollars, and materials can cost \$100 to \$150 per pound,⁵³ representing a substantial price premium over traditional machines and materials.

Speed - Additive manufacturing can help save considerable amounts of money when producing at low volumes or in the production of customized parts because retooling costs are not an issue. Companies that have adopted additive technologies

consider it a cost-effective alternative for smaller production runs.⁵⁴ Additive technologies; however, can be slow when producing large parts and large quantities. In these instances, additive manufacturing is not cost-effective because slow fabrication speed limits the return on investment manufacturers can expect when producing large quantities.⁵⁵

replacement parts, but the real value in additive is in the production of parts that are no longer made or parts that require complex geometries other methods cannot produce. Industry is thus still building expertise in additive with the largest, most profound changes likely to come when engineers being trained today in additive techniques begin to lead the sector.

Qualification and Repeatability – The Defense and Aerospace sectors are highly regulated and impose strict standards for qualification of critical parts. The qualification process poses a “serious hurdle” for additive manufacturing to meet the metal parts needs of Defense and Aerospace.⁵⁶ Porosity (“some applications require parts with a density greater than 99 percent”) and “surface finish and thermal stress” are among the metal part production challenges additive manufacturing must overcome.⁵⁷

The Federal Aviation Administration defines a Flight Safety-Critical Aircraft Part as “any part, assembly, or installation containing a critical characteristic whose failure, malfunction or absence could cause (1) a catastrophic failure resulting in loss or serious damage to the aircraft, or (2) an uncommanded engine shutdown resulting in an unsafe condition.”⁵⁸ Additively manufactured parts have yet to be “qualified for critical defense or aerospace applications.”⁵⁹

Qualification includes certification of equipment and materials. Repeatability and consistency are required “over the entire build volume and between builds for each machine, as well as across different machines of the same make.”⁶⁰ Today, 3D printing technology cannot “guarantee material properties for a given process” and it is inhibiting “additive manufacturing’s wide industry adoption because many companies do not have confidence that the manufactured parts will have the mechanical properties and dimensional accuracy required to meet specific application needs.”⁶¹

Expertise – Additive manufacturing is a complex technology that will take more time to understand. Some industry leaders have discovered ways to overcome the obstacles and challenges associated with it while some of the smaller companies, universities, and laboratories are seeking to do the same. There are many discussions about how additive technologies can be used to produce



Recommendations

“We must always be asking ‘how are we disrupting ourselves?’”

-- A representative from a large American manufacturer

Since a country must retain some level of manufacturing to remain a global power, policy must be used to redirect the macroeconomic trends that have made other manufacturing destinations more attractive than the United States.⁶² In this, policies that amplify existing trends and leverage the comparative advantages of the United States will be more effective than policies that attempt to completely alter them.

The United States can make advanced manufacturing a priority by: 1) encouraging foreign manufacturers to move production to the United States; 2) making its existing industrial base more advanced, and, as a result, more productive and flexible; and 3) creating the conditions that incentivize innovative firms to disrupt the market with new technologies and capabilities. Pursuing these goals will require coordinated actions across the whole of government. They will also need to be supported through workforce development initiatives that prepare today’s labor force for the jobs of the future. Priority should be given to policies that can catalyze significant private sector

investment in breakthrough technologies like rapid prototyping, additive manufacturing, metrology, and machine learning, as these sectors compete on quality and technological capability with less reliance on price to differentiate themselves from foreign competitors. These are also the sectors that offer the highest-value defense capabilities, making them ideal for bolstering the country’s manufacturing capacity, capability, and national power.

The policy recommendations offered below incentivize private sector investment in plant modernization and productivity growth, using government tools to create the conditions necessary to encourage firms to invest their own money in retooling without relying on an abundance of government funding.

The DoD has an important role in shaping the advanced manufacturing industry given its symbiotic relationship with advanced manufacturing, immense size, and budget relative to other agencies. DoD support to the industrial base

has lasting impacts across a range of technologies and should embrace its ability to remake and reinvigorate the U.S. manufacturing sector.

Manufacturing and security are highly globalized. The resurgence of major military competitors and the need to strengthen alliances to confront them have impacts unique to DoD. No other nation has collective defense responsibilities on par with the United States. Given DoD's outsize role in advancing manufacturing, particularly in funding it, it deserves a stand-alone discussion found in Appendix 1.

The following recommendations are aligned to support the above mentioned three categories of focus for action. The human element – the workforce – is addressed separately as it spans all three focus areas.

Returning Manufacturing to the U.S. Playing Fields—Creating an Attractive Environment

The first category is to rebuild domestic manufacturing capacity by attracting manufacturers from abroad to build their next facility in the United States. This will require policies and regulations to make the United States a *more* attractive destination than other would-be competitors.

