3D Printing Changes U.S. Government Operations and Procurement

Michael Erbschloe

3D Printing Changes U.S. Government Operations and Procurement

Edited by

Michael Erbschloe

Connect with Michael on LinkedIn

Table of Contents

About the Editor

Michael Erbschloe has worked for over 30 years performing analysis of the economics of information technology, public policy relating to technology, and utilizing technology in reengineering organization processes. He has authored several books on social and management issues of information technology that were published by McGraw Hill and other major publishers. He has also taught at several universities and developed technology-related curriculum. His career has focused on several interrelated areas:

- Technology strategy, analysis, and forecasting
- Teaching and curriculum development
- Writing books and articles
- Publishing and editing
- Public policy analysis and program evaluation

Books by Michael Erbschloe

Social Media Warfare: Equal Weapons for All (Auerbach Publications)

Walling Out the Insiders: Controlling Access to Improve Organizational Security (Auerbach Publications)

Physical Security for IT (Elsevier Science)

Trojans, Worms, and Spyware (Butterworth-Heinemann)

Implementing Homeland Security in Enterprise IT (Digital Press)

Guide to Disaster Recovery (Course Technology)

Socially Responsible IT Management (Digital Press)

Information Warfare: How to Survive Cyber Attacks (McGraw Hill)

The Executive's Guide to Privacy Management (McGraw Hill)

Net Privacy: A Guide to Developing & Implementing an e-business Privacy Plan (McGraw Hill)

Introduction

Additive manufacturing—also known as three-dimensional (3D) printing—has the potential to fundamentally change the production and distribution of goods. Unlike conventional or subtractive manufacturing processes, such as drilling, which create a part by cutting away material, additive manufacturing builds a part using a layer-by-layer process. Additive manufacturing has been used as a design and prototyping tool, but the focus of additive manufacturing is now shifting to the direct production of functional parts—parts that accomplish one or more functions, such as medical implants or aircraft engine parts—that are ready for distribution and sale.

Support from federal agencies, such as the National Science Foundation (NSF) and the Department of Defense (DOD), was instrumental in the early research and development into additive manufacturing. According to the Science and Technology Policy Institute, since 1986 when it first began funding additive manufacturing, NSF has expended more than $200 million on additive manufacturing research and related activities.

Now, several federal agencies are involved with the research and development of additive manufacturing, including NSF, the National Aeronautics and Space Administration (NASA), NIST, DOD, and the Department of Energy. Within DOD, several research organizations are involved, including the research laboratories of the Army, Navy, and Air Force and the Defense Advanced Research Projects Agency (DARPA).

These federal agencies support research at federal laboratories, academic institutions, and small and large companies, sponsor technical conferences, and participate in standards development. To help guide research and development efforts, federal research and development agencies have supported the development of several technology roadmaps. Further, in August 2012, the National Additive Manufacturing Innovation Institute, also known as America Makes, was founded as a public-private partnership to accelerate the research, development, and demonstration of additive manufacturing and transition technology to the manufacturing industry in the United States. Its federal partners include the Departments of Commerce, Defense, Education, and Energy, NASA, and NSF. America Makes is part of a broader National Network for Manufacturing Innovation that is designed to stimulate advanced manufacturing technologies and accelerate their commercialization in the United States. The interagency Advanced Manufacturing National Program Office manages the network and includes participation from all federal agencies involved in U.S. manufacturing. It is designed to enable more effective collaboration in identifying and addressing manufacturing challenges and opportunities that span technology areas and cut across agency missions.

On October 15-16, 2014, the U.S. General Accountability Office (GAO), with the assistance of the National Academies, convened a forum to discuss the use of additive manufacturing to directly produce functional parts, including its opportunities, (2) key challenges, and (3) key considerations for any policy actions that could affect its future use. Forum participants included officials from government, business, academia, and nongovernmental organizations that were selected to represent a range of viewpoints and backgrounds.

Forum participants identified many opportunities for using additive manufacturing to produce functional parts and discussed benefits that have been realized in the medical, aerospace, and defense sectors. For example, they said that the medical industry is using additive manufacturing to produce customized prosthetics and implants, including cranial implants. Because it is made specifically for a patient, the part results in a better fit, which leads to a better medical outcome. In the aerospace industry, participants said additive manufacturing was used to design and produce a complex jet engine fuel nozzle as a single part, which will reduce assembly time and costs for the engine. Participants identified some future applications of additive manufacturing including enhancing supply chain management. Overall, participants concluded that additive manufacturing will not replace conventional manufacturing, but rather it will be an additional tool for manufacturers to use when it is appropriate from a cost-benefit perspective.

Forum participants identified three broad groups of challenges in using additive manufacturing to produce functional parts: (1) ensuring product quality, (2) limited design tools and workforce skills, and (3) supporting increased production of functional parts. First, they identified challenges related to building quality parts, such as the need to improve the quality control of the additive manufacturing process. Second, they said that existing design and analytical tools combined with an insufficiently skilled workforce could limit the use of additive manufacturing and its ability to reach its potential for greater innovation. Finally, participants identified challenges that affect the increased production of functional parts, such as the need for an improved industrial infrastructure, including more robust supply chains of machines and materials.

Forum participants identified key considerations for potential federal policy actions that could affect the future use of additive manufacturing, including industry challenges, areas affected by additive manufacturing growth, and tradeoffs. Although there was no consensus on specific policy actions needed and many participants suggested caution on potential government action, participants discussed several areas of potential government involvement, such as coordinating standards setting, considering risks for infringement of intellectual property rights with regard to additive manufacturing products, and encouraging a national dialogue about the government's role and its goals.

Additive manufacturing is a layer-by-layer process of producing 3D objects directly from a digital model unlike conventional or subtractive manufacturing processes, such as drilling or milling, which create a part or product by cutting away material from a larger piece, additive manufacturing builds a finished piece in successive layers, generally without the use of molds, casts, or patterns, which can potentially lead to less waste material in the manufacturing process.

While the concepts have existed for decades, commercialization of additive manufacturing began in the mid-1980s and its first uses were primarily for presentation purposes. For more than 20 years, the technology has been evolving as a design and prototyping tool. Additive manufacturing offers the ability to rapidly create prototypes that can help validate the fit, form, and functionality of proposed products, which has provided both great time and cost savings in the product development cycle. As the technology has matured, the use of additive manufacturing has become more widespread and has expanded into more applications. For instance, one of the significant applications for additive manufacturing has been the production of tools and casts for conventional manufacturing. Lower manufacturing tool costs have allowed manufacturers to produce in lower volumes that previously may not have been cost-beneficial.

The use of additive manufacturing for prototyping and manufacturing tooling has helped to improve the efficiencies of conventional manufacturing processes, and the use of additive manufacturing is now shifting to the direct production of goods that are ready for distribution and sale. The emergence of desktop equipment for additive manufacturing has enabled the production of jewelry, art replicas, toys, models, and other artistic products. However, it is the potential to use additive manufacturing to produce functional parts and products, particularly in critical applications such as medicine and aerospace, that has generated a lot of attention

(Link: http://gao.gov/products/GAO-15-505SP)

How 3D Printers Work

Not many years ago, printing three-dimensional objects at home might have sounded like a thing out of *The Jetsons*. But in just a few short years, 3D printing has exploded -- shifting from a niche technology to a game-changing innovation that is capturing the imagination of major manufacturers and hobbyists alike.

3D printing has the potential to revolutionize manufacturing, allowing companies (and individuals) to design and produce products in new ways while also reducing material waste, saving energy and shortening the time needed to bring products to market.

What is 3D printing?

First invented in the 1980s by Chuck Hull, an engineer and physicist, 3D printing technology has come a long way. Also called additive manufacturing, 3D printing is the process of making an object by depositing material, one tiny layer at a time.

The basic idea behind additive manufacturing can be found in rock formations deep underground (dripping water deposits thin layers of minerals to form stalactites and stalagmites), but a more modern example is a common desktop printer. Just like an inkjet printer adds individual dots of ink to form an image, a 3D printer only adds material where it is needed based on a digital file.

In comparison, many conventional manufacturing processes -- which have recently been termed “subtractive manufacturing” -- require cutting away excess materials to make the desired part. The result: Subtractive manufacturing can waste up to 30 pounds of material for every 1 pound of useful material in some parts, according to a finding from the Energy Department’s Oak Ridge National Lab.

With some 3D printing processes, about 98 percent of the raw material is used in the finished part. Not to mention, 3D printing enables manufacturers to create new shapes and lighter parts that use less raw material and require fewer manufacturing steps. In turn, that can translate into lower energy use for 3D printing -- up to 50 percent less energy for certain processes compared to conventional manufacturing processes.

Though the possibilities for additive manufacturing are endless, today 3D printing is mostly used to build small, relatively costly components using plastics and metal powders. Yet, as the price of desktop 3D printers continues to drop, some innovators are experimenting with different materials like chocolate and other food items, wax, ceramics and biomaterial similar to human cells.

How does a 3D printer work?

Additive manufacturing technology comes in many shapes and sizes, but no matter the type of 3D printer or material you are using, the 3D printing process follows the same basic steps.

It starts with creating a 3D blueprint using computer-aided design (commonly called CAD) software. Creators are only limited by their imaginations. For example, 3D printers have been used to manufacture everything from robots and prosthetic limbs to custom shoes and musical instruments. Oak Ridge National Lab is even partnering with a company to create the first 3D printed car using a large-scale 3D printer, and America Makes -- the President's pilot manufacturing innovation institute that focuses on 3D printing -- recently announced it was providing funding for a new low-cost 3D metal printer.

Once the 3D blueprint is created, the printer needs to be prepared. This includes refilling the raw materials (such as plastics, metal powders or binding solutions) and preparing the build platform (in some instances, you might have to clean it or apply an adhesive to prevent movement and warping from the heat during the printing process).

Once you hit print, the machine takes over, automatically building the desired object. While printing processes vary depending on the type of 3D printing technology, material extrusion (which includes a number of different types of processes such as fused deposition modeling) is the most common process used in desktop 3D printers.

Material extrusion works like a glue gun. The printing material -- typically a plastic filament -- is heated until it liquefies and extruded through the print nozzle. Using information from the digital file -- the design is split into thin two-dimensional cross-sections so the printer knows exactly where to put material -- the nozzle deposits the polymer in thin layers, often 0.1 millimeter thick. The polymer solidifies quickly, bonding to the layer below before the build platform lowers and the print head adds another layer. Depending on the size and complexity of the object, the entire process can take anywhere from minutes to days.

After the printing is finished, every object requires a bit of post-processing. This can range from unsticking the object from the build platform to removing support structures (temporary material printed to support overhangs on the object) to brushing off excess powders.

Types of 3D printers

Over the years, the 3D printing industry has grown dramatically, creating new technologies (and a new language to describe the different additive manufacturing processes). To help simplify this language, ASTM International -- an international standards organization -- released standard terminology in 2012 that classified additive manufacturing technologies into seven broad categories. Below are quick summaries of the different types of 3D.

- **Material Jetting**: Just like a standard desktop printer, material jetting deposits material through an inkjet printer head. The process typically uses a plastic that requires light to harden it (called a photopolymer) but it can also print waxes and other materials. While material jetting can produce accurate parts and incorporate multiple materials through the use of additional inkjet printer nozzles, the machines are relatively expensive and build times can be slow.
- **Binder Jetting**: In binder jetting, a thin layer of powder (this can be anything from plastics or glass to metals or sand) is rolled across the build platform. Then the printer head sprays a binding solution (similar to a glue) to fuse the powder together only in the places specified in the digital file. The process repeats until the object is finished printing, and the excess powder that supported the object during the build is removed and saved for later use. Binder jetting can be used to create relatively large parts, but it can be expensive, especially for large systems.
- **Powder Bed Fusion**: Powder bed fusion is similar to binder jetting, except the layers of

powder are fused together (either melted or sintered -- a process that uses heat or pressure to form a solid mass of material without melting it) using a heat source, such as a laser or electron beam. While powder bed processes can produce high quality, strong polymer and solid metal parts, the raw material choices for this type of additive manufacturing are limited.

- **Directed Energy Deposition**: Directed energy deposition can come in many forms, but they all follow a basic process. Wire or powder material is deposited into thin layers and melted using a high-energy source, such as a laser. Directed energy deposition systems are commonly used to repair existing parts and build very large parts, but with this technology, these parts often require more extensive post processing.
- **Sheet Lamination**: Sheet lamination systems bond thin sheets of material (typically paper or metals) together using adhesives, low-temperature heat sources or other forms of energy to produce a 3D object. Sheet lamination systems allow manufacturers to print with materials that are sensitive to heat, such as paper and electronics, and they offer the lowest material costs of any additive process. But the process can be slightly less accurate than some other types of additive manufacturing systems.
- **Vat Photopolymerization**: Photopolymerization -- the oldest type of 3D printer -- uses a liquid resin that is cured using special lights to create a 3D object. Depending on the type of printer, it either uses a laser or a projector to trigger a chemical reaction and harden thin layers of the resin. These processes can build very accurate parts with fine detail, but the material choices are limited and the machines can be expensive.

Creating a country of Makers

While 3D printing isn't new, recent advancements in the technology (along with the rise in popularity of sites like Esty and Kickstarter) have sparked a creative manufacturing renaissance -- where anyone with access to a printer is a manufacturer and product customization is nearly unlimited.

3D printers and other manufacturing technologies are turning consumers into creators -- or makers of things. This movement, often called the Maker Movement, is helping spur innovation and creating a whole new way of doing business. Products no longer have to be mass manufactured -- they can be made in small batches, printed on the spot or customized for an individual's unique needs.

This new way of thinking is also trickling down into the classroom through access to 3D printers. Students aren't limited to imagining cool, new ideas -- they can make them a reality, and it's inspiring them to go into STEM (science, technology, engineering and math) fields. To educate students about additive manufacturing and the potential it holds, the Energy Department, Oak Ridge National Lab and America Makes donated almost 450 3D printers to teams competing in the FIRST Robotics competition this year.

The rise of the Maker Movement -- embraced by both the young and old -- represents a huge opportunity for the United States. It can create a foundation for new products and processes that can help revitalize American manufacturing. To celebrate this potential, President Obama hosted the first White House Maker Faire -- allowing innovators and entrepreneurs of all ages to show what they've made and share what they've learned.

The future of 3D printing

Additive manufacturing isn't just impacting the Maker Movement, it's also changing the way companies and federal agencies do business.

Companies are turning to additive manufacturing to build parts that weren't possible before -- an example that many point to is GE's use of 3D printers to create fuel nozzles for a new jet engine that are stronger and lighter than conventional parts -- and federal agencies are exploring ways to use the technology to better meet their missions. The U.S. Department of Health and Human Services created the NIH 3D Print Exchange to better share biomedical 3D-printable models across the medical community while NASA is exploring how 3D printing works in space.