Rebuilding American Manufacturing Bonds Program

The U.S. manufacturing sector invests roughly \$200 billion annually in capital improvements, as firms replace older machines with newer ones. Yet, only a tiny fraction of industry's investment is dedicated to the acquisition of breakthrough technologies – most merely maintain the firm's competitive position in the market. Technologies like additive machines, increased digitization, and AI are still considered too risky and too unproven to elicit significant investment and the companies that do purchase these technologies often do so using their own R&D budgets – not their much larger capital improvements budget.

The U.S. industrial base requires an influx of capital to purchase the cutting-edge machines, systems, and software packages needed to compete more effectively in global markets. This capital cannot be provided directly by the U.S. Government. Needed are new sources of capital to fuel industry's demand for breakthrough technologies, both creating demand for groundbreaking products and helping

the industrial base grow more competitive. One source of this potential funding is the U.S. public.

A Rebuilding American Manufacturing Bond Program would allow individual investors to invest directly in the health and productivity of the country's industrial base. The United States has used bonds throughout its history to push the country in an advantageous direction. During World War II, bonds raised revenue to buy war material. Selling bonds to investors with a guaranteed and tax exempt three percent annual return would provide the Department of Commerce (DoC) and the Small Business Administration the financing it needs to lend to manufacturers for the sole purpose of modernizing their production capabilities. The government could focus efforts through maintaining a list of technologies its bonds program would support. The Manufacturing USA Institutes could act as a clearinghouse for such bonds, using profits to invest in workforce development or training.

By charging a five percent fee on the loans, the government could pay back its bond holders *and* significantly lower the hurdle rate for investments in new machines and lower the risk associated with adopting cutting-edge technologies. A key to the bond program is the tax exemption on the bonds' low interest rate. This would incentivize long-term investors to purchase them. Allowing the average citizen to invest in the country's productivity through bonds would expand the number of investors and the amount of money available to support manufacturing, in essence, crowdsourcing the sector's rebirth.

Although Congressional and Treasury Department support would be required, it would be cost positive for the government as a whole. A bond program would also be politically palatable, since investment in the sector would be voluntary, only those interested in purchasing bonds would be impacted.

Align Manufacturing Extension Partnership Program Under Manufacturing USA

The Manufacturing Extension Partnership (MEP) has been an important facet of the U.S. Government's support for manufacturing since its creation in the 1980s. Aligning the Partnership Program under the Manufacturing USA Institutes will provide local access to the network of research

laboratories and industry leaders. This arrangement can more effectively diffuse the knowledge developed by the institutes' network to a wide range of manufacturers who may not have the capacity to stay current on recent developments or how such developments may complement their own operations. Moving the MEP under Manufacturing USA would require Congressional approval. MEP had its budget cut in the President's FY18 budget request only to be restored by Congress. As such, moving the program may require additional explanation so as to not imply it is being cut entirely.

Collaborate with Partners and Allies

Finance and manufacturing power is amplified when it is supported by partners and allies around the world. Even though each nation will seek to make their countries more productive, there is significant willingness to collaborate on projects such as innovation hubs and concepts such as "Factories of the Future."⁶³ Trading partners facilitate U.S. economic growth and innovation. Moreover, allies and partners who have similar world views and appreciation for the rule-of-law can help establish global norms for cybersecurity and the protection of IP. For this reason, the United States should reconsider its participation in regional trade agreements that include provisions for IP protection, cybersecurity, and electronic commerce.⁶⁴

Develop a Strategic Communication Plan to Attract Talent Into Manufacturing

The majority of the Manufacturing USA Institutes' outward communication is self-promotional without informing information-seekers about advanced manufacturing. Each institutes' website is set up differently and a visitor interested in advanced manufacturing would have to visit more than one institute's site and learn how to navigate different web layouts to find information – if the same sort of information is even resident on their sites. Manufacturing USA should shift its focus from promoting the institutes to promoting industry and advances that make manufacturing a more attractive career for talented workers. To do this, Manufacturing USA should employ an accredited public relations professional (to manage relationships among publics), not a marketing professional (to sell things).

Target SelectUSA Program to Attract Foreign Direct Investment in Support of the DIB

The DoC's SelectUSA Program has been an effective means of attracting foreign direct investment into the United States. The program is designed to be agnostic toward the types of green field investments sought after; and unbiased toward where foreign investors choose to develop their projects. Given the importance of manufacturing to the country's economic future, the SelectUSA Program should target certain investors. In particular, foreign companies that can fill gaps in the DIB's capabilities as well as firms that provide upstream technologies like 3D printers, special alloys, and digital products that can make existing firms more productive. This can be done within existing authorities but may require additional funding from Congress.

Developing and Deploying Advanced Manufacturing

The second category is meant to deploy advanced manufacturing technologies across industries more broadly, making today's manufacturers more productive and competitive. This will likely require changes to financing structures, access to new sources of capital, and updates to the nation's tax code.