Yet, this is just the tip of the iceberg when it comes to additive manufacturing's potential. For manufacturers, additive manufacturing will enable a wide range of new product designs that can increase industry competitiveness, lower industry energy consumption and help grow the clean energy economy.

From helping fund America Makes, a public-private partnership designed to make the U.S. the leader in 3D printing, to establishing the Manufacturing Demonstration Facility at Oak Ridge Lab, the Energy Department is providing companies with access to 3D printing technologies and educating them -- and future engineers -- about the technology's possibilities. To ensure the technology moves forward, the Department's National Labs are partnering with industry to create new 3D printing technology. Lawrence Livermore National Lab recently announced a collaboration to develop new 3D printing materials, hardware and software, and Oak Ridge National Lab is partnering to develop a new commercial additive manufacturing system that is 200 to 500 times faster and could print plastic components 10 times larger than today's commercial 3D printers.

As the prices drop and the technology becomes faster and more precise, 3D printing is poised to change the way companies and consumers think about manufacturing -- much in the same way the first computers led to the rapid access to knowledge that we now take for granted.

(Link: https://energy.gov/articles/how-3d-printers-work)

Digital manufacturing paves the way for innovation, mass customization, and greater energy efficiency as part of the national all-of-the-above energy strategy. sAdditive manufacturing techniques create 3-D objects directly from a computer model, depositing material only where required. These new techniques, while still evolving, are projected to exert a profound impact on manufacturing. They can give industry new design flexibility, reduce energy use, and shorten time to market. The process is often called 3-D printing or digital manufacturing because of similarities to standard desktop printing.

Interest in additive techniques has grown swiftly as applications have progressed from rapid prototyping to the production of end-use products. Additive equipment can now use metals, polymers, composites, or other powders to “print” a range of functional components, layer by layer, including complex structures that cannot be manufactured by other means.

The ability to modify a design online and immediately create the item—without wasteful casting or drilling—makes additive manufacturing an economical way to create single items, small batches, and, potentially, mass-produced items. The sector-wide ramifications of this capability have captured the imaginations of investors.

Revolutionary Speed, Efficiency, Optimization

Additive manufacturing has the potential to vastly accelerate innovation, compress supply chains, minimize materials and energy usage, and reduce waste.

Lower energy intensity: These techniques save energy by eliminating production steps, using substantially less material, enabling reuse of by-products, and producing lighter products. Remanufacturing parts through advanced additive manufacturing and surface treatment processes can also return end-of-life products to as-new condition, using only 2−25% of the energy required to make new parts.

- *Less waste:* Building objects up layer by layer, instead of traditional machining processes that cut away material can reduce material needs and costs by up to 90%.
- *Reduced time to market:* Items can be fabricated as soon as the 3-D digital description of the part has been created, eliminating the need for expensive and time-consuming part tooling and prototype fabrication.
- *Innovation:* Additive manufacturing eliminates traditional manufacturing-process design restrictions. It makes it possible to create items previously considered too intricate and greatly accelerates final product design. Multi-functionality can also be embedded in printed materials, including variable stiffness, conductivity, and more. The ability to improve performance and functionality—literally customizing products to meet individual customer needs—will open new markets and could improve profitability.
- *Agility:* Additive techniques enable rapid response to markets and create new production options outside of factories, such as mobile units that can be placed near the source of local materials. Spare parts can be produced on demand, reducing or eliminating the need for stockpiles and complex supply chains.

Applications

Industry is taking advantage of additive manufacturing to produce plastic, metal, or composite parts and custom products without the cost, time, tooling, and overhead required in the traditional machining or manufacturing processes. This technology is particularly advantageous in low-to-moderate volume markets (defense and aerospace) that regularly operate without economies of scale.

Today, additive manufacturing is reducing the aerospace industry's important materials measure, the "buy-to-fly" ratio—pounds of material needed to make one pound of aerospace-quality material—by more than half. For example, engineers are taking advantage of additive manufacturing to simultaneously reduce material requirements and easily create engine parts with complex internal structures. Jet ducts in Boeing F-18 fighters can be made with smoothly curving channels that allow more efficient air and fluid flow than those created with the difficult traditional method of boring through solid structures.

Many military applications also often require miniaturized, custom-designed units in relatively small numbers. Additive manufacturing also supports rapid development and production to meet the military's specialized functional requirements.

For the automotive industry, additive manufacturing holds great promise. Vehicle bodies and engines could be made using fewer parts and rapidly redesigned to minimize failures. The traditional assembly line could even become a thing of the past for some industries.

The healthcare industry is investing in tailored prosthetics, dental implants, hearing aids, and other types of medical devices and tools. Manufacturers of many consumer products may soon be using additive techniques in their production processes to embed electronic components and circuits in substrates, reduce device weight and volume, and improve electrical performance.

Challenges

While some manufacturers have been using additive manufacturing to make prototypes, improved additive processes are gaining acceptance in some markets. To achieve a wider range of applications, research will need to overcome some key challenges, including the following:

- *Process control:* Feedback control systems and metrics are needed to improve the precision and reliability of the manufacturing process and to increase throughput while maintaining consistent quality.
- *Tolerances:* Some potential applications would require micron-scale accuracy in printing.
- *Finish:* The surface finishes of products manufactured using additive technology require further refinement. With improved geometric accuracy, finishes may impart corrosion and wear resistance or unique sets of desired properties.
- *Validation and demonstration:* Manufacturers, standards organizations, and others maintain high standards for critical structural materials, such as those used in aerospace applications. Providing a high level of confidence in the structural integrity of components built with additive technology may require extensive testing, demonstration, and data collection.

The full potential of additive manufacturing will be realized when the technology is integrated into broad manufacturing solutions. In applications where additive manufacturing is competitive, 50% or more energy savings can be realized. Companies that explore the potential of these game-changing techniques and introduce novel products can earn a competitive edge in global markets.

(Link: https://energy.gov/sites/prod/files/2013/12/f5/additive_manufacturing.pdf)

3D Printing of Medical Devices

3D printing is a type of additive manufacturing. There are several types of additive manufacturing, but the terms 3D printing and additive manufacturing are often used interchangeably. Here we will refer to both as 3D printing for simplicity.

3D printing is a process that creates a three-dimensional object by building successive layers of raw material. Each new layer is attached to the previous one until the object is complete. Objects are produced from a digital 3D file, such as a computer-aided design (CAD) drawing or a Magnetic Resonance Image (MRI).

The flexibility of 3D printing allows designers to make changes easily without the need to set up additional equipment or tools. It also enables manufacturers to create devices matched to a patient’s anatomy (patient-specific devices) or devices with very complex internal structures. These capabilities have sparked huge interest in 3D printing of medical devices and other products, including food, household items, and automotive parts.

Medical devices produced by 3D printing include orthopedic and cranial implants, surgical instruments, dental restorations such as crowns, and external prosthetics. Due to its versatility, 3D printing has medical applications in:

- Medical devices regulated by FDA's Center for Devices and Radiological Health (CDRH),
- Biologics regulated by FDA's Center for Biologics Evaluation and Research, and
- Drugs regulated by FDA's Center for Drug Evaluation and Research

(Link: http://www.fda.gov/MedicalDevices/ProductsandMedicalProcedures/3DPrintingofMedicalDevices/default.h

Oak Ridge National Laboratory produced the world's largest solid 3D-printed object.

When Boeing makes big airplanes, it needs special tools that you can't find in a hardware store. But ordering custom metal tools is expensive and takes months. That's where 3D-printing comes in.

Researchers at Oak Ridge National Lab developed a 3D-printed version of a "trim-and-drill" tool that Boeing uses to build the wings on its passenger aircraft. About the size of an SUV, the tool weighs 1,650 lbs and measures 17.5 feet long, 5.5 feet wide and 1.5 feet tall, making it the world's largest solid object made with a 3D printer. It took 30 hours to print using carbon fiber and composite plastic materials.

Using 3D-printing makes the final product cheaper and quicker to manufacture, and it works just as well as the conventional metal version. The tool promises to save energy, time and money once Boeing begins the production of its 777X passenger jet in St. Louis starting in 2017.

Advanced manufacturing is transforming the way we make everything, and Oak Ridge is pushing the frontier. At the lab's Manufacturing Demonstration Facility, the goal is to show off the potential for new methods like 3D-printing and new materials like advanced composites. In addition to the tool for Boeing, this facility 3D-printed a Shelby Cobra sports car, a house/car energy system and an Army Jeep. And they're also experimenting with 3D-printed molds for wind turbine blades, which would drastically cut down manufacturing time for turbine blades and make it easier to test out new designs.

Why is the Energy Department investing in manufacturing technologies? Building lighter products in less time offers huge energy savings. And when it's quicker and cheaper to build things, the pace of innovation accelerates as well. That combination is great news for our clean energy future.

(Link: https://www.energy.gov/articles/world-s-largest-3d-printed-object)

3D Printed Shelby Cobra

Next-generation manufacturing takes on a 50 year old icon as ORNL researchers transform this classic sports car into a 3D- printed laboratory on wheels. Additive manufacturing enables the seamless integration of advanced technologies with design flexibility and modularity while providing a platform for rapid development and evaluation. The printed car incorporates "plug and play" components such as new engine, battery, and fuel cell technologies; hybrid system designs; and power electronics and wireless charging systems, allowing researchers to easily and quickly test out innovative ideas in a driving laboratory.

(Link: http://web.ornl.gov/sci/manufacturing/shelby/)

Wind Turbine Manufacturing Transforms with Three-Dimensional Printing

Research that supports the Energy Department's Atmosphere to Electrons (A2e) initiative is applying 3-D-printing processes to create wind turbine blade molds. Oak Ridge National Laboratory has developed the Big Area Additive Manufacturing machine, which is being used to apply 3-D printing processes to manufacture wind turbine components for use in Energy Department research. The groundbreaking tool is capable of printing objects that are 10 times larger at speeds up to 1,000 times faster than today's industrial additive machines.

This research promises to reduce the cost of blade manufacturing and wind energy overall, as blades represent one of the most expensive components of a wind turbine. The processes currently used to manufacture utility-scale wind turbine blades—which can average over 150 feet in length—are complex, energy-intensive, and time-consuming. Trends toward larger blades, coupled with the drive for global competitiveness, inspired the Energy Department's Wind Program and the Advanced Manufacturing Office to explore new manufacturing technologies.

As part of an effort to expand the throughput and size of the additive manufacturing process, Oak Ridge National Laboratory partnered with Cincinnati Incorporated to develop the Big Area Additive Manufacturing (BAAM) machine. BAAM created a 3-D-printed replica Shelby Cobra automobile, which was displayed at the Energy Department's Washington, D.C., headquarters and showcased in Paris at the United Nations Framework Convention on Climate Change and the JEC World Conference. BAAM is capable of printing a staggering 100 pounds of polymer materials per hour, which is 500 to 1,000 times faster than conventional 3-D printers. Moreover, BAAM can print components that are 10 times larger (20 feet long, 8 feet wide, and 6 feet tall) than today's industrial additive machines.

The technology is also scalable, making the manufacture of other large components a future possibility. For now, the Energy Department will take advantage of the availability of BAAM to evaluate whether it can simplify the manufacture of turbine blade molds. Currently, a "plug" must be manufactured and then used to form a mold out of which fiberglass blades can be constructed. Eliminating the plug by applying 3-D printing directly to the mold process will reduce the costs and amount of time required for blade manufacture.

In this demonstration project, the Energy Department will partner with Oak Ridge, Sandia National Laboratories, NREL, and TPI Composites Incorporated to use 3-D printing in the manufacture of a mold for special scaled-down turbine blades designed to simulate the aerodynamic characteristics of a full-size turbine. These research blades will measure 13 meters (approximately 43 feet) in length and undergo static and fatigue testing at NREL. The blades will then be operated using wind turbines at the Energy Department's Scaled Wind Farm Technology (SWiFT) facility in Texas. This effort will help researchers study wake aerodynamics—that is, the effects that turbines in close proximity to one another can have on productivity. This research will be used to understand and enhance the efficiency of a complete wind plant, comprised of numerous wind turbines.

Three-dimensional printing is just one way the Energy Department is leading the United States toward a clean energy future and increasing our nation's competitiveness through research into new, more efficient technologies.

(Link: https://www.energy.gov/eere/wind/articles/wind-turbine-manufacturing-transforms-three-dimensional-printing)

The Potential Impact of 3D Printing on Postal Operators

3D printing is changing the world in ways that demand the attention of postal operators and anyone else who works in or adjacent to the logistics industry. In July 2014, the U.S. Postal Service Office of Inspector General issued a white paper detailing how widespread adoption of 3D printing could lead to a major increase in commercial package shipments for the U.S. Postal Service. However, recent research has shown that 3D printing's impact on the Postal Service goes well beyond just more packages shipped, as it promises to reshape today's supply chains and transform entire industries.

It appears that mainstream in-home 3D printing could still be a decade away. However, recent research also suggests that business adoption of 3D printing is having far greater impact on the global economy than previously imagined. Improvements in evolving 3D printing technology have accelerated its adoption in critical industries, across both new sectors and those that have been using 3D printing for years to revolutionize their processes. In addition, many retailers have entered the 3D printing market, which speaks to increasing demand. Consumers can now buy finished 3D printed goods from multiple providers and have them delivered without needing to purchase their own printer.

Experts say that the largest disruptions from 3D printing will fall on the logistics industry, which is very important to the Postal Service. In fact, 3D printing could disrupt more than a third of global air cargo or ocean container shipments, as well as a quarter of the freight trucking business. This would fuel a shift in shipping demand from long-distance transportation to last-mile delivery, with products printed locally instead of requiring assembly from parts coming from all corners of the world. These changes could catalyze the trend toward reshoring American manufacturing jobs that went overseas decades ago. In addition, warehouses will convert to digital inventories with on-demand printing, resulting in much less need for thousands of spare parts that might sit on shelves for years. On top of that, small retail spaces will convert to showrooms for products that can be fully customized for each consumer.

Simply put, 3D printing will fundamentally change where and when products will be produced, stored, and ultimately delivered. Supply chains will collapse in distance and time as manufacturing is performed as quickly and as close to the point of consumption as possible. More consumers may come to expect same-day delivery, possibly even early morning and late evening delivery. There will be heightened activity in the last mile from localized production, so speed on that final track will be essential. In such an environment, the location and size of delivery base stations will also be critical.

Other organizations involved in logistics and delivery are taking note of 3D printing's possibilities and the vast changes it will bring about. For example, UPS recently partnered with the company CloudDDM to open a 3D printing mini-factory at its World Port facility in Louisville, KY. The facility has 100 industrial printers running day and night to produce high-quality parts for corporate customers. UPS also offers 3D printing services inside many of its retail locations, geared toward supporting local businesses. In addition, a growing number of foreign posts are exploring the potential of 3D printing and related technologies. France's La

Poste, for example, offers a range of services, including 3D printers inside post offices, 3D printed jewelry based on children's artwork, and fully customized packaging cut to the exact shape of delicate objects to offer protection during shipping. Additionally, the U.S. government is diving into 3D printing across a wide range of agencies, including NASA, the Department of Defense, and the National Institutes of Health.

Because 3D printing technology is fundamentally changing the logistics industry, now is the time for the Postal Service to associate itself with 3D printing in the minds of the public. The Postal Service should observe, learn, and examine the potential of 3D printing to the extent allowable under its existing authority. The examples of La Poste, UPS, and others show that there may be demand for printing services inside post offices. The Postal Service also could partner with 3D printing companies, provide 3D printing materials and support services for local small businesses, or serve as a community maker space. In addition, it could establish a reverse logistics service to handle recycling and processing of 3D printed goods, so that materials can be reused for future printing.

Waiting for a full-blown consumer 3D printing revolution could mean missing the multitude of ways that businesses are already embracing the technology and changing the world. Thanks to 3D printing, the supply chains of the future will little resemble the world we know today. Organizations might be ill equipped to work with tomorrow's supply chains without fully understanding the implications of 3D printing right now.

At a basic level, 3D printing takes digital representations of objects and creates them in physical form by building up multiple layers of plastics, metals, powders, liquid resins, and other materials. People often refer to 3D printing as additive manufacturing to contrast it with traditional "subtractive" manufacturing techniques, which involve cutting, milling, or otherwise removing material to create an object. A major part of 3D printing's appeal is that it allows for an unprecedented degree of rapid prototyping and mass customization.

While media coverage of 3D printing has often focused on cheap plastic 3D printed goods — such as smartphone cases, figurines with people's faces scanned onto them, and other customized knickknacks — some of the most important advances in 3D printing are taking place in business applications. Manufacturers have used it for decades to do rapid prototyping of new products. More recently, 3D printing has been employed for uses as varied as revolutionary prosthetic limbs, aircraft jet engine parts that weigh significantly less and have fewer components than previous parts, and even simple houses. In fact, 3D printing has already fundamentally changed some industries. For example, a recent *Harvard Business Review* article reported that it took only 500 days for all hearing aid manufacturers in the United States to make the switch to 3D printing-based fabrication.

Taken as a whole, 3D printing is transforming manufacturing and reconfiguring supply chains not only within the United States, but around the world. It is changing the way consumers get the products they need and shifting power to individuals with unique preferences. Postal operators and nearly every organization that works in shipping, delivery, or other aspects of logistics should keep a very close eye on it.

OIG Research on 3D Printing and the Postal Service

The OIG's 2014 white paper, *If It Prints, It Ships: 3D Printing and the Postal Service,* explained how 3D printing works and examined its potential impact on the Postal Service. Namely, the technology could lead to increased volume in the kind of small, lightweight package shipments that the Postal Service excels at delivering. Its ubiquitous physical network and excellent last-mile delivery service position the Postal Service to benefit more from 3D printing than other delivery companies will.

The Postal Service has an unmatched last-mile delivery network — no other organization covers as much territory as frequently and regularly as the Postal Service. It is often not cost effective for private delivery firms to make separate stops to deliver small, relatively inexpensive packages, particularly in rural areas. However, the Postal Service visits these locations nearly every day. Accordingly, other delivery firms often use the Postal Service for final delivery of many packages: the Postal Service delivers nearly two-thirds of lightweight, commercial packages to their final destination. This natural advantage in delivering lightweight packages is critical to benefiting from the growth of 3D printing given that the majority of 3D printed consumer goods are relatively lightweight. In addition, the Postal Service has begun introducing new Small Parcel Sorting System (SPSS) machines at plants across the country, which are intended to help it to quickly process many small packages.

Discussion Forum on 3D Printing and Postal Organizations

In August 2014, the OIG held a discussion forum to further explore how 3D printing could affect postal organizations. The forum included presentations by international experts on 3D printing, logistics, and other key areas. The discussion covered a range of topics, including the future market for 3D printing, consumer preferences related to 3D printing, the effects of 3D printing on supply chains and logistics, establishing community maker spaces through 3D printing, and other issues.

Participants at the forum discussed some of the major implications of 3D printing for postal organizations and logistics operators. Our subsequent research into recent developments in 3D printing supports the following findings:

- For the immediate future, most consumers will likely access 3D printing by purchasing finished goods or pieces through businesses or service bureaus that specialize in 3D printing. In-home 3D printing on a wide scale still requires technological advancement and more consumer awareness of 3D printing's capabilities. In addition, the software for developing or modifying 3D design files is still too complex for many consumers.
- There has been a rise in the number of service bureaus that produce professional-quality parts and finished products for businesses or consumers that need a way to access 3D printing, but typically do not have a 3D printer of their own.

Businesses that offer 3D printing sometimes face challenges with getting products in consumers' hands quickly for multiple reasons. When print jobs fail due to problems with the design or materials, it can add a day or more to the interim between when a customer places an order and when the product is delivered. In addition, it is often difficult or impossible to anticipate demand when so many 3D printed goods are customized for individual consumers. When modern consumers expect very fast shipping, even short delays can have a negative impact on their experiences ordering 3D printed goods.

3D printing promises to reshape traditional supply chains. 3D printing will likely bring production closer to consumption, which could lead to dramatic increases in local shipping. This could also lead to less need for redundant physical inventories in large warehouses. As items such as spare parts can be printed on demand, the nature of inventory will transform from physical to digital.

The Changing 3D Printing Marketplace

The 3D printing industry is rapidly changing. While manufacturers have been using 3D printing for rapid prototyping for decades, it has recently caught a great deal of attention as a means of producing innovative goods. Widespread consumer adoption might still be years or even a decade away, but there are clear signs of strong current growth in businesses' use of 3D printing and of its impact on delivery and logistics markets.

3D Printing Technology Is Improving

Although many people talk about 3D printing as one technology, the field actually encompasses several. The most familiar — and the one most often found in consumer 3D printers — is material extrusion, which uses a heated nozzle to dispense materials like plastics to slowly build an object in fine layers. Other 3D printing technologies use different techniques, such as fusing powdered substances with a liquid bonding agent or heat, laminating sheets of materials together, or using lasers to selectively harden liquid resins.

The company Carbon3D claims that its new 3D printing technology called Continuous Liquid Interface Production (CLIP) can print objects up to 100 times more quickly than previous technologies. CLIP uses ultraviolet light to harden a pool of liquid resin, with the solidified object rising up throughout the process. It remains to be seen how widely this technology will be used, or if other new technologies make 3D printing even faster. However, some experts speculate that mass adoption of 3D printing could take off if new technologies make the process significantly faster and capable of producing stronger objects. For industrial uses of 3D printing, variations in printers, quality or source of printing materials, and manufacturing practices can affect the consistency and quality of the functional parts being produced. Such challenges will need to be addressed before 3D printing reaches its full potential.

The 3D Printing Market Is Expanding Quickly

One sign of this growth is the recent surge in the number of major retailers that have started selling 3D printers, products, or printing services, including Staples, Home Depot, Walmart, Best Buy, Amazon, and Target. Merchants such as these may be entering this space because 3D printing addresses two critical trends in retail which are consumers expectations of stock availability and the desire for personalized and customized products.

Despite strong growth in the 3D printing market overall, experts estimate that mainstream consumer adoption of 3D printing is still 5 to 10 years away. One possible reason: many of the things that today's affordable consumer 3D printers can make, such as toys or small trinkets, are the kinds of things consumers can already purchase cheaply and easily at stores or online. Moreover, the printers themselves may still be too expensive for most people, especially when compared to the costs of traditional "2D" ink printers. Consumer 3D printers can be complex, slow, and unwieldy to use. Analysts expect demand to increase as consumer-grade 3D printers become faster, cheaper, more capable of printing high-quality objects, and easier to use — including more user-friendly and accessible design software.

Even though mainstream consumer adoption of 3D printing may still be years away, many businesses and industries have already adopted 3D printing to revolutionize their products and processes. It has become a vital tool for advanced manufacturing, as important goods such as industrial parts can be produced with geometries that have not been possible with traditional methods. Additionally, 3D printing is now cost-competitive with traditional manufacturing for small production runs and production of single, customized units. Such factors are having a dramatic effect on industries adjacent to manufacturers, and, as the following section discusses, this is especially the case for the logistics industry.

3D Printing Will Disrupt the Logistics Industry

The logistics industry is likely to experience some of the biggest changes resulting from 3D printing. For example, 3D printing may cause some manufacturing to move back to the United States. In addition, warehouses will shift from physical to digital, as the designs of spare parts are stored in vast libraries for future on-demand printing. Moreover, some retailers may convert to shop windows for manufacturers with custom printing as each item is ordered, keeping only a model in stock.

Moving Production Closer to Consumption

Some of the biggest changes promised by 3D printing center around where goods will be produced and stored, which will in turn influence how goods will be delivered to consumers. In fact, in a recent survey, 30 percent of manufacturers said that 3D printing's greatest disruption would land on supply chains. According to DHL, aftermarket supply chains like warehousing and spare parts distribution will be particularly affected by 3D printing. As 3D printing allows manufacturers to move production closer to the point of consumption, it can dramatically decrease the costs and environmental impact of maintaining global supply chains. In addition, it could make supply chains more efficient by delaying production until the last possible point in the supply chain for a given product because 3D printing often responds to consumer demand for highly customized goods.

Some goods that used to require assembly from dozens or even hundreds of different parts can now be 3D printed in one or only a few parts. If an increasing number of products can be 3D printed locally instead of requiring parts, components, or materials from around the world, this will shake up major parts of the transportation and logistics industry. In fact, some estimates have found that localized 3D printing could affect up to 41 percent of global air cargo shipments and 37 percent of ocean container shipments, as well as 25 percent of the trucking freight business that would have moved the goods coming in from air cargo or ocean containers. These major shifts could bolster the present reshoring trend, in which some manufacturing is moving back to the United States (and other home markets) due to rising manufacturing costs and other factors at international production sites.30 3D printing can address these problems by reducing manufacturing costs, increasing the flexibility of production, and producing higher quality products.

New Opportunities for Companies Involved in Logistics

3D printing offers logistics companies significant new opportunities to expand their services. For example, they could provide materials and support services to 3D printing companies, establish reverse logistics services to handle recycling and processing of 3D printed goods made of reusable materials, host data for 3D designs, or offer 3D printing services in warehouses or near major transportation hubs. In addition, logistics companies already often provide replacement parts services for their clients — this could be done more efficiently by 3D printing from a digital inventory of spare parts and components, with minimal need for expensive storage space for pieces that clients or consumers may not request for years. Third party logistics providers (3PLs) may need to adapt to 3D printing because it could reduce manufacturers' need for the global reach and distribution capability that 3PLs provide.

UPS and Amazon Move into 3D Printing

Some major companies are already exploring ways to integrate 3D printing into their services and supply chains. For example, UPS has made significant investment in 3D printing, offering 3D printing services at about 100 of its UPS Store retail locations in the United States. UPS gears this service primarily to small businesses that require a way to use 3D printing to meet their own customers' needs. The services offered include printing prototypes, creating complex parts to support small-scale manufacturing, designing custom accessories, and even printing architectural models.

CloudDDM claims that running this many printers CloudDDM claims that running this many printers in a single location allows it to reduce production costs by up to 50 percent compared to traditional manufacturing. Moreover, by locating the factory at that UPS facility, CloudDDM says it can gain as much as a 6-hour advantage over its competitors, allowing it to enter more packages into UPS's network before its cutoff time each day. UPS handles all packaging and logistics for CloudDDM's products. Through this arrangement, CloudDDM claims it is the first company able to offer same-day shipping for dimensionally accurate 3D printed parts in real engineering plastics, which it says will be critical as more and more companies move to rapid design iteration, virtual inventory, and fast-turn spare parts replacement.

In the future, Amazon may also alter traditional supply chains using 3D printing. It recently filed patent applications for delivery trucks that 3D print goods while in transit to customers. All items would be printed on demand, eliminating the need to maintain physical inventory. The system is not in place yet, so it remains to be seen whether it is feasible. If it does work out, in-transit 3D printing could be a major new development in the world of package delivery.

Foreign Posts Are Exploring the Use of 3D Printing

Several foreign postal organizations already see the value in 3D printing. By embracing these new technologies, posts are meeting the emerging needs of consumers and businesses, enhancing the value of their brands, and positioning themselves for the future in which 3D printing will be more prevalent. For the 3D printing companies that partner with posts, the benefit comes in the form of more direct connections to millions of customers.

France

In our July 2014 white paper, we mentioned how France's La Poste first began offering 3D printing services by forming a partnership with the company Sculpteo in late 2013. Through this partnership, La Poste placed 3D printers in three post offices in and near Paris and offered an online marketplace where consumers can order 3D printed products. Customers can submit their own designs or pick and customize from a catalog with about 40,000 existing designs. After each order, La Poste delivers the products to the customer's home or holds them for pickup at the post office.

La Poste has expanded in-store 3D printers to a total of six post offices. Beyond just printing in-store and offering a catalog of 3D printed products, La Poste now offers consulting services to help refine customers' designs, which could help small businesses improve their 3D printed offerings. In addition, La Poste recently teamed with the Dutch company UCKi to offer a service that converts children's unique artwork into 3D printed jewelry.

La Poste also partners with CIRTES (an engineering research center in France) to create fully customized packaging that protects fragile or unusually-shaped items during shipping. Through this process, which is available at a few post offices near Paris, La Poste takes a 3D scan of a customer's item and then a machine precisely cuts layers of durable packing materials, like cardboard, so that they exactly conform to the shape of the item.48 With fully customized packing materials, items have substantial protection during the shipping process.

United Kingdom

In December 2014, Royal Mail started a 2-month trial program in which it partnered with the 3D printing company iMakr to place a 3D printer at a post office in London. Customers could select to have designs printed from the iMakr website at MyMiniFactory.com, or could bring in their own designs for printing. The products could be printed at the post office or an iMakr store, as well as delivered by Royal Mail. Through this partnership, Royal Mail made 3D printing services convenient and accessible for businesses and customers who might otherwise be unable to afford their own 3D printer.

The 2-month trial program was considered a success, and Royal Mail still offers an online catalog of 3D printed products for customers to order. The available products include reproductions of historical artifacts and archaeological objects, smartphone cases, office supplies, and other items.

By all accounts, the partnership has been mutually beneficial for Royal Mail and iMakr. Royal Mail found a partner with existing knowledge and experience related to 3D printing, so it did not need to develop those resources itself. iMakr benefited because such a high-profile partnership brought significant attention to 3D printing and made people aware of the types of products they could order or create. Because 3D printing is not yet fully in the mainstream of public consciousness, any increase in awareness can help the growth of the industry and the value of customizable goods.