Loan Guarantee Program

The Treasury Department could guarantee loans to lenders for manufacturers to update their facilities with more advanced technologies. The guarantee program could offer lower rates to those firms that deploy the most cutting-edge technologies. A company that installs advanced technologies like a new 3D printer in place of a legacy technology could receive a lower rate than a firm that purchases a like replacement. A loan guarantee program would require Congressional action and would incur upfront costs.

Tax Policy

Tax policies provide necessary incentives for industry to align with government strategic objectives. To promote advanced manufacturing investment, Congress should evaluate three tax policy updates for equipment purchases, R&D expenses, and workforce training.

Tax Policy – Equipment Purchases

The recently passed Tax Cuts and Jobs Act allows 100 percent first-year bonus depreciation of plant and equipment and increased maximum expense limitation.⁶⁵ Congress should expand the terms for advanced manufacturing equipment and facilities to longer than five years and increase the spend limit. The tax credit increase will promote U.S. private sector investment in advanced manufacturing and influence the financial calculation when manufacturers consider updating equipment with new technology and expanding their facilities.

Tax Policy - R&D

Advanced manufacturing technologies are still in their infancy and continued research and development are critical to their long-term success. The Tax Cuts and Jobs Act reduced the amount of credit a firm can claim for research and experimental (R&E) expenditures,⁶⁶ an unfavorable change for taxpayers involved in research. Congress should modify the tax code to exempt advanced manufacturing related R&D from the amortization restrictions in the new tax code.

Tax Policy - Workforce

Tax policy can also promote workforce training and the reskilling of workers for the jobs of the future. Two options should be considered. One is to create a corporate tax to directly fund work force training programs like apprenticeships, vocational schools, and community colleges. The United Kingdom's recent tax of 0.5 percent on all businesses earning over £3 million is a good model. The United Kingdom's goal is to have three million apprentices by 2020. Its corporations largely support the effort because they are involved in the development of curriculum for apprentices in training.⁶⁷ A new corporate tax would likely be politically challenging but would allow a more coordinated and comprehensive national-level strategy to train tomorrow's workers. The second option is a workforce training tax credit for companies that transition their factories and people into advanced manufacturing technologies. This option is likely more politically palatable but would place the decisions about workforce training in the hands of private firms, making national-level coordination more difficult.

Increase Urgency for Digital Thread and Advanced Manufacturing Standards

The advanced manufacturing industry, and the additive manufacturing processes more specifically, lack the standards and certifications required for widespread deployment. Professional organizations are currently convening to develop standards with input from U.S. scientists, engineers, academia, and industry partners. The National Institute of Standards and Technology should take the lead in keeping relevant publics informed of and involved in the most current standards-setting activities with the aim of maintaining an influential U.S. voice in the creation of international, fair, and acceptable standards for privacy, cybersecurity, repeatability, and material properties.

Launch Manufacturing USA 2.0

The Manufacturing USA Institutes provided the United States a first step in the development of a national strategy to deploy advanced manufacturing technologies broadly across industry. Going forward, the program requires an update to ensure its effectiveness. The DoC should initiate a comprehensive review of the institutes, their charters, progress, and financial models. Some institutes are more effective than others. Those providing industry a unique and useful service should be recapitalized and supported, while those that have been less successful should be allowed to atrophy. Fewer, better capitalized, and more empowered institutes should be a priority.

The DoC, with authority from Congress, should focus the Manufacturing USA Institutes on clusters of specific technology challenges and merge institutes to take advantage of expertise and combined funding.³⁹ Three principles should apply to the revamped program. First, the new institutes should be required to raise at least an equal amount of private sector investment annually as they receive in public funding. This would require the institutes to adapt to the evolving needs of industry and operate more like a Working Capital Fund. Second, via subsuming the MEPs, the new institutes should develop an effective outreach campaign and workforce development program to balance their support for technology innovation. Third, less emphasis should be placed on small and medium sized business incubation. Most demand for advanced manufacturing comes from large

companies whose capital will be needed to push technology into their supply chains.

Encouraging Innovative Firms to Enter the Market

The third category involves encouraging innovative firms to enter the market with new technologies and new capabilities. This will require investments in human capital, new financing options, and refinements to the government's acquisition system so leading-edge applied science can reach end users "at the speed of relevance."⁶⁸

Update Patent and IP Law for the Digital Age

The U.S. patent system ensures inventors can profit from their ideas and investments. The Patent and Trademark Office should streamline procedures for businesses and entrepreneurs to patent their ideas and ensure both the process and the patent fee structures are not cost prohibitive for small and medium size enterprises. Additionally, a fresh look at the laws that govern patents and trademarks should be conducted by the DoC. For example, many of the Manufacturing USA Institutes expressed that small businesses are challenged to file quickly enough and noted that the debate between "first to file" versus "first to show production capability" should be settled.⁶⁹ Changing the fee structure could occur within the existing authorities of the DoC, but will likely require consultation with Congress as fee structures could impact the Department's budget.