Switzerland

In late 2014, Swiss Post entered a partnership with the 3D printing company my3Dworld. Together, they opened an online marketplace and organized a 3D printing "roadshow" across the country that gave customers the opportunity to buy 3D printed miniature replicas of themselves. Unlike the initiatives of other posts, the Swiss Post marketplace primarily focuses on selling a wide range of 3D printers, many different types of printing filaments and other supplies, a 3D scanner, and other items useful for customers to do their own printing. While it also offers some 3D printed jewelry and miniature figurines, the general goal of Swiss Post's initiative appears to be meeting the needs of the country's maker community.

Singapore

Singapore Post has recently introduced several "new generation" post offices that strive to meet evolving customer demands in the digital age. These locations offer high-tech services like 24/7 fully automated lobbies, tablets that let customers browse a wide range of products and start their transactions before they approach the counter, a business solutions center for local enterprises, and other features. Singapore Post describes these revamped post offices as lifestyle hubs for traditional and essential services.

At its flagship new generation post office, Singapore Post also offers 3D printing services. Customers and business owners can go to that post office to print out customized gifts or prototypes, or get their image 3D scanned and printed onto small figurines. The 3D printing and scanning services are part of an “Innovation Center” at that post office, which serves as a community maker space and fuels creativity.

Suggestions for the Postal Service

The Postal Service should continue to observe the 3D printing market as it further develops, learn from the examples of foreign posts and logistics companies, and examine the potential of 3D printing to the extent allowable under its existing statutory authority. Doing so would help the Postal Service to position itself to meet the emerging 3D printing needs of citizens and businesses. According to observers of the industry, transportation companies have often waited to see what changes new technologies bring, instead of trying to anticipate the change by positioning themselves accordingly. With 3D printing, the opportunities may be far too good for the Postal Service to wait and see before responding.

Identify Models Based on the Experiences of Foreign Posts

Now that a growing number of foreign posts have started offering various 3D printing services, they provide valuable models that the Postal Service could potentially emulate. In addition, the offerings from UPS and major retailers show that 3D printing has broad appeal and applicability. There are a number of opportunities the Postal Service could consider, including but not limited to the following:

- Establish a reverse logistics service to handle recycling and processing of 3D printed goods, so that materials can be reused for future printing.
- Provide 3D printing materials and other support services for small businesses and makers in neighborhoods where there is demand, or potentially online. Given that 3D printing for consumers and small businesses is an emerging market, no organization has yet established itself as the go-to provider for a wide range of printing materials at many locations across the United States. These locations need to be both convenient to customers and appropriate for storing 3D printing materials under the right conditions. This could be a tremendous opportunity for whoever manages to provide an effective solution. However, it is important to note that it could be quite expensive to maintain a stock of a wide range of 3D printing materials at every location.
- Offer 3D printing services inside post offices, similar to the offerings of La Poste and UPS, potentially by partnering with a company that already has experience with 3D printing. Such a partner could help the Postal Service with, or cover entirely, the initial investment needed to roll out 3D printing services. A partner might also be able to help the Postal Service stay up-to-date with technological and other advancements in the quickly changing 3D printing industry.

It is important to keep in mind that the Postal Accountability and Enhancement Act of 2006 (PAEA) prohibits the Postal Service from offering new non-postal services. Some 3D printing services, including those offered by other posts, may not be permissible under the Postal Service's current authority. However, the Postal Service could make a case to the Postal Regulatory Commission (PRC) that some services — such as customized packaging created through 3D scanning — are ancillary to its existing offerings. The potential for substantial new annual revenue from increased package shipments of 3D printed goods, as identified in the OIG's July 2014 paper, speaks to the benefit of the Postal Service establishing a role in the industry.

Serve as a Community Maker Space

As another possibility, the Postal Service could consider using room in its facilities to provide community maker spaces built around 3D printers. Libraries, universities, and other public institutions around the country have already started to experiment with such offerings, sometimes by teaming up with major 3D printing companies. For example, the State University of New York, New Paltz, worked with MakerBot to build an Innovation Center on campus with dozens of 3D printers. Students and staff can use the 3D printers to expand their skills and knowledge in arts, science, engineering, and other areas. Artists and other community members can also enroll in a digital design program that utilizes the center. At the Public Library of Cincinnati and Hamilton County, community members can access 3D printers as well as sewing machines, laser engravers, cameras, audiovisual equipment, and other tools to support their creative activities.

The Postal Service has a presence in every community across the United States. In addition, it has more than 60 million square feet of excess space nationwide, much of which is in mail processing centers. Some estimates find that effective 3D printing maker spaces can be set up for less than $10,000.

Understand the Shipping Needs of 3D Printing Companies

When a consumer orders a 3D printed product, it can sometimes take weeks before it arrives on their doorstep. This often depends on the type of material used for printing. The total time can be even longer if there are failed prints. It may be worthwhile for the Postal Service to reach out to 3D printing companies to learn more about their shipping needs and to identify potential solutions that could help minimize the time it takes to get products in consumers' hands. For example, in a 2014 white paper, we suggested that 3D printing facilities located at or near shipping nodes like postal facilities could help reduce shipping time.

Consider Offering Postal-Themed 3D Printed Goods or Designs

The Postal Service could look into whether it can sell 3D printed goods or designs based on postal artifacts or history. It has a long and rich archive of images and memorabilia that it could draw upon for this purpose. For example, there may be antique stamp designs that would make interesting 3D printed pieces, similar to the 3D printed Queen's Head Stamp sold by Royal Mail. If the Postal Service wanted to offer postal-themed 3D printed items it would need to determine whether it holds the copyright for the original work in question.

Conclusion

3D printing technology promises to shake up the manufacturing and logistics industries, shifting production closer to consumption and potentially revamping vast parts of the global supply chain. These changes will make fast, on-demand service and last-mile delivery more and more important in coming years. Meeting these growing demands represents a major opportunity in delivery and logistics. The Postal Service could play an important role in the future of 3D printing, given the complementary nature of its nationally distributed processing facilities and last-mile delivery network, and the localized nature of 3D printed manufacturing.

Logistics companies and foreign posts are actively partnering with 3D printing companies as a way to meet new customer needs while positioning their organizations to be beneficiaries of a

3D printing revolution. Others are experimenting with 3D printing services tailored for business clients with clear shipping or logistics needs. It makes sense for the Postal Service to consider similar initiatives. As the Postal Service looks to the future, anticipating the 3D printing needs of citizens and businesses will be critical, especially as it pertains to the new logistics needs that the technology is creating. 3D printing technology will soon fundamentally change the logistics industry, and this is the right time for the Postal Service to start associating itself with 3D printing in the minds of the public.

Many federal agencies have benefited from the use of 3D printing. In particular, the Department of Defense has shown great interest in the technology, deploying 3D printers across its service branches. The U.S. Navy is currently working on around 3D printing projects hosted at dozens of its sites. It also uses a 3D printer onboard at least one ship, the U.S.S. Essex, to print various small items it needs, from oil tank caps to organizational tools. Defense manufacturers including Lockheed Martin, Aerojet Rocketdyne, and General Electric are working to improve the ability of 3D printing to create parts suitable for the military to use in weapons, ships, and vehicles.

Defense manufacturers like these, other high-tech manufacturers, universities, and various companies with financial interest in 3D printing, including UPS, have established a nonprofit organization called the National Center for Defense Manufacturing and Machining (NCDMM). The organization's goal is to develop and promote advanced and cost-effective manufacturing tools for defense suppliers, including 3D printing. NCDMM also manages America Makes, a public-private partnership of federal agencies, manufacturing companies, and universities similarly devoted to developing and accelerating the use of 3D printing across government and the manufacturing sector.69 Federal agencies' work on 3D printing through partnerships like these demonstrates strong belief that the technology holds great promise for advanced manufacturing and for helping to meet agencies' supply needs.

In addition, NASA recognizes the potential of 3D printing to decrease the cost and risk of meeting its mission supply needs. Its work with 3D printing is still in the early stages, but continued research and experience with 3D printing will allow NASA to give its astronauts more autonomy and flexibility on their missions. NASA has deployed a 3D printer on the International Space Station, where it has already demonstrated that astronauts can use 3D printing in microgravity conditions to build small tools and parts in ABS plastic. Once NASA has determined that these goods are suitable and safe for astronauts to use on missions in space, 3D printers will be a ready source of these tools and parts, reducing the high costs of sending spares on missions to space. Long-term missions will benefit even more from in-space manufacturing, which could eventually construct everything from small tools to deep space habitats. NASA and America Makes are currently holding a competition to design and build a 3D printed habitat for deep space exploration, including a journey to Mars.

The Department of Energy's (DOE) Oak Ridge National Laboratory, a member organization of America Makes, has demonstrated the ability to create large objects in advanced materials with 3D printing. Its Big Area Additive Manufacturing Machine (BAAM) has the ability to print in carbon fiber-reinforced ABS, an advanced material suitable for aerodynamic vehicle frames. The laboratory demonstrated the capability by creating a replica Shelby Cobra automobile for display at the 2015 Detroit Auto Show. Researchers with the lab constructed the vehicle's frame and body with the BAAM, and have found that the carbon fiber-reinforced ABS exhibits strength and stiffness comparable to or better than the steel or aluminum often used for the frames and bodies of automobiles. According to DOE, this capability makes the BAAM suitable for many research applications for clean energy manufacturing, not just for automobiles.

Additionally, the Critical Materials Institute at DOE's Ames Laboratory is using advanced laser-based 3D printing technology to develop new metal alloys to replace rare-earth elements and other materials needed in critical technologies, including clean energy systems. The institute's 3D printer, which uses the heat of a laser to fuse metal powders, will allow its researchers to produce a large number of different metal alloys far more quickly than they could with traditional casting methods. In a demonstration, researchers used the printer to produce a small rod made out of stainless steel in just 20 seconds. The speed at which the 3D printer can generate a library of alloys for testing makes it a powerful tool for the Critical Materials Institute as it continues its work on energy innovation.

The ability of 3D printing to decentralize production of objects manufactured with high levels of precise detail has applications for more public facing government services as well. In 2014, the National Institutes of Health (NIH) and the Department of Health and Human Services launched the NIH 3D Print Exchange, a program that provides biomedical models formatted for 3D printers and offers tools for users to create and share such models. Prior to the launch of this program, few scientifically accurate or medically applicable 3D-printable models were available, as researchers in the field lacked the ability and tools to generate them. The program provides these tools, and now hosts over 5,000 3D-printable files of biomedical models on the first government-sponsored website devoted to 3D printing. As 3D printers become increasingly accessible and affordable, this free, readily available library of biomedical models will help facilitate research, medical practice, and education. Additionally, in January 2015, the NIH's National Institute of Allergy and Infectious Diseases made 3D technologies, including 3D printing, the subject of its annual Bioinformatics and Computational Biosciences Festival, demonstrating that NIH sees great potential to improve the field of medicine through the increased use of the technology.

Centralized 3D Printing: Businesses Sell Finished 3D Printed Goods to Consumers

In the first scenario, consumers buy finished 3D printed goods from retailers, specialized businesses, or services bureaus. Those companies could end up increasingly competing on speed as the 3D printing market grows larger, leading some of them to locate their printing facilities at or near shipping nodes. Doing so would allow them to get their products into the delivery stream more quickly. The Postal Service could act as a logistics partner for companies located near postal facilities, in a sense becoming a hub for 3D printing. Under this scenario, the Postal Service's commercial package revenue could increase by as much as $646 million per year.

The Postal Service's benefit from 3D printing and its attractiveness as a logistics partner for 3D printing companies would come from the strength of its network. In this scenario, any weakening of the Postal Service's network — through reductions in important features like service frequency, number of delivery points, tracking and tracing services, or pick-up options — could result in lower additional new revenue from package shipments.

In addition, the Postal Service has more than 60 million square feet of excess space nationwide, much of which is in mail processing centers. These are industrial facilities that could accommodate the electrical power and ventilation needs of large 3D printers. The Postal Service could lease some of this space directly to 3D printing businesses, making it even easier for them to ship products quickly.

Decentralized 3D Printing: People Print Some Goods at Home Instead of Buying Them

The second scenario involves people using in-home or desktop 3D printers to print out a variety of items. Much of the buzz around 3D printing is based on this notion — that people will one day use affordable, high quality in-home printers to make many, if not most, of the items they now purchase from retailers. This is highly unlikely. If in-home 3D printers do manage to become ubiquitous, they would probably only be used for relatively few items. However, if people do end up using in-home 3D printers to create many things and not just a small handful of items, the result could be massive disruption to existing retail supply chains. It could lead to big cuts in brick-and-mortar and e-commerce sales, and a corresponding drop in the number of commercial packages shipped.

Even though products under this second scenario would be printed at home, those in-home printers would need a regular stream of 3D printing materials. After all, people could not print things at home without printing materials on hand. In addition, if people are printing many different types of items, they are going to need to stock a variety of printing materials. This all adds up to a significant increase in package shipments. Under this scenario, the Postal Service could see an increase in annual commercial package revenue as high as $1.1 billion if people 3D print many things at home.

Although there would be a drop in the number of finished goods being shipped by the Postal Service, this drop would likely be small because most household items are currently purchased at brick-and-mortar retail stores. In other words, shipments of printing materials would replace brick-and-mortar purchases that were not shipped through the Postal Service to begin with. The new shipments of 3D printing materials could more than make up for any of this small decrease. However, it is worth repeating that this scenario is not only unlikely, but also highly uncertain.

The Postal Service Could Play an Important Role in 3D Printing

The 2014 white paper included several suggestions for the Postal Service to consider if it seeks to play a role in the 3D printing industry. For example, as the Postal Service continues to consolidate its processing network, it could guard against any changes that would lessen the value of its delivery network. The Postal Service could also establish a platform for 3D printing that uses its national retail network and last-mile delivery capabilities, potentially by partnering with companies that specialize in 3D printing. Designs sent to the platform could be 3D printed and then shipped via same-day or next-day delivery. Customers could also order designs to be printed from an online marketplace and then delivered or held for pickup at a Post Office. Other ideas proposed in the 2014 white paper include ways that the Postal Service could use 3D printing to improve internal operations, and the use of 3D printing to create customized packing materials for individual items that are oddly shaped or otherwise unsuited for ready-made boxes and packing supplies.

(Link: https://www.uspsoig.gov/sites/default/files/document-library-files/2015/RARC-WP-16-001.pdf)

Manufacturing USA: National Network for Manufacturing Innovation

The National Network for Manufacturing Innovation has a public name: Manufacturing USA. Over the past several years of the program, nine manufacturing innovation institutes have been established or announced, with six more planned by 2017. These manufacturing institutes are public-private partnerships that each have distinct technology focus areas but work towards a common goal: to secure America's future through manufacturing innovation, education, and collaboration.

Through Manufacturing USA, industry, academia, and government partners are leveraging existing resources, collaborating, and co-investing to nurture manufacturing innovation and accelerate commercialization. Each institute is designed to be a public-private membership organization that provides vision, leadership, and resources to its members.

Manufacturing USA connects people, ideas, and technology to solve industry-relevant advanced manufacturing challenges. Its goals are to enhance industrial competitiveness, increase economic growth, and strengthen U.S. national security. Reaching across industries, Manufacturing USA brings members of the manufacturing community together to overcome technical hurdles and to enable innovative new products. It seeks to restore American preeminence in manufacturing by addressing shared manufacturing technology and workforce challenges.

Manufacturing USA institutes focus on moving promising, early-stage research into proven capabilities ready for adoption by U.S. manufacturers. Their diverse membership includes small, mid-sized, and large manufacturers, as well as researchers from universities and government laboratories. The institutes provide members with access to state-of-the-art facilities and equipment, as well as workforce training and skills development customized to support new technology areas. Collaboration at institutes, and now through the network, creates an innovation community ushering in the next generation manufacturing supply chains located in America and employing Americans.

The Manufacturing USA network is operated by the interagency Advanced Manufacturing National Program Office, which is headquartered in the National Institute of Standards and Technology, in the Department of Commerce. The office is staffed by representatives from federal agencies with manufacturing-related missions as well as fellows from manufacturing companies and universities.

The office operates in partnership with the Department of Defense, the Department of Energy, NASA, the National Science Foundation, the Department of Education and the Department of Agriculture. The office began as a pilot, recommended by the President's Council of Advisors on Science and Technology, but the overarching mission has not changed:

- To convene and enable industry-led, private-public partnerships focused on manufacturing innovation and engaging U.S. universities.
- To design and implement an integrated whole-of-government advanced manufacturing initiative to facilitate collaboration and information sharing across federal agencies.

By coordinating federal resources and programs, the Advanced Manufacturing National Program Office enhances technology transfer in U.S. manufacturing industries and helps companies overcome technical obstacles to scale up of new technologies and products.

History

In June 2011, U.S. President Barack Obama launched the Advanced Manufacturing Partnership (AMP) on the recommendation of the President's Council of Advisors on Science and Technology (PCAST) in a report issued that same month. The partnership was led by Dow Chemical Company President, Chairman, and CEO Andrew Liveris, and MIT President Susan Hockfield. AMP was charged with identifying collaborative opportunities between industry, academia and government that will catalyze development and investment in emerging technologies, policies and partnerships with the potential to transform and reinvigorate advanced manufacturing in the United States. Its first set of recommendations, "Report to the President on Capturing Domestic Competitive Advantage in Advanced Manufacturing," was issued in July 2012.

Subsequently, after a nationwide outreach and engagement effort, the White House National Science and Technology Council and the AMNPO issued "The National Network for Manufacturing Innovation: A Preliminary Design," in January 2013.

In September 2013, the President launched the Advanced Manufacturing Partnership Steering Committee 2.0 (AMP 2.0). AMP 2.0 focused oa a renewed, cross-sector, national effort to secure U.S. leadership in the emerging technologies that will create high-quality manufacturing jobs and enhance America's global competitiveness. The steering committee, whose members are among the nation's leaders in industry, academia, and labor, was a working group of the President's Council of Advisors on Science and Technology. Its final report on accelerating U.S. advanced manufacturing was issued in October 2014.

In his 2013 and 2014 State of the Union Addresses, the President called for the creation of a Nationwide Network for Manufacturing Innovation (now known as Manufacturing USA) to scale up advanced manufacturing technologies and processes. He asked Congress to authorize investment—to be matched by private and non-federal funds to create an initial network of up to 15 institutes. Over 10 years, he proposed that the Manufacturing USA network encompass 45 institutes.

On December 16, 2014, the President signed the Revitalize American Manufacturing and Innovation Act into law, which gave Congressional authorization to the AMNPO and authorized the Department of Commerce to hold "open-topic" competitions for manufacturing innovation institutes where those topics of highest importance to industry could be proposed.

In addition to the Manufacturing USA, there are a number of advanced manufacturing innovation initiatives aimed at increasing the competitiveness of the United States in advanced manufacturing. These programs support, supplement and integrate with the Manufacturing USA to maximize their combined benefits.

Advanced Manufacturing Technology Consortia (AMTech)

Launched in 2013, AMTech is a competitive grants program intended to establish new or strengthen existing industry-driven consortia that address high-priority research challenges impeding the growth of advanced manufacturing in the United States. The AMTech program funds broad participation across the value-chain including companies of all sizes, universities and government agencies. It is modeled on successful national efforts within various industry and technology sectors.

Through the competitive planning grants it offers, AMTech incentivizes the formation and strengthening of industry-driven technology consortia in areas of national importance in advanced manufacturing. Activities supported by Planning Awards include detailed technology roadmaps of critical advanced manufacturing technologies and associated long-term industrial research challenges.

In FY2016 AMTech was merged into the National Network for Manufacturing Innovation. No changes have been made to program operations regarding prior awards, and there were no current plans to hold a future AMTech competition.

MForesight: The Alliance for Manufacturing Foresight

The Report to the President Accellerating U.S. Advanced Manufacturing, produced by the Steering Committee of the Advanced Manufacturing Partnership 2.0 (AMP 2.0) in October 2014 for the President's Council of Advisors on Science and Technology (PCAST), calls for the creation of a mechanism to provide coordinated private-sector input on national advanced manufacturing technology research and development priorities. MForesight was established to implement that recommendation. It informs and promotes regular and sustained communication and research coordination across the public and private sectors, provides federal decision-makers with timely access to top university and industry experts and responds quickly to requests from federal decision-makers for detailed input on nascent opportunities and priorities in manufacturing. These activities are designed to improve the coordination of federal advanced manufacturing technology and research and development strategies. The Consortium cooperates with the Advanced Manufacturing National Program Office (AMNPO) of NIST, the President's National Science and Technology Council (NSTC), and the U.S. Government Agencies that support advanced manufacturing to help provide the timely information needed to achieve that coordination. NSF is the program lead and is solely responsible for the solicitation and the resulting award. NIST, acting on behalf of the Advanced Manufacturing National Program Office, is the program co-sponsor with NSF and provides financial and administrative support to NSF.

Hollings Manufacturing Extension Partnership (MEP)

Since 1988, the Hollings Manufacturing Extension Partnership (MEP) has been committed to strengthening U.S. manufacturing, continually evolving to meet the changing needs of manufacturers. Through its services and partnerships it has had a profound impact on the growth of well-paying jobs, the development of dynamic manufacturing communities, and the enhancement of American innovation and global competitiveness.

MEP's strength is in its partnerships. Through its collaborations at the federal, state and local level, MEP puts manufacturers in position to develop new products and customers, expand into global markets, adopt new technology, reshore production, and more. And because of its direct contact with manufacturers, MEP serves as a valuable bridge to other organizations that share a passion for enhancing the manufacturing community.

MEP's strategic objective is to create value for all manufacturers, with a particular focus on small and mid-sized enterprises (SMEs). SMEs represent nearly 99% of manufacturing firms in the U.S. and form the essential fabric of the U.S. manufacturing infrastructure. MEP is able to provide this support to individual manufacturers through its nationwide network of local centers made up of teams of experts and business professionals.

As a public/private partnership, MEP delivers a high return on investment to taxpayers. For every dollar of federal investment, MEP clients generate nearly $19 in new sales, which translates into $2.5 billion annually. And for every $2,001 of federal investment, MEP creates or retains one U.S. manufacturing job. Since 1988, MEP has worked with nearly 80,000 manufacturers, leading to $88 billion in sales and $14 billion in cost savings, and it has helped create more than 729,000 jobs.

After nearly 30 years, MEP continues to innovate, meeting the challenge of developing new programs, services, and partnerships to help manufacturers flourish in the 21st century. MEP is a part of the National Institute of Standards and Technology (NIST), a U.S. Department of Commerce agency.

Investing in Manufacturing Communities Partnership

The Investing in Manufacturing Communities Partnership (IMCP) program is an initiative designed to revolutionize the way federal agencies leverage economic development funds. It encourages communities to develop comprehensive economic development strategies that will strengthen their competitive edge for attracting global manufacturer and supply chain investments. Through IMCP, the federal government is rewarding best practices – coordinating federal aid to support communities' strong development plans and synchronizing grant programs across multiple departments and agencies. Non-designated communities nationwide can learn from the best practices employed by these designated communities to strengthen American manufacturing.

The Investing in Manufacturing Communities Partnership (IMCP) is a government-wide initiative to help communities cultivate an environment for businesses implemented in 2013 to create well-paying manufacturing jobs in regions across the country and thereby accelerate the resurgence of manufacturing.

The IMCP is designed to reward communities that demonstrate best practices in attracting and expanding manufacturing by bringing together key local stakeholders and using long-term planning that integrates targeted public and private investments across a community's industrial ecosystem to create broad-based prosperity.

Up to 12 communities will be designated as Manufacturing Communities for a period of two years. After two years, communities will be invited to apply to renew their designation as Manufacturing Communities; they will be evaluated based on: (a) performance against the terms of the designation and post-designation awards received (if any); and (b) progress against project-specific metrics as proposed by communities in their applications, designed to also help communities track their own progress.

To earn the initial designation, communities had to demonstrate the strength of an existing manufacturing industry in their region/community and develop strategies to make investments in six areas: workforce and training; (2) research and innovation; (3) infrastructure and site development; (4) supply chain support; (5) trade and international investment; and (6) operational improvement and capital access.

IMCP Participating Agencies have agreed to provide preferential consideration, and/or consideration in the determination of application merit, and/or grant supplemental awards (totaling approximately $1.3 billion) for Manufacturing Communities for the following 18 economic development programs:

- Appalachian Regional Commission (ARC)
- Delta Regional Authority (DRA)
- Department of Housing and Urban Development (HUD)
- Department of Transportation (DOT)
- Environmental Protection Agency (EPA)
- National Science Foundation (NSF)
- Small Business Administration (SBA)
- U.S. Department of Agriculture
- U.S. Department of Commerce (DOC)
- Institute for Standards and Technology (NIST)

Materials Genome Initiative

The Materials Genome Initiative (MGI) is a multi-agency initiative designed to create a new era of policy, resources, and infrastructure that support U.S. institutions in the effort to discover, manufacture, and deploy advanced materials twice as fast, at a fraction of the cost.

Advanced materials are essential to economic security and human well being, with applications in industries aimed at addressing challenges in clean energy, national security, and human welfare, yet it can take 20 or more years to move a material after initial discovery to the market. Accelerating the pace of discovery and deployment of advanced material systems will therefore be crucial to achieving global competitiveness in the 21st century.

Since the launch of MGI in 2011, the Federal government has invested over $250 million in new R&D and innovation infrastructure to anchor the use of advanced materials in existing and emerging industrial sectors in the United States.

National Export Initiative/NEXT

Commerce Secretary Penny Pritzker announced in May 2014 that the Obama Administration will build on the success of the National Export Initiative (NEI) by launching NEI/NEXT: a new customer service-driven strategy with improved information resources that will ensure American businesses are fully able to capitalize on expanded opportunities to sell their goods and services abroad.

NEI/NEXT will help more American companies reach more overseas markets by improving data, providing information on specific export opportunities, working more closely with financing organizations and service providers, and partnering with states and communities to empower local export efforts.

NEI/NEXT will be implemented through the Export Promotion Cabinet and Trade Promotion Coordinating Committee (TPCC), which consists of representatives from 20 federal departments and agencies with export-related programs. The Secretary of Commerce chairs the TPCC.

National Nanotechnology Initiative

The National Nanotechnology Initiative (NNI) is a U.S. Government research and development (R&D) initiative involving the nanotechnology-related activities of 20 departments and independent agencies. The United States set the pace for nanotechnology innovation worldwide with the advent of the NNI in 2000. The NNI today consists of the individual and cooperative nanotechnology-related activities of Federal agencies with a range of research and regulatory roles and responsibilities. Funding support for nanotechnology R&D stems directly from NNI member agencies, not the NNI. As an interagency effort, the NNI informs and influences the Federal budget and planning processes through its member agencies and through the National Science and Technology Council (NSTC). The NNI brings together the expertise needed to advance this broad and complex field—creating a framework for shared goals, priorities, and strategies that helps each participating Federal agency leverage the resources of all participating agencies. With the support of the NNI, nanotechnology R&D is taking place in academic, government, and industry laboratories across the United States.

Manufacturing USA

About the Initiative: In the President’s 2013 and 2014 State of the Union Addresses, he called for the creation of a Nationwide Network for Manufacturing Innovation, now known as Manufacturing USA, to scale up advanced manufacturing technologies and processes. He asked Congress to authorize investment—to be matched by private and non-federal funds—to create an initial network of up to 15 institutes. Over 10 years, he proposed that the Manufacturing USA encompass 45 institutes. On December 16, 2014, the President signed the Revitalize American Manufacturing Act, into law.

Manufacturing USA consists of linked Institutes for Manufacturing Innovation (IMIs) with common goals, but unique concentrations. Here industry, academia, and government partners are leveraging existing resources, collaborating, and co-investing to nurture manufacturing innovation and accelerate commercialization.

The Manufacturing USA program is managed by the interagency Advanced Manufacturing National Program Office (AMNPO). Participating agencies include the Department of Defense, Department of Energy, Department of Commerce’s National Institute of Standard and Technology (NIST), NASA, the National Science Foundation, Department of Agriculture, Department of Education, and other agencies.

National Robotics Initiative

The goal of the National Robotics Initiative is to accelerate the development and use of robots in the United States that work beside or cooperatively with people. Innovative robotics research and applications emphasizing the realization of such co-robots working in symbiotic relationships with human partners is supported by multiple agencies of the federal government including the National Science Foundation (NSF), the National Aeronautics and Space Administration (NASA), the National Institutes of Health (NIH), the U.S. Department of Agriculture (USDA), and the U.S. Department of Defense (DOD). The purpose of this program is the development of this next generation of robotics, to advance the capability and usability of such systems and artifacts, and to encourage existing and new communities to focus on innovative application areas. It will address the entire life cycle from fundamental research and development to manufacturing and deployment. Questions concerning a particular project's focus, direction and relevance to a participating funding organization should be addressed to that agency's point of contact listed in section VIII of this solicitation.

SelectUSA

Recognizing that the competitiveness and job-generating ability of a nation is determined by its desirability as a place for businesses to operate, SelectUSA was created at the federal level to showcase the United States as the world's premier business location and to provide easy access to federal-level programs and services related to business investment. SelectUSA is designed to complement the activities of states—the primary drivers of economic development in the United States.

SelectUSA is housed within the U.S. Department of Commerce, which maintains a network of personnel throughout the United States and in nearly 80 countries, and is led by an Executive Director, appointed by the Secretary of Commerce.

SelectUSA is a convening authority of the Federal Interagency Investment Working Group and responds to specific federal-level concerns impacting the attraction and retention of business investment. The Obama Administration is committed to enhancing U.S. efforts to win the growing global competition for business investment by leveraging our resources and advantages as the premier business location in the world.