Global Engagement to Promote IP Enforcement

The United States should work with global partners to develop a mechanism to identify IP rights violators, hold them accountable for their actions and warn others of their actions. Accountability is particularly challenging; while firms have made great strides in protecting IP, laws and their enforcement across the globe struggle to keep pace with the latest technological advances.⁷⁰ As such, the fast-paced development of advanced manufacturing and its related technologies will mean IP protection instruments such as copyrights and patents must be reexamined to protect the design of the physical and digital representations of an object.⁷¹

Update the Patent and Trademark Law Amendments Act of 1980 (the Bayh-Dole Act)

The original Bayh-Dole language required products developed using federal R&D funding and licensed

exclusively to a private firm for commercialization be "substantially manufactured" in the United States.⁷² This has not been adequately enforced. For example, despite almost all solar technology deployed around the planet being in some way funded with U.S. Government R&D dollars, almost no solar technologies are still manufactured domestically.⁷³ Therefore, updating the Bayh-Dole Act could better tie taxpayer support for innovation and commercialization to actual manufacturing, should a company successfully scale.

Focus National Labs on Commoditizing Advanced Manufacturing Resources

Advanced manufacturing techniques require raw materials that themselves are created in advanced ways. For example, at the Institute for Advanced Composites Manufacturing Innovation (IACMI), small businesses and the institute work collaboratively to create carbon fiber at a lower cost. One industry representative remarked that once the composite industry can commoditize carbon fiber, the demand for the material would grow. The process for creating the homogeneous metal powders used in 3D powder bed printers is similarly expensive to create. The national laboratories should focus significant research time, in partnership with their associated academic and industrial partners, to lowering the cost of producing these essential raw materials.

Human Capital and Talent Management

Spanning all aspects of advancing manufacturing is the human element. People make things and people make things that make things. Support for workforce development and training is therefore critical. Hiring a talented workforce is foundational to a company's ability to compete and grow; and in a time of mass mobilization, the country's workforce must have the skills necessary to operate the machines necessary to produce the country's weapons of war.

Funding Science, Technology, Engineering, and Mathematics Education

There are several ways to improve talent management and the attraction of top talent into advanced manufacturing. The challenges range from the instilling school-aged children with an interest in manufacturing to the funding of Science, Technology, Engineering, and Mathematics (STEM) education in universities and other technical

colleges and even the retraining of existing manufacturers. As such, federal and state governments, industry, and academia are going to be vitally important in establishing policies, programs, and partnerships to properly educate a workforce to fill the next generation factories.

The Department of Education's 2019 budget request focuses on STEM education with \$200 million requested and promotes pathways to careers starting in high school.⁷⁴ The pathways to careers include support for technical schools, community colleges, and apprenticeships. Funding at this level is important and should be increased in the years ahead. Manufacturing STEM scholarships should be created to ensure STEM education funnels into manufacturing-supported fields of study.

Increasing the Amount of Apprenticeships

In 2016, the United States had approximately 505,000 apprenticeships. Only 14,422 were in the manufacturing field. Comparatively, Germany has 50-60 percent of their young population participate in a combined vocational and on-the-job training.⁷⁵ The United Kingdom has a commitment to have three million apprentices by 2020. The United States should commit to doubling the amount of apprenticeships to one million by 2025 targeting at least 100,000 in manufacturing.

As a challenge to this initiative, a recent study found nearly two-thirds of parents would not recommend their children pursue careers in manufacturing despite the sector offering higher salaries and a commitment to skills development.⁷⁶

Manufacturing USA strategic communication should include parents of and middle-through-high school students as targeted publics. The goal should be to educate and inform parents and students on what skills and education are required for employment in advanced manufacturing and what the rewards of working in the sector are.

Vocational Education and Training

Vocational certified training and community college degrees are the path to transition workers to new-collar workers. Community colleges and vocational schools have the opportunity to develop associates and technical degrees that create graduates with new-collar skills. Additionally, DoD apprentice programs could certify military engineers and like-

skilled occupations with civilian-recognized credentials.

The DoD Manufacturing Engineering Education Grant program, intended to assist universities (or academic-industry consortia) in revamping their engineering programs to focus more on manufacturing engineering,⁷⁷ should be moved into the Manufacturing USA Program to consolidate and coordinate all manufacturing-development initiatives. Companies that likewise support local schools with advanced manufacturing-focused curriculum development could be further encouraged with tax incentives thus subsidizing the cost of talent development.

Already Honeywell has partnered with others to fund an additive manufacturing lab at Arizona State University.⁷⁸ General Electric (GE) has an additive program through which they are partnering with more than 400 schools and providing them 3D printers.⁷⁹ Pratt and Whitney partnered with the University of Connecticut to launch an Additive Manufacturing Innovation Center to expand advanced manufacturing research and development.⁸⁰ However, these are just a start to the actions required to adequately prepare the U.S. workforce for the digital, advanced manufacturing jobs of the future.