Sustainable Manufacturing Clearinghouse

About the Initiative: The Sustainable Manufacturing Clearinghouse is an archived database which was created to provide U.S. companies with a central portal for information on programs and resources that can assist in enhancing competitiveness and profitability in environmentally sustainable ways.

The Sustainable Business Clearinghouse was originally developed by the U.S. Department of Commerce, with about 800 federal, state, and non-governmental resources. They include: case studies, compliance assistance, financial assistance, general information, how-to guides, metrics/assessment tools, research, tax incentives, technical assistance, training opportunities, and voluntary or partnership programs.
(Link: https://www.manufacturing.gov/nnmi/)

Partners

The interagency Advanced Manufacturing National Program Office (AMNPO) helps to coordinate the efforts of all federal agencies involved in advanced manufacturing. First recommended by the Advanced Manufacturing Partnership (AMP), a steering committee under the President's Council of Advisors on Science and Technology (PCAST) comprised of national leaders from industry and academia, the office was established in 2012 by the Secretary of Commerce and the Director of the National Economic Council. The AMNPO provides both a key convening body for requesting and accepting multi-sector input as well as a platform for communication, collaboration, and coordination among the federal agencies participating in Manufacturing USA. The following agencies and offices participate in the Manufacturing USA Program:

The National Economic Council (NEC) was established in 1993 to advise the President on U.S. and global economic policy. It resides within the Office of Policy Development and is part of the Executive Office of the President. The NEC has four principal functions: to coordinate policy-making for domestic and international economic issues, to coordinate economic policy advice for the President, to ensure that policy decisions and programs are consistent with the President's economic goals, and to monitor implementation of the President's economic policy agenda. More information is available at www.whitehouse.gov/administration/eop/nec.

The Office of Science and Technology Policy (OSTP) was established by the National Science and Technology Policy, Organization, and Priorities Act of 1976. OSTP's responsibilities include advising the President in policy formulation and budget development on questions in which science and technology are important elements; articulating the President's science and technology policy and programs; and fostering strong partnerships among federal, state, and local governments, and the scientific communities in industry and academia. The Director of OSTP also serves as Assistant to the President for Science and Technology and manages the National Science and Technology Council (NSTC). More information is available at www.ostp.gov.

The National Science and Technology Council (NSTC) is the principal means by which the Executive Branch coordinates science and technology policy across the federal research and development enterprise. A primary objective of the NSTC is establishing clear national goals for federal science and technology investments. The NSTC prepares research and development strategies that are coordinated across federal agencies to form investment packages aimed at accomplishing multiple national goals. The work of the NSTC is organized under committees that oversee subcommittees and working groups focused on different aspects of science and technology.

The NSTC Subcommittee on Advanced Manufacturing (SAM) serves as a forum for information-sharing, coordination, and consensus-building among participating agencies regarding federal policy, programs, and budget guidance for advanced manufacturing. Originally chartered in 2012, the Subcommittee seeks to identify: gaps in federal advanced manufacturing research and development portfolio and policies, programs and policies that support technology commercialization, methods of improving business climate, and opportunities for public-private collaboration. Regarding advanced manufacturing programs conducted by the Federal Government, the Subcommittee engages in the identification and integration of multi-agency technical requirements, joint program planning and coordination, and development of joint strategies or multi-agency joint solicitations.

The Advanced Manufacturing National Program Office is hosted by the Department of Commerce at the National Institute of Standards and Technology (NIST), the AMNPO is an interagency team with participation from federal agencies involved in advanced manufacturing. Principal participant agencies currently include the Departments of Commerce, Defense, Education, and Energy, the National Aeronautics and Space Administration, and the National Science Foundation. Established in 2012, the AMNPO reports to the Executive Office of the President and operates under the NSTC on cross-agency initiatives. The office reports to the Secretary of Commerce in its role as the "the National Office of the Network for Manufacturing Innovation Program," also referred to as the "National Program Office," as described by the Revitalize American Manufacturing and Innovation Act of 2014. More information is available at www.manufacturing.gov.

Department of Commerce has as part of its mission to support innovation, manufacturing, exports, and foreign direct investment, the Department of Commerce (DOC) supports the work of the Manufacturing USA Program by establishing industry-led Manufacturing Innovation Institutes. The Department hosts the AMNPO, an interagency team with participation from federal agencies that oversees the planning, management, and coordination of the Manufacturing USA Program.

Innovation results from initial advances that lead to additional technology and process improvements, with resulting benefits accruing to industry, the economy, and society as a whole. Innovation in advanced manufacturing begins with the generation of new ideas that are refined and matured through applied research, development, and invention. Manufacturers then scale those ideas for mass production in order to generate process improvements and make new products. The experience and knowledge gained through manufacturing then leads to new ideas that start the cycle again. The Department has central responsibility for supporting and expanding each part of this cycle and has the relationships with businesses necessary to identify the workforce skills needed to support new and growing industries.

The Department increases regional and national capacity for innovative manufacturing through partnerships with state and local governments, academic institutions, and the private sector. Through the Department's convening power, regional economic development programs, and statistical and economic analysis, it empowers industry-driven solutions to the shortage of high demand skills. Finally, the Department supports research and development leading to transformative changes in technology and promotes intellectual property policy that supports and protects innovation. By supporting public-private partnerships, such as the Manufacturing USA, the Department helps to accelerate technology development and commercialization, and strengthen the Nation's position in the global competition for new products, new markets, and new jobs.

National Institute of Standards and Technology (NIST) is the only research laboratory in the U.S. government specifically focused on enhancing industrial competitiveness, including a robust research portfolio concentrated on the technical challenges associated with advanced manufacturing. In addition, the NIST Manufacturing Extension Partnership (MEP) is a critical resource to engage small and mid-size manufacturers to develop new products, expand into global markets, and adopt new technologies, such as those in development in the Institutes.

The **Department of Defense (DoD)** requires a mechanism for shaping and developing the domestic design and manufacturing industrial base in support of national security needs. The Manufacturing Technology (ManTech) Program was established in 1956 to advance the maturity of manufacturing processes in order to bridge the gap from research and development to full-scale production and aid in the economical and timely acquisition of weapon systems and components. New emerging technologies hold strategic promise for the DoD, but fragmented and frail ecosystems are at risk of collapse due to infrastructure and workforce complexities. An ecosystem established for DoD requirements only is insufficient to establish a robust and sustainable ecosystem. Instead, advanced manufacturing ecosystems must be built on common commercial and defense manufacturing and design challenges for shared risks and shared benefits.

The **DoD Manufacturing Innovation Institutes**, a key investment strategy for the DoD and ManTech program, are designed to overcome many of these challenges by advancing manufacturing innovation for specific, focused technology area manufacturing ecosystems. The DoD has established six institutes and has two more planned for Fiscal Year 2017. The five institutes, America Makes, the National Additive Manufacturing Innovation Institute; the Digital Manufacturing and Design Innovation Institute (DMDII); Lightweight Innovations For Tomorrow (LIFT),at the time called the Lightweight and Modern Metals Manufacturing Innovation Institute; the American Institute for Manufacturing integrated Photonics – AIM Photonics; and NextFlex | America's Flexible Hybrid Electronics Manufacturing Institute, and AFFOA – Advanced Functional Fabrics of America. The DoD plans to award a cooperative agreement for Revolutionary Fibers and Textiles in Fiscal Year 2016. More information is available at: https://www.dodmantech.com/.

The **Department of Education (DoEd)** supports education at all levels with across-the-board relevance to the knowledge and skill needs of the economy. Particular programs and initiatives focus on Science, Technology, Engineering, and Mathematics (STEM) fields, which are especially important in building the technically skilled workforce needed by the advanced manufacturing industry. Most significantly, the Department administers funds that support career and technical education programs in local education agencies and community colleges across the nation. Further, the Department conducts leadership and technical assistance activities to promote quality career and technical education programs that are well articulated between secondary and postsecondary levels, and lead to successful careers. A particular focus for leadership and assistance programs is on advanced manufacturing, and the Department is supporting federal efforts to revive this sector through its support for the technical skills agenda.

The Department has been active in helping develop Manufacturing USA from its formation, and collaborates with other federal agencies, in particular those that focus on the knowledge and skill needs of the economy and efforts related to student success.

The **Department of Energy (DOE)** mission is to ensure America's security and prosperity by addressing its energy, environmental and nuclear challenges through transformative science and technology solutions. This includes catalyzing the timely, material and efficient transformation of the nation's energy system and securing U.S. leadership in clean energy technologies, as well as, maintaining a vibrant U.S. effort in science and engineering as a cornerstone of our economic prosperity. To accomplish these goals, the DOE has established the Clean Energy Manufacturing Initiative (CEMI) as a cross-cutting initiative within the department to strengthen U.S. clean energy manufacturing competitiveness and to increase U.S. manufacturing competitiveness across the board by boosting energy productivity and leveraging low-cost domestic energy resources and feedstocks. Clean energy manufacturing involves the minimization of the energy and environmental impacts of the production, use, and disposal of manufactured goods, which range from fundamental commodities such as metals and chemicals to sophisticated final-use products such as automobiles and wind turbine blades. The manufacturing sector, a subset of the industrial sector, consumes 25 exajoules (24 quads) of primary energy annually in the U.S. — about 79% of total industrial energy use. The DOE partners with private and public stakeholders to support the research, development, and deployment of innovative technologies that can improve U.S. competitiveness, save energy, and ensure global leadership in advanced manufacturing and clean energy technologies.

The DOE uses Manufacturing Innovation Institutes to develop energy efficiency and renewable energy technologies to support the CEMI. To date, the DOE has awarded two Manufacturing Innovation Institutes. The first, PowerAmerica, is focused on wide bandgap semiconductor technologies for next generation power electronics. The second, the Institute for Advanced Composites Manufacturing Innovation, is focused on composite technologies for vehicles, wind turbine blades, and compressed gas storage tanks. A third institute, Smart Manufacturing: Advanced Sensors, Controls, Platforms and Modelling for Manufacturing, will be awarded in Fiscal year 2017.More information is available at: http://energy.gov/eere/amo/advanced-manufacturing-office.

The **National Aeronautics and Space Administration (NASA)** depends on manufacturing innovation to enhance its technical and scientific capabilities in aeronautics and space exploration. NASA will support the Manufacturing USA Program through funded research and development to help stimulate its mission-related capacity for innovation and economic growth within the government, at universities, and at industrial companies.

NASA’s Space Technology Mission Directorate (STMD) serves as the Agency’s principal organization supporting the Manufacturing USA Program. STMD rapidly develops, demonstrates, and infuses revolutionary, high-payoff technologies through transparent, collaborative partnerships, expanding the boundaries of the aerospace enterprise. By investing in bold, broadly applicable, disruptive technology that industry cannot tackle today, STMD seeks to mature the technology required for NASA’s future missions in science and exploration while proving the capabilities and lowering the cost for other government agencies and commercial space activities. These collective efforts give NASA the ability to do first of a kind missions and longer-term advancements in research and technology — those beyond what industry will take on and those focused on national advancement in aeronautics and space that also align with NASA’s role in the Manufacturing USA Program.

NASA will leverage the Manufacturing USA Program to support advanced manufacturing technology research and development as a critical means of addressing improved affordability, enhanced performance, and improved safety and reliability for NASA’s aerospace research and development efforts. NASA investments span low, mid, and high technology readiness levels (TRLs) through multiple NASA programs including Small Business Innovation Research (SBIR) Program, Small Business Technology Transfer (STTR), Game Changing Development, Technology Demonstration Missions, and other grant opportunities.

Advanced manufacturing research and development at NASA is focused in several areas: cutting-edge materials, additive manufacturing (3D printing), polymer matrix composites, metals processing/joining, robotics, computational physics-based modeling, non-destructive evaluation, and other highly specialized areas. This research and development is conducted through a combination of in-house activities at NASA centers, competitively funded research with universities and industry, and collaborations with other agencies, universities, and industry. The rapid infusion of advanced manufacturing technologies into mission applications is a major emphasis of NASA’s technology investment plan.

NASA is expanding its efforts to engage industry and academia on advanced manufacturing topics central to the nation’s space mission through its National Center of Advanced

Manufacturing, with a particular focus to develop “technology testbeds” within its research facilities and manufacturing technologies that reduce the weight of materials during space flight.

NASA has participated in the Manufacturing USA since its inception and is committed to partnering with other participating agencies to identify key technical challenges in advanced manufacturing research and development, focus resources to address these challenges, and accelerate the development of advanced manufacturing breakthroughs and their translation into commercial products.

The **National Science Foundation (NSF)** supports fundamental advanced manufacturing research, education and workforce training in its Directorates for Engineering, Computer and Information Science and Engineering, Mathematical and Physical Sciences, and Education and Human Resources. It also promotes advanced manufacturing innovation through a variety of translational research programs, including the SBIR, STTR, and Grant Opportunities for Academic Liaison with Industry (GOALI) Programs, and by partnering with industry, states, and other agencies. In fiscal year 2015 the NSF and NIST jointly established and funded MForesight: Alliance for Manufacturing Foresight, a think-and-do tank that harnesses the expertise of the broad U.S.-based manufacturing community to forecast future advanced manufacturing technologies.

The NSF advanced manufacturing investment is primarily through its Cyber-enabled Materials, Manufacturing and Smart Systems (CEMMSS) priority area. An estimated $231.46 million was invested in CEMMSS in fiscal year 2015, with an estimated $164.73 million of that in advanced manufacturing. These programs support fundamental research leading to transformative advances in manufacturing that address size scales from nanometers to kilometers, including process modeling, advanced sensing and control techniques, smart manufacturing using sustainable materials, chemical reactor design and control, and manufacturing processes and enabling technology to support the biopharmaceutical, biotechnology, and bioenergy industries, with emphases on efficiency, economy, and minimal environmental impact. Advanced manufacturing is also supported through the Engineering Research Centers (ERC), Industry/University Cooperative Research Centers (I/UCRC) and Advanced Technological Education (ATE) programs. With an emphasis on two-year colleges, the ATE program focuses on the education of technicians for the high-technology fields that drive our nation’s economy.

All NSF programs welcome the submission of proposals to collaborate with Manufacturing USA Institutes in cutting-edge research and educational projects. Projects that are currently funded by NSF are also encouraged to request funding supplements to perform collaborate research and/or educational projects with institutes. It is expected that the incorporation of the resources, expertise, and experience of Manufacturing Innovation Institutes members will increase the competitiveness of such proposals in merit review.

The U.S. **Small Business Administration (SBA)** was created in 1953 as an independent agency of the federal government to aid, counsel, assist and protect the interests of small business concerns, to preserve free competitive enterprise and to maintain and strengthen the overall economy of our nation. We recognize that small business is critical to our economic recovery and strength, to building America’s future, and to helping the U.S. compete in today’s global marketplace. Although SBA has grown and evolved in the years since it was established in 1953, the bottom line mission remains the same. The SBA helps Americans start, build, and grow businesses. Through an extensive network of field offices and partnerships with public and private organizations, SBA delivers its services to people throughout the United States, Puerto Rico, the U.S. Virgin Islands and Guam.