Immigration and the Attraction of Foreign Talent

Finally, immigration laws should enable the most talented individuals to stay in the United States. In a year, the top 50 graduate schools for engineering produce about 95,884 graduate level engineers, but 60.5 percent of them are international students.⁸¹ Too often, highly-skilled foreigners are unable to stay and when they leave they take their talents and productive potential with them. "According to a recent Brookings Institute study, in 2010 more than 96,000 foreign students were in the United States pursuing graduate degrees in STEM fields; however, a mere 19,000 stayed after graduation to work in the United States."⁸²

CONCLUSION

The United States needs to renew its commitment to manufacturing. The further behind the country falls in the move toward Industry 4.0, the wider the gap will be between it and those who have kept pace and advanced. The fourth industrial revolution

offers the opportunity to digitize and automate manufacturing across multiple industries, making production more efficient, flexible, scalable, and sustainable. It presents the opportunities to make things previously impossible to make and to employ people in previously non-existent ways. It also presents an important opportunity to rebuild and retool the country's DIB.

Policies, regulations, and a national investment commensurate with the sector's importance to economic and national security will incentivize production flow into the country and anchor those already producing in the United States. The symbiotic relationships between innovation and production, and defense acquisition programs and manufacturing, and manufacturing and the economy offer a wide swath of opportunities to strengthen each.



Appendix 1

DOD's Role in Supporting Advanced Manufacturing

The DoD must play an important role in shaping the advanced manufacturing industry given its immense size and budget relative to other agencies. As such, the decisions made by DoD to either support or ignore the industrial base will have lasting impacts across a range of technologies. DoD should embrace its ability to remake and reinvigorate U.S. manufacturing, building on its long history of supporting breakthrough manufacturing technologies.

In November 2016, DoD released an integrated DoD Additive Manufacturing Roadmap to serve as a “foundation and framework for focusing any desired collaboration and coordination of the DoD’s activities in Additive.”⁸³ The roadmap provides four primary focus areas: design, materials, process, and value chain. Further it provides high-level objectives for each focus area and seeks to synergize the activities of individual organizations within the additive sector.⁸⁴

The roadmap is not without issues. First, it is not authoritative and serves only as a guide for individual Services and Agencies. This ultimately leads to duplication of effort or specific organizational-use cases. Second, the roadmap is sequenced, but not prioritized. The lack of prioritization fails to create the push necessary to help the most promising additive capabilities across the valley of death. Finally, the roadmap does not incorporate transition plans for the focus areas which help create the pull necessary for program offices to request additive technologies.

More importantly, the scale of DoD’s investment in the sector remains paltry at best. At the Office of the Secretary of Defense (OSD) level, the FY19 R&D budget request for the Defense-Wide Manufacturing Science and Technology Program and the ManTech program are only \$114 million and \$49 million respectively.⁸⁵ In fact, the total FY19 advanced manufacturing budget request of \$163 million is much less than one percent of the overall R&D budget request and is not significant enough to help the individual Services to accelerate the adoption of additive. But even without additional funding, the DoD can play an effective and important role in shaping the manufacturing sector’s movement towards more advanced production techniques. Using its ability to set standards, certify different parts, and educate tomorrow’s leaders, DoD can do more than any other agency to position the country’s industrial base for success in the 21st century.

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An Open Innovation Strategy

A better approach to advanced manufacturing – and one far more catalytic to U.S. competitiveness – would be to focus on capabilities in DoD acquisition programs, rather than the

types of production. An open innovation strategy would ensure DoD's investments provide demand for breakthrough technologies by allowing private firms, contractors, research labs, universities, and others to invent the technologies of the future knowing they will be purchased once commercialized. This would engage all elements of the "triple helix" to support and sponsor innovation, breakthrough technologies, and the adoption of advanced manufacturing across industry. DoD must go from demanding exactly what product it wants and instead describe the capability it wishes to purchase. Simply put, if machine learning, big data, and additive can produce a capability cheaper, more efficiently, or more lethally, it is a net-positive for the country and should not be hamstrung by old requirements or the bureaucracy of acquisitions.

Establish a DoD Advanced Manufacturing Lead with Acquisition Authority

DoD should increase the percentage of resources dedicated to research, development, demonstration, and deployment across a range of advanced manufacturing technologies. The lack of a clear focal point for advanced manufacturing technology is one of the principal challenges preventing widespread adoption of advanced manufacturing. The DoD Agencies (e.g., Defense Logistics Agency, Missile Defense Agency, DARPA), the individual Service components, and the various DoD laboratories have largely invested in advanced manufacturing technologies that meet their own individual organizational needs without synchronization across the enterprise.