U.S. Department of Agriculture. Worldwide, the bioenergy and bio-products industries are emerging as new and rapidly growing sectors; given the high productivity of the U.S. agricultural industry, bio-based product manufacturing is a significant opportunity for the U.S. to support growth of a bio-economy. Expansion of the bio-economy has the potential to sustainably harvest and utilize 1 billion tons of new biomass in the U.S. without affecting existing farm and forestry product markets, growing the current market five-fold over the next 15 years and adding $500 billion to the annual bio-economy.

The agricultural sector is essential for ensuring sustainable, reliable, and accessible production of bioenergy and bio-based products that: 1) replace the use of petroleum and other strategic materials that would otherwise need to be imported, 2) create higher-value revenue streams for producers in rural and agricultural communities, 3) improve the nutrition and well-being of animals and humans; and 4) provide ecosystem services such as ensuring clean air and water, biodiversity, and nutrient cycling to the environment and society.

The U.S. Department of Agriculture (USDA) recognizes the role that manufacturing plays in maximizing the benefits of a sustainable, rural economy. Areas of interest include bio-manufacturing and bio-products development to: 1) establish processes and chemical platforms leading to high-value intermediate and end-use products, 2) support commercialization of products developed from basic and applied research, 3) build domestic capability for ongoing bio-manufacturing and bio-products development, and 4) educate and train needed workforce. The growth of the bio-economy also depends upon understanding and addressing the entire supply chain of the bio-economy, rural America’s role in the bio-economy, and the role of research and development.

In addition, nanocellulose materials have enormous promise to bring about fundamental changes in and significant benefit from our Nation’s use of renewable resources. These cellulose nanomaterials when derived from trees: 1) are renewable and sustainable; 2) are produced in trees via photosynthesis from solar energy, atmospheric carbon dioxide, and water; 3) store carbon; and 4) depending upon how long cellulose-based products remain in service, are carbon negative or carbon neutral. Cellulosic nanocrystals, for example, are predicted to have strength properties comparable to Kevlar, have piezoelectric properties comparable to quartz, and can be manipulated to produce photonic structures. Current global research directions in cellulose nanomaterials indicate that this material could be used for a variety of new and improved product applications, including lighter and stronger paper and paperboard products; lighter and stronger building materials; wood products with improved durability; barrier coatings; body armor; automobile and airplane composite panels; electronics; biomedical applications; and replacement of petrochemicals in plastics and composites.

(Link: https://www.manufacturing.gov/agency-partners/)

Department of Defense Additive Manufacturing

Additive manufacturing—building products layer-by-layer in a process often referred to as three-dimensional (3D) printing—has the potential to improve aspects of DOD's mission and operations. DOD and other organizations, such as America Makes, are determining how to address challenges to adopt this technology throughout the department.

Senate Report 113-44 directed DOD to submit a briefing or report on additive manufacturing to the Senate Armed Services Committee that describes three elements. Senate Report 113-176 included a provision that GAO review DOD's use of additive manufacturing. This report addresses the extent to which (1) DOD's briefing to the Committee addresses the directed elements; (2) DOD has taken steps to implement additive manufacturing to improve performance, improve combat capability, and achieve cost savings; and (3) DOD uses mechanisms to coordinate and systematically track additive manufacturing efforts across the department. GAO reviewed and analyzed relevant DOD documents and interviewed DOD and academia officials.

DOD uses various mechanisms to coordinate on additive manufacturing efforts, but it does not systematically track components' efforts department-wide. DOD components share information regarding additive manufacturing via mechanisms such as working groups and conferences that, according to DOD officials, provide opportunities to discuss challenges experienced in implementing additive manufacturing—for example, qualifying materials and certifying parts. However, DOD does not systematically track additive manufacturing efforts, to include (1) all activities performed and resources expended by DOD; and (2) results of these activities, including actual and potential performance and combat capability improvements, cost savings, and lessons learned. DOD has not designated a lead or focal point at a senior level to systematically track and disseminate the results of these efforts, including activities and lessons learned, department-wide. Without designating a lead to track information on additive manufacturing efforts, which is consistent with federal internal control standards, DOD officials may not obtain the information they need to leverage ongoing efforts.

GAO determined that the Department of Defense's (DOD) May 2014 additive manufacturing briefing for the Senate Armed Services Committee addressed the three directed elements—namely, potential benefits and constraints; potential contributions to DOD mission; and transition of the technologies of the National Additive Manufacturing Innovation Institute (“America Makes,” a public-private partnership established to accelerate additive manufacturing) for DOD use.

DOD has taken steps to implement additive manufacturing to improve performance and combat capability, and to achieve cost savings. GAO obtained information on multiple efforts being conducted across DOD components. DOD uses additive manufacturing for design and prototyping and for some production, such as parts for medical applications; and it is conducting research to determine how to use the technology for new applications. For example, according to a senior Air Force official, the Air Force is researching potential performance improvements that may be achieved by embedding devices such as antennas within helmets through additive manufacturing that could enable improved communications; and the Army used additive manufacturing to prototype aspects of a Joint Service Aircrew

Mask to test a design change, and reported thousands of dollars thereby saved in design development.

GAO recommended that DOD designate an Office of the Secretary of Defense lead to be responsible for developing and implementing an approach for systematically tracking department-wide activities and resources, and results of these activities; and for disseminating these results to facilitate adoption of the technology across the department. DOD concurred with the recommendation.

DoD Abbreviations
3D Three-dimensional
DOD Department of Defense
GO Additive Government Organization for Additive Manufacturing
OSD Office of the Secretary of Defense
RDECOM Research, Development and Engineering Command

Multiple DOD components—at the OSD, military department (Army, Navy, and Air Force), Defense Logistics Agency, and Defense Advanced Research Projects Agency levels—are involved in additive manufacturing efforts. At the OSD-level, the Office of the Assistant Secretary of Defense for Research and Engineering develops policy and provides guidance for all DOD activities on the strategic direction for defense research, development, and engineering priorities and coordinates with the Office of the Deputy Assistant Secretary of Defense for Manufacturing and Industrial Base Policy to leverage independent research and development activities, such as additive manufacturing research activities. The Defense Advanced Research Projects Agency's Defense Sciences Office and the military departments—through the U.S. Army Research, Development and Engineering Command (RDECOM); the Office of Naval Research; and the U.S. Air Force Research Laboratory—have laboratories to conduct additive manufacturing research activities. According to Navy officials, the military depots use additive manufacturing for a variety of applications using various material types. These efforts largely include polymer, metal, and ceramic-based additive manufacturing processes for rapid prototyping, tooling, repair, and development of non-critical parts. The DOD components lead and conduct activities related to several types of technology research and development and advancements. Additive manufacturing is one of these activities, and the components are involved to the extent that some of the broader activities include additive manufacturing including:

The Office of the Secretary of Defense (OSD) Office of the Under Secretary of Defense for Acquisition, Technology and Logistics, reporting to the Secretary of Defense, is responsible for all matters relating to departmental acquisition systems, as well as research and development, advanced technology, and developmental test and evaluation, among other things.

The OSD Office of the Assistant Secretary of Defense for Research and Engineering, reporting to the Under Secretary of Defense for Acquisition, Technology and Logistics, is responsible for providing science and engineering integrity leadership throughout DOD and facilitating the sharing of best practices to promote the integrity of DOD scientific and engineering activities. According to DOD senior officials, the Materials and Manufacturing Processes community of interest is one of 17 department-wide coordination groups organized by the Office of the Assistant Secretary of Defense for Research and Engineering to provide broad oversight of the DOD components' efforts in the Science and Technology areas for which the department has responsibilities. The senior officials added that this community of interest does not track all aspects of additive manufacturing and that the information that is tracked and communicated to the Office of the Assistant Secretary of Defense for Research and Engineering is rolled up to a high level.

The OSD Office of the Deputy Assistant Secretary of Defense for Maintenance Policy and Programs provides the functional expertise for centralized maintenance policy and management oversight for all weapon systems and military equipment maintenance programs and related resources within DOD.

The OSD Office of the Deputy Assistant Secretary of Defense for Manufacturing and Industrial Base Policy, reporting to the Under Secretary of Defense for Acquisition, Technology and Logistics, develops DOD policy and provides guidance, oversight, and technical assistance on assessing or investing in defense industrial capabilities, and has oversight responsibility for the Manufacturing Technology program, among other programs, which develops technologies and processes that ensure the affordable and timely production and sustainment of defense systems, including additive manufacturing. In addition, OSD manages the Defense-wide Manufacturing Science and Technology program, which seeks to address cross-cutting initiatives that are beyond the scope of any one military service or defense agency. The Army, the Navy, the Air Force, and the Defense Logistics Agency each have their own manufacturing technology programs, which select and execute activities, such as additive manufacturing research activities.

The Army, the Navy, and the Air Force have research and development laboratories—that is, U.S. Army Research, Development and Engineering Command; Office of Naval Research; and U.S. Air Force Research Laboratory—for projects on the use of new materials, processes, and applications for additive manufacturing.

- **Army, Navy, and Air Force depots and arsenals** use additive manufacturing to produce plastic parts and prototypes for tooling and repairs, such as dust caps for radios, to reduce costs and turnaround time.
- **The Army Rapid Equipping Force** will be reporting to the U.S. Army Training and Doctrine Command in October 2015, according to Army officials. It uses additive manufacturing to produce prototypes forrepairs, such as tooling and fixtures, to reduce costs and turnaround time.
- **Navy components, including the Office of the Chief of NavalOperations, Navy Business Office; the Naval Air Systems Command; and Naval Sea Systems Command**, plan to use additive manufacturing to enable a dominant, adaptive, and innovative Naval force that is ready, able, and sustainable. According to Navy officials, in November 2013, the Chief of Naval Operations directed the Deputy Chief of Naval Operations for Fleet Readiness and Logistics to develop, de-conflict, and manage additive manufacturing effortsacross the Navy. That office has since developed Navy's 20-yearadditive manufacturing vision, according to Navy officials.

The Defense Advanced Research Projects Agency Defense Sciences Office identifies and pursues high-risk, high-payoff fundamental research initiatives across a broad spectrum of science and engineering disciplines, and transforms these initiatives into radically new, game-changing technologies for U.S. national security. According to a senior Defense Advanced Research Projects Agencyofficial, the agency has initiated the Open Manufacturing program, which allows officials to capture and understand the additive concepts, so that they can rapidly predict with high confidence how the finished part will perform. The program has two facilities —one at Pennsylvania State University and the other at the U.S. Army Research Laboratory— establishing permanent reference repositories and serving as testing centers to demonstrate applications of the technology being developed and as a catalyst to accelerate adoption of the technology.

The Defense Logistics Agency procures parts for the military services and is developing a framework to determine how to use additive manufacturing, according to Defense Logistics Agency officials.

The Walter Reed National Military Medical Center 3D Medical Applications Center is a military treatment facility that provides, among other things, computer-aided design and computer-aided manufacturing for producing medical models and custom implants through additive manufacturing. The Walter Reed National Military Medical Center falls within the National Capital Region Medical Directorate and is controlled by the Defense Health Agency, which in turn reports to the Assistant Secretary of Defense for Health Affairs.

DOD has taken steps to implement additive manufacturing to improve performance and combat capability, as well as achieve associated cost savings. GAO obtained information on multiple efforts being conducted across DOD components. For example, the Army used additive manufacturing, instead of conventional manufacturing, to prototype aspects of a Joint Service Aircrew Mask to test a design change, and it reported thousands of dollars saved in design development and potential combat capability improvements. According to a senior Navy official, to improve performance, the Navy additively manufactured circuit card clips for servers on submarines, as needed, because the original equipment manufacturer no longer produced these items. This official also stated that the Navy is researching ways to produce a flight critical part by 2017.

According to a senior Air Force official, the Air Force is researching potential performance improvements that may be achieved by embedding devices such as antennas within helmets through additive manufacturing that could enable improved communications. According to Defense Logistics Agency officials, they have taken steps to implement the technology by additively manufacturing the casting cores for blades and vanes used on gas turbine engines. According to a senior Walter Reed National Military Medical Center official, the Center has used additive manufacturing to produce cranial implants for patients.

DOD uses additive manufacturing for design and prototyping and for some production—for example, parts for medical applications—and it is conducting research to determine how to use the technology for new applications, such as printing electronic components for circuitry and antennas. DOD is also considering ways in which it can use additive manufacturing in supply chain management, including for repair of equipment and production of parts in the field so as to reduce the need to store parts; for production of discontinued or temporary parts as needed for use until a permanent part can be obtained; and for quickly building parts to meet mission requirements. According to DOD officials, such usage will enable personnel in the field to repair equipment, reduce equipment down-time, and execute their missions more quickly.

Some examples that DOD officials provided include the following:

The U.S. Army RDECOM Armament Research, Development and Engineering Center, according to Army officials, plans to achieve performance improvements by developing an additively manufactured material solution for high demand items such as nuts and bolts, providing the engineering analysis and qualification data required to make these parts by means of additive manufacturing capability at the point of need in theater. These officials stated that this solution could potentially reduce the logistics burden on a unit and improve its mission readiness, thus enabling enhanced performance. The U.S. Army RDECOM Armament Research, Development and Engineering Center, in conjunction with the Defense Logistics Agency, evaluated high-demand parts in the Afghanistan Theater of Operations and determined that nuts and bolts were high demand parts that were often unavailable due to the logistical challenges of shipping parts. According to Army officials, additive manufacturing offers customers the opportunity to enhance value when the lead time needed to manufacture and acquire a part can be reduced. According to these officials, in military logistics operations in theater, the manufacture of parts to reduce the lead time to acquire a part is of paramount importance. As of August 2015 the Center had additively manufactured several nuts and bolts to demonstrate that they can be used in equipment and it plans to fabricate more of these components for functional testing and qualification. The officials also stated that this testing will verify that the additively manufactured components can withstand the rigors of their intended applications.

The U.S. Army RDECOM Edgewood Chemical Biological Center prototyped aspects or parts of a Joint Service Aircrew Mask via additive manufacturing to test a design change, which officials stated has resulted in thousands of dollars saved and potential combat capability improvements. A new mask ensemble was built using these parts and was worn by pilots to evaluate comfort and range of vision. Once confirmed, the parts were produced using conventional manufacturing. Since this example was one in a prototyping phase, only low quantities were needed for developmental testing, and additive manufacturing combined with vacuum silicone/urethane casting allowed the Army to obtain a quantity of parts that was near production level. According to Army officials, if conventional production level tools (also called injection molds) had been developed and used in this prototyping phase, costs might have ranged from $30,000-$50,000, with a 3- to 6-month turnaround. These officials stated that additive manufacturing and urethane casting comprised a fraction of the cost—approximately $7,000–$10,000—with a 2- to 3-week turnaround. Had the Army alternatively developed a production tool at this proof-of-concept phase, time and financial investment might have been wasted if the concept had to be changed or started over from the beginning of the design phase, according to the officials.