Previous calls to establish a DoD focal point have fallen short of the authority and responsibility needed to mainstream advanced manufacturing. A lead would establish a single focal point with the acquisition authority to evaluate advanced manufacturing technology readiness and work with milestone decision authorities, service acquisition executives, program executive officers, program managers, and product support managers to establish transition insertion plans into major weapon systems and logistical supply chains. The DoD advanced manufacturing lead should also have a small staff to track and evaluate activities with the goal of synergizing the most productive activities within DoD. This office would also need the authority to train service members on how to utilize advanced manufacturing technologies in the field. For example, an Advanced Manufacturing lead, organizationally under the DoD's newly aligned Under Secretary for Research and Engineering, could spur, marshal, and invest in advanced manufacturing technologies across programs, ensuring the Services the technology they require while also spurring innovation within DoD's supplier base.

Certify Processes and Printers – Not Parts

Given DoD's large budget, it uniquely possesses the ability to set industry standards necessary for the commercial sector to fully engage in this rapidly evolving technology. DoD should establish an office under the advanced manufacturing lead to certify printers, procedures, and materials it deems safe for the military's use. This would ensure DoD receives parts that meet its standards and could create an industry standard that would drive more widespread adoption of advanced manufacturing technologies. For additively-generated aviation, for example, the costs of certifying parts is not yet established and will require significant investments if the Services and/or the FAA disagree. In order to reduce this risk, the DoD should coordinate across the major certification bodies (e.g., NASA, FAA, NIST, DoD, USAF, USN, USA) and develop common standards and certification processes.

Create a Repository for Designs

A single DoD repository, created and managed by Defense Information Systems Agency, for design files of component parts – to include legacy systems – is a significant issue impacting not just parts today, but DoD’s ability to produce substitute parts for its warfighters in the future. Additive manufacturing allows for the reproduction of no-longer-made parts. DoD already requires program managers to understand the government’s rights to IP and data rights for acquisition programs. Depending on the program, the government can acquire unrestricted, limited, restricted, and specifically-negotiated data rights. Acquisition programs should pursue unrestricted data rights for part production to allow for the production of these parts via advanced manufacturing options existing today and in the future.

New systems should have design file requirements as part of their technical data package deliverable; and each part of older, already deployed technologies should be scanned and cataloged. The latter of which is important since so many products currently used in DoD machines are no longer manufactured.

Use Defense Production Act Authority to Build Capacity within Current DIB

Title 3 of the Defense Production Act (DPA), allows the President to grant loans to industry “for the expansion of productive capacity and supply.”⁸⁶ Through this title, the government can grant loans to companies for work on specific projects while allowing the companies to use the experience and equipment to compete commercially. For example, in Knoxville, Tennessee, a small start-up company was contracted to design rocket parts for the Air Force. By using DPA, the Air Force enabled the start-up to purchase an additive printer and the company is now supplying component parts to industry, learning the skills needed to compete in today’s market, and maintaining productive potential should DoD require the use of its machine in the future.

DPA could be used to fund the deployment of additive printers across industries that could be quickly used by the United States should it need to surge the production of war materiel in a time of mobilization.

Deploy Experimental 3D printers in the Field

Supply chains are long and any anti-access/area denial scenario limits the United States’ ability to stockpile parts in theater. Certain types of additive manufacturing can serve as solutions to the logistical problems associated with the tyranny of distance. The military can play an important role in proving that advanced manufacturing, particularly additive processes, can work in complicated and challenging environments. For example, Marines in the Pacific theater recently 3D printed a part for a Joint Strike Fighter.⁸⁷ For this reason – in addition to potential combat benefits – OSD should initiate programs to deploy prototypes with small expeditionary units.

Already, the Army’s Rapid Equipping Force has deployed “Fablabs” to Afghanistan equipped with “3D printers, laser cutters, milling machines and other equipment.”⁸⁸ In these self-contained and containerized facilities, the Fablabs provide “military commanders and warfighters agility in engineering specific rapid solutions to their problems in the field. As the environment or battle evolves, so can their equipment.”⁸⁹

Similarly, the Navy provides a far-forward platform for production without requiring host nation support to forward base this capability. Binder and direct binding printing methods present unique advantages for deployed forces. They could be mounted inside Factory in a Box structures, CONEX boxes, or installed in useable industrial space aboard ships, either in the existing workshop spaces or in hangar spaces with the appropriate support infrastructure.

If accepted for testing, Naval Sea Systems Command would need to design appropriate mounting hardware and set prescribed pitch and roll limits so as to not adversely impact any print in progress. More work is also required to find less caustic binder material so as to reduce the hazardous materials requirements.

To prove the concept, test units should be installed on large deck amphibious ships for proof of concept. If results merit additional investment, all aircraft carriers, cruisers, and destroyers could receive similar test equipment. It is not recommended to ships smaller than destroyers.

Critically Evaluate New Materials for Military Platforms

DoD should increase research activities, in partnership with universities, focused on utilization of advanced manufacturing technologies for weapon system development and sustainment. As an example, IACMI is developing new applications for carbon fiber. Piping systems made of carbon fiber can now be created in any size or shape, resist corrosion, can handle flammable fluids such as fuel or lube oil, and in fact, are being introduced into the energy sector for lightweight piping systems. The Department of the Navy should consider evaluating replacing existing copper-nickel or steel piping systems on surface combatants with carbon fiber piping systems. They can easily be retrofitted at the flanges and use existing valves. The reduction in weight would make the ship more fuel efficient and reduce corrosion, risks of leaks, and costly repairs.