The U.S. Army RDECOM Edgewood Chemical Biological Center achieved combat capability improvements by designing holders through additive manufacturing, to carry pieces of sensor equipment in the field, according to Army officials. The Center coordinated with the U.S. Army Research Laboratory to develop the holder to carry a heavy hand-held improvised explosive device detection sensor. According to Army officials, the lab wanted a holder that would cradle the handle so as to distribute more weight to the soldier’s vest and back rather than confining it to the soldier’s forearm. Officials at the Center stated that they had additively manufactured many prototypes that were tested by soldiers at various locations around the country within 1 to 2 weeks. According to Army officials, after achieving positive testing results the Center used additive manufacturing to produce the molds that otherwise would have added weeks or months to the process via conventional manufacturing. The final products—10,000 plastic holders—were then produced at the Center through conventional manufacturing.

The Army Rapid Equipping Force achieved combat capability improvements by using additive manufacturing, as part of its expeditionary lab capability, to design valve stem covers for a military vehicle, according to Army officials. An Army unit had experienced frequent failures due to tire pressure issues on its Mine-Resistant Ambush Protected vehicles caused by exposed valve stems; for example, during missions, the tires would deflate when the valve stem was damaged by rocks or fixed objects. The additive manufacturing interim solution was developed in just over 2 weeks, because the additive manufacturing process allowed them to prototype a solution more quickly, according to Army Rapid Equipping Force officials. As shown in figure 5, the Army additively manufactured prototypes for versions 1 through 4 of the covers before a final part was produced in version 5 through conventional manufacturing processes.

The Army Rapid Equipping Force also achieved combat capability improvements, through its expeditionary lab, by producing prototypes of mounting brackets using additive manufacturing, according to Army officials. Army soldiers using mine detection equipment required illumination around the sensor sweep area during low visibility conditions in order to avoid impact with unseen objects resulting in damage to the sensor. Using additive manufacturing, a mounting bracket was prototyped for attaching flashlights to mine detectors in several versions. According to Army officials, due to requests exceeding the expeditionary lab's production capability, the Army coordinated with a U.S. manufacturer to additively manufacture 100 mounting brackets at one-fourth the normal cost.

Tobyhanna Army Depot achieved performance improvement by using additive manufacturing to produce dust caps for radios, according to Army officials. These officials stated that a shortage of these caps had been delaying the delivery of radios to customers. Getting the part from a vendor would have taken several weeks, but the depot additively manufactured 600 dust caps in 16 hours. According to the depot officials, the dollar savings achieved were of less importance than the fact that they were able to meet their schedule.

The Navy is increasingly focused on leveraging additive manufacturing for the production of replacement parts to improve performance, according to Navy officials. When the original equipment manufacturer was no longer producing these parts, the Navy used additive manufacturing to create a supply of replacement parts to keep the fleet ready. This was the case for the Naval Undersea Warfare Center-Keyport, which used additive manufacturing to replace a legacy circuit card clip for servers installed on submarines, as needed/

The Navy installed a 3D printer aboard the USS Essex to demonstrate the ability to additively develop and produce shipboard items such as oil reservoir caps, drain covers, training aids, and tools to achieve performance improvements, according to a senior Navy official. According to Navy officials, additive manufacturing is an emerging technology and shipboard humidity, vibration, and motion may create variances in the prints. Navy officials also stated that while there is not a structured plan to install printers on all ships, it is a desired result and vision to have the capability on the fleet. These officials stated that the Navy plans to install 3D printers on two additional ships.

The U.S. Air Force Research Laboratory, according to a senior Air Force official, is researching potential performance improvements that may be achieved by (1) additive manufacturing of antennas and electronic components; and (2) embedding devices (such as antennas) within helmets and other structures through additive manufacturing, thereby potentially enabling improved communication. The laboratory has a six-axis printing system that has demonstrated the printing of antennas on helmets and other curved surfaces, according to the official. The official also stated that the laboratory conducts research and development in materials and manufacturing in order to advance additive manufacturing technology such that it can be used affordably and confidently for Air Force and DOD systems. Additionally, according to Air Force officials, the Air Force sustainment organizations use additive manufacturing for tooling and prototyping.

According to the December 2014 DOD Manufacturing Technology document the Defense Logistics Agency projected cost savings of 33-50 percent for additively manufacturing casting core tooling. The Defense Logistics Agency—working with industry, including Honeywell, and leveraging the work of military research labs—helped refine a process to additively manufacture the casting cores for engine airfoils (blades and vanes) used on gas turbine engines, according to Defense Logistics Agency officials. According to these officials, printing these casting cores will help reduce the cost and production lead times of engine airfoils, especially when tooling has been lost or scrapped or when there are low quantity orders for legacy weapon systems.

The Walter Reed National Military Medical Center achieved performance improvements by additively manufacturing items that include customized cranial plate implants and medical tooling and surgical guides, according a senior official within the Center. According to the official, additive manufacturing offers a more flexible and applicable solution to aid surgeons and provide benefits to patients. Since 2003, according to the official, the Walter Reed National Military Medical Center has additively manufactured more than 7,000 medical models, more than 300 cranial plates, and more than 50 custom prosthetic and rehabilitation devices and attachments, as well as simulation and training models. The official stated that using additive manufacturing enables each part to be made specifically for the individual patient's anatomy, which results in a better fit and an implant that is more structurally sound for a longer period of time, which, in turn, leads to better medical outcomes with fewer side effects. Furthermore, the official stated that additive manufacturing has been used for producing patient-specific parts, such as cranial implants, in 1 to 5 days, and these parts are being used in patients.

DOD uses various mechanisms to coordinate on additive manufacturing efforts, but it does not systematically track components' efforts department-wide. DOD components share information regarding additive manufacturing through mechanisms such as working groups and conferences that, according to DOD officials, provide opportunities to discuss challenges experienced in implementing additive manufacturing—for example, qualifying materials and certifying parts. However, DOD does not systematically track additive manufacturing efforts, to include (1) all projects, henceforth referred to as activities, performed and resources expended by DOD; and (2) results of their activities, including actual and potential performance and combat capability improvements, cost savings, and lessons learned. DOD has not designated a lead or focal point at the OSD level to systematically track and disseminate the results of these efforts, including activities and lessons learned, department-wide. Without designating a lead to track information on additive manufacturing efforts, which is consistent with federal internal control standards, DOD officials may not obtain the information they need to leverage ongoing efforts.

(Link: http://www.gao.gov/products/GAO-16-56)

Glossary of Advanced Manufacturing Terms

3D Printing: A specific additive manufacturing technology, however, this term has gained common usage to describe all manner of additive manufacturing. See Additive Manufacturing.

Additive Manufacturing: The construction of complex three-dimensional parts from 3D digital model data by depositing successive layers of material. Metal, polymer, and ceramic materials can be used to manufacture parts of a geometry that often cannot be produced by any other manufacturing technology. The names of specific additive manufacturing technologies include: 3D printing, layered object manufacturing, selective laser sintering, selective laser melting, LENS, stereolithography, and fused deposition modeling. Synonyms include layered manufacturing, solid freeform manufacturing, direct digital manufacturing, rapid prototyping.

Advanced Manufacturing: Use of innovative technologies to create existing products and the creation of new products. Advanced manufacturing can include production activities that depend on information, automation, computation, software, sensing, and networking.

Agile Manufacturing: Tools, techniques, and initiatives (such as lean and flexible manufacturing) to help a plant and/or organization rapidly respond to their customers, the market, and innovations. It can also incorporate “mass customization” concepts to meet unique customer needs as well as “quick response manufacturing” to reduce lead times across an enterprise.

Automation: Using control systems to operate an apparatus, process, or system with minimal or reduced direct human intervention.

Benchmarking: Formal programs that compare a plant’s practices and performance results against “best-in-class” competitors or against similar operations.

Bottleneck: A point of congestion in a manufacturing system that arises when parts arrive at a given machine/operation faster than that machine/operation can process them.

Cellular Manufacturing: When dissimilar equipment and workstations to produce a family of similar components or subassemblies are arranged close together to save space and time, and simplify process routing and supervision. Workers are typically cross-trained to perform multiple tasks within a manufacturing cell.

Composites: Materials comprised of two or more components with significantly different physical or chemical properties, that when combined, produce a material that behaves differently from the individual components. The individual components remain separate and distinct within the finished structure. Examples of engineered composite materials include: carbon fiber-reinforced polymers, metal matric composites, ceramic matrix composites, cement, concrete. Wood is an example of a naturally occurring composite material.

Computer-Aided Design: “Computer-aided design (CAD) is the use of a wide range of computer-based tools that assist engineers, architects, and other design professionals in their design activities. It is the main geometry authoring tool within the Product Lifecycle Management process and involves both software and sometimes special-purpose hardware.”

Computer-Aided Manufacturing: In general, computer-aided manufacturing (CAM) refers to "the use of computer systems to plan, manage, and control the operations of a manufacturing plant through either direct or indirect computer interface with the plant's production resources." Computer-aided manufacturing (CAM) often refers to software that takes the geometric design authored with CAD software as input and outputs manufacturing instructions that are downloaded to automated equipment such as a computer numerically controlled (CNC) machine tool. Is also referred to as computer-assisted manufacturing.

Continuous-Flow Manufacturing: A manufacturing method in which the materials (dry bulk or fluids) that are being processed are continuously in motion, undergoing mechanical, thermal, and/or chemical treatment. This is the opposite of batch production. Synonyms include: continuous manufacturing, continuous processing, continuous production, and continuous flow process.

Computer-Integrated Manufacturing: "An approach to integrate production-related information and control entire production processes, automated lines, plants, and networks by using computers and a common database."

Computer Numerical Control: The digital control of a physical machine that consists of a series of integrated actuators, power electronics, sensors, and dedicated computer running under a real-time operating system. Computer numerical control (CNC) can control multiple machines, usually when they are grouped in a manufacturing cell. This is a form of digital automation.

Cross-Training: Training employees in several skill sets so they can fill in for one another as needed.

Digital Manufacturing: Aims to improve product design and manufacturing processes across the board seamless integration of information technology systems across the supply chain. Digital manufacturing focuses on reducing the time and cost of manufacturing by integrating and using data from design, production, and product use; digitizing manufacturing operations to improve product, process, and enterprise performance, and tools for modeling and advanced analytics, throughout the product life cycle.

Discrete Manufacturing: Producing finished products that can be recognized as distinct physical units via serial numbers or other labeling methods.

Flexible Manufacturing System: Integrated group of manufacturing equipment and/or cross-trained work teams that can produce a variety of parts in the mid-volume production range. Flexible refers to the systems capability to manufacture different part variants and production quantity can be adjusted in response to changing demand.

Industry 4.0: A term coined in Germany, popularly used in Europe, and equivalent to smart manufacturing. See Digital Manufacturing.

Just-in-Time: Just-in-time (JIT) techniques reduce setup times, inventory, and waste, and improve products and reduce manufacturing cycle time. Synonyms include: continuous-flow production. JIT is a total manufacturing system that was first introduced by Toyota Motor Corporation.

Kaizen: Practice of focusing on continuous process improvement.

Lean Manufacturing: A manufacturing practice that aims to reduce wasted time, effort or other resources in the production process.

Manufacturing cost: Includes quality-related costs, direct and indirect labor, equipment repair and maintenance, other manufacturing support and overhead, and other costs directly associated with manufacturing operations.

Manufacturing Cycle Time: The time of actual production from the moment a customer order arrives on the plant floor to the completion of all product manufacturing, assembly, and testing.

Manufacturing Innovation Institute: A Manufacturing Innovation Institute is a public-private partnership of companies, academia, state and local governments and federal agencies that co-invest in developing world-leading technologies and capabilities. Each institute creates the necessary focus and provides the state-of-the-art facilities needed to allow collaborative, mostly pre-competitive development of promising technologies. An institute provides workforce education and training in advanced manufacturing. An institute promotes the creation of a stable and sustainable innovation ecosystem for advanced manufacturing.

Manufacturing USA: the brand name for the National Network for Manufacturing Innovation Program.

National Network for Manufacturing Innovation: As a part of the strategy to revitalize American manufacturing, the Revitalize American Manufacturing and Innovation Act of 2014 authorizes the Department of Commerce to establish and convene a nationwide "network" comprised of the individual Manufacturing Innovation Institutes, which can enhance their impacts and further strengthen America's global competitiveness.

North American Industry Classification System: A coding system of the U.S., Mexican, and Canadian governments that identifies specific economic sectors.

OEM: Original equipment manufacturer.

Planning and Scheduling Technologies: A variety of software-based advanced planning, scheduling, and optimization systems.

Process Manufacturing: Manufacturing products such as chemicals, gasoline, beverages, and food products in "batch" quantities.

Product-Development Cycle: Often called time to market, this is the period from when design/development work begins to the time that the final product is available for purchase.

Rapid Prototyping: Techniques to quickly fabricate a scale model of a physical part or assembly. Historically, this term has referred to the use of additive manufacturing to create the part. The term is falling out of favor to describe all additive manufacturing technologies because they are seen as being able to do more than just prototyping: i.e., they are now being used for production of final parts and assemblies.

Robotics: Mechanical or electrical engineering coupled with computer science used to design, construct, operate, and apply robots. It also includes the computer systems for their control, sensory feedback, and information processing. Where a robot is a reprogrammable, multifunctional manipulator designed to move material, parts, tools, or specialized devices through various programmed motions for the performance of a variety of tasks.

Six Sigma: One method of preparing and controlling the compliance of processes and products with predetermined quality standards. Six Sigma at many organizations simply means a measure of quality that strives for near perfection. Six Sigma is a disciplined, data-driven approach and methodology for eliminating defects (driving toward six standard deviations between the mean and the nearest specification limit) in any process. To achieve Six Sigma, a process must not produce more than 3.4 defects per million opportunities.

Smart manufacturing: Aims to reduce manufacturing costs from the perspective of real-time energy management, energy productivity, and process energy efficiency. Initiatives will create a networked data driven process platform that combines innovative modeling and simulation and advanced sensing and control. Integrates efficiency intelligence in real-time across an entire production operation with primary emphasis on minimizing energy and material use; particularly relevant for energy-intensive manufacturing sectors.

Supply-Chain/Logistics Systems: Manufacturing software to optimize scheduling and other activities throughout the supply chain.

Total Quality Management: A company-wide approach to improving quality and customer satisfaction–including fast response and service, as well as product.

(Link: https://www.manufacturing.gov/news-2/news/glossary-of-advanced-manufacturing-terms/)