It is also recommended that national laboratories and the Manufacturing USA Institutes present current projects to members of Defense Innovation Unit Experimental and other service think tanks annually to keep DoD leaders abreast of the latest technological innovations.

Create a “Demand” Strategy for Advanced Manufacturing in DoD

Today, program managers are not incentivized to take on the risk of large scale advanced manufacturing products in weapon systems. A “Demand” Strategy would help align “incentives to motivate program managers to review advanced manufacturing technology options that improve performance and reduce cost.” The willingness of DoD’s program managers to seek out new technologies would likely motivate technologists to develop, innovate, and de-risk emerging technologies.⁹⁰ For example, additional funding available under separate contract-line items (CLIN) for pre-planned product improvements that utilize a certain percentage of additive printed parts could incentive program managers to pull advanced manufacturing technologies across the “valley of death.” In fact, the separate CLIN structure could segregate out additive costs from the primary program of record while allowing program managers and product support managers to build on-ramps for advanced manufacturing technology insertion.

Given the new structure within DoD research and engineering, program offices within the Assistant Secretary for Defense (ASD) for Research and Technology and the ASD for Advanced Capabilities have the unique opportunity to target policies and projects to address the initial

R&D levels (TRL 1-3) and intermediate levels (TRL 4-7). Although these ASDs do not have the ability to allocate funds, they can create policies and coordinate with program managers, research labs, and other partners to create the demand necessary to incentivize companies and corporations to pursue solutions within advanced manufacturing.

Another recommendation to create demand from program offices is to adopt a “parts criticality model.” Low-end applications such as additive printed tooling and fixtures can be given the lowest criticality rating (I) and high-end applications such as flight critical parts can be given the highest criticality rating (IV). DoD should establish targets and incentives at the program executive officer level for adoption of additive printed parts ranging from Criticality Level I-IV. Goals should be higher for Level I parts compared to Level IV parts, and incentives (i.e., additional funding, delegated decision authority) can be provided to Program Executive Officers who look across their portfolios and help drive investments and acquisition decisions to on-ramp additive printed parts. All of these initiatives lead to the pursuit of the Secretary of Defense’s goals of to “help DoD achieve global technology dominance by 2028” as described in the recently published National Defense Strategy.⁹¹

Appendix 2

Recommendations by Agency

Department of Defense

Establish an Advanced Manufacturing Lead under the Under Secretary of Defense for Research and Engineering to develop and execute DoD's advanced manufacturing strategy. This lead would determine milestone decisions and work directly with acquisition executives, program executive officers, program managers, and product support managers to transition advanced manufacturing technologies into major weapon systems development and sustainment.

- The Advanced Manufacturing Lead should evaluate and recommend opportunities to utilize DPA authority to build advanced manufacturing capacity within the DIB.
- The Advanced Manufacturing Lead should establish a working group with the service commands and leadership organizations (Defense Standardization Program Office, DLA, Materiel Commands, and Civil Agencies) to create guidelines to certify printers, procedures, and materials it deems safe for DoD use.

Expand the Defense Information Systems Agency's focus on systems engineering, technology, and innovation to include work flow development and repository for design files to support advanced manufacturing methods.

OSD should establish programs within the Army's Rapid Equipping Force and related organizations within other services to deploy 3D printers in the field to accelerate adoption and capability development.

The Service research labs (ARL, AFRL, and ONR) should increase research activities, in partnership with universities, focused on utilization of advanced manufacturing technologies for weapon system development and sustainment.

The Services should sponsor additional graduate level research in advanced manufacturing technologies, particularly additive processes and products.

Department of Commerce

Maintain the Advanced Manufacturing Program Office to oversee and promote Manufacturing USA. The office must create a mechanism to assess their effectiveness and potential to aid industry.

Consider combining ineffective or underperforming institutes or moving them to more viable locations based on anchor institutions and appropriate private and public organizations to maximize impact.

The Advanced Manufacturing Program Office should create a Strategic Plan for Manufacturing and Advanced Manufacturing with milestones and incentives to promote and achieve future U.S. dominance in this area.

NIST should increase funding to the Measurement Science for Additive Manufacturing Program and expedite national standards for advanced manufacturing processes and systems. The U.S. Patent and Trademark Office (USPTO) should streamline procedures for businesses and entrepreneurs to patent their ideas and ensure the process is prohibitive due to time or cost. Reassess the rationale of “first to file” versus “first to show production capability” in the additive manufacturing realms.

The Economic Development Administration should establish and fund a guaranteed loan program to provide capital for manufacturers to update their facilities with the newer, more advanced manufacturing technologies.

USPTO should determine an updated and timely IP rights process for additive and other advanced manufacturing technologies. This is especially important in this area due to the computer programs and files used in Industry 4.0, the Internet of Things, and code for additive machines are vulnerable to cyber-attacks.

Work with global partners to develop a mechanism to identify IP rights violators and hold them accountable for their actions.

Department of Labor

The Employment and Training Administration should enhance Reemployment Services and Eligibility Assessments, Dislocated Worker Employment and Training Activities, Job Corp, and Apprenticeships work-force training programs to address nearly 2 million projected unfilled manufacturing jobs in 2025 due to inadequate skills.

- The office should target a 100 percent increase in the amount of apprenticeships to 1 million by 2025 with at least 10 percent participation in manufacturing.

Department of Education

Increase STEM education funding for K-12 schools. \$200 million for STEM education in FY19 is inefficient. The FY19 PB requests a decrease in the education budget by \$8B or 12 percent.⁹² Reduce the budget cut by only 10 percent and use the increase funds directly to STEM education through the Office of Innovation and Improvement.

Establish a grant program to enhance salaries for teachers in STEM to increase the amount of qualified STEM teachers in K-12 education.

Work with Department of Labor and the Task Force on Apprenticeship Expansion to incentivize Vocational, Technical schools, Community Colleges, and Industry to create advanced manufacturing programs while expanding apprenticeship education.

Department of State

Create exemption criteria for foreign graduates with exceptional abilities whose employment will be in the national interest. This is a way for the brightest minds from foreign countries to remain in the United States and continue to contribute to the areas of additive manufacturing.

U.S. Congress

Modernize of the Bayh-Dole Act to better ensure technology development funded in part by U.S. taxpayers is produced in the United States.

Update the tax code to facilitate investments in advanced manufacturing equipment, research and development, and employee training.

Department of Energy

Increase investments in additive manufacturing research and development to lowering the cost of producing these additive manufacturing raw materials.

Notes

¹ This report is the synthesis of papers submitted by individual seminar members: Nawaf Alajmi, “Innovation issues -- how can we ensure the sector is as innovative as possible, but also able to meet the near-term needs of the DOD?” Eisenhower Individual Industry Study Paper, National Defense University, 2018; Barbara Bartsch-Allen, “European Approaches to Intellectual Property and Cyber-Security Protections in Advanced Manufacturing” Eisenhower Individual Industry Study Paper, National Defense University, 2018; Eduardo Bitanga, “Applying Additive Manufacturing to Mobilization of the Defense Industrial Base” Eisenhower Individual Industry Study Paper, National Defense University, 2018; Laura Calese, “Ecosystems and Empires: National Initiatives for Additive Manufacturing” Eisenhower Individual Industry Study Paper, National Defense University, 2018; Matthew Fandre, “The Perils of Promise and the Opportunity for Revolutionary Resurgence” Eisenhower Individual Industry Study Paper, National Defense University, 2018; Kelly Freshour, “Additive Manufacturing and the Defense Industrial Base” Eisenhower Individual Industry Study Paper, National Defense University, 2018; Matthew Holston, “Accelerating Adoption of Additive Manufacturing within the Department of Defense” Eisenhower Individual Industry Study Paper, National Defense University, 2018; Jose Ilarazza Rivera, “Industry Study: Individual Paper” Eisenhower Individual Industry Study Paper, National Defense University, 2018; Gregory Kimmel, “Industry Study: Individual Paper” Eisenhower Individual Industry Study Paper, National Defense University, 2018; Anthony Littmann, “The Factory of the Future” Eisenhower Individual Industry Study Paper, National Defense University, 2018; Samuel Meyer, “The Triple Helix and Advanced Manufacturing” Eisenhower Individual Industry Study Paper, National Defense University, 2018; Ryan Mulholland, “Power and Production: Establishing the Link Between Manufacturing Prowess and Global Influence” Eisenhower Individual Industry Study Paper, National Defense University, 2018; Erin Pacific, “Intellectual Property, Cyber Security, and Advanced Manufacturing in China and Singapore Case Studies” Eisenhower Individual Industry Study Paper, National Defense University, 2018; Ed Quick, “Intellectual Property and Cyber Challenges in Advanced Manufacturing” Eisenhower Individual Industry Study Paper, National Defense University, 2018; Mark VanBrunt, “Manufacturing Workforce Transition from Blue Collar to New Collar” Eisenhower Individual Industry Study Paper, National Defense University, 2018; Sasa Veselinovic, “Economic Factors of the U.S. Advanced Manufacturing Innovation and Long-Term Competitiveness” Eisenhower Individual Industry Study Paper, National Defense University, 2018.

Attributable material from sources that contributed to each individual contribution is noted throughout this group product; because the IS format involves personal interaction with industry and international officials, often with non-disclosure agreements (NDAs), contact with the individual author is recommended for further attribution clarifications.

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