

Additive Manufacturing: Pursuing the Promise

Digital manufacturing paves the way for innovation, mass customization, and greater energy efficiency as part of the national all-of-the-above energy strategy.

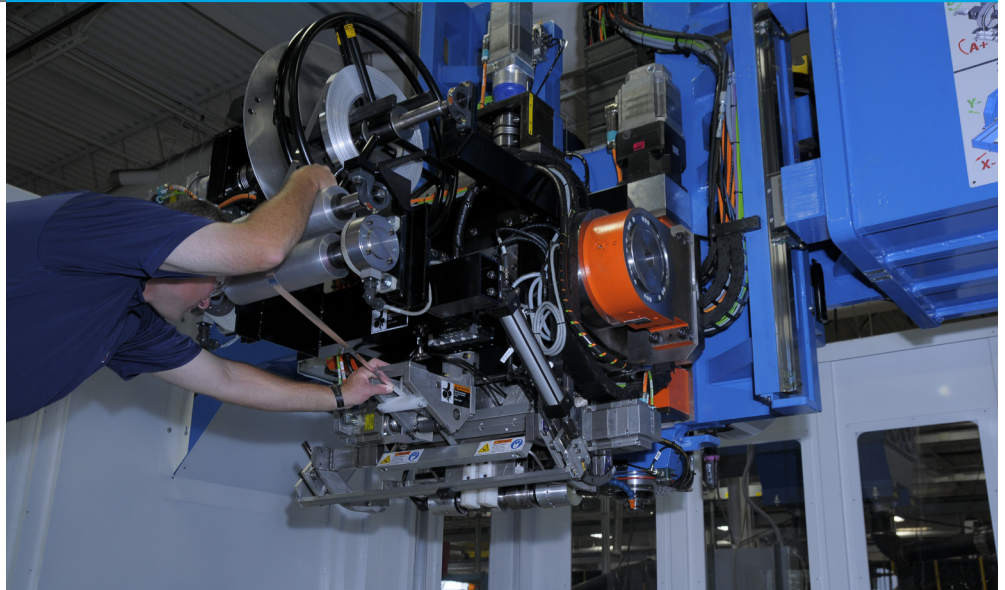
Additive manufacturing techniques create 3-D objects directly from a computer model, depositing material only where required. These new techniques, while still evolving, are projected to exert a profound impact on manufacturing. They can give industry new design flexibility, reduce energy use, and shorten 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.



Thin metal foil is being loaded into an additive manufacturing welding system that uses sound to print parts from dissimilar metals like aluminum, copper, steel, and titanium.

Photo courtesy of Fabrisonic.

- **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,¹ using only 2–25% of the energy required to make new parts.²
 - **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%.³
 - **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.

1 Advanced Manufacturing Office, U.S. DOE, “Materials: Foundation for the Clean Energy Future,” January 2012. http://energy.tms.org/docs/pdfs/Materials_Foundation_for_Clean_Energy_Age_Press_Final.pdf

2 John Sutherland et al., “A Comparison of Manufacturing and Remanufacturing Energy Intensities with Application to Diesel Engine Production,” *CIRP Annals—Manufacturing Technology*, vol. 57, no. 1 (2008): 5-8.

3 *The Economist*, “The Printed World: Three-dimensional printing from digital designs,” 10 February 2011. www.economist.com/node/18114221

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.⁴

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.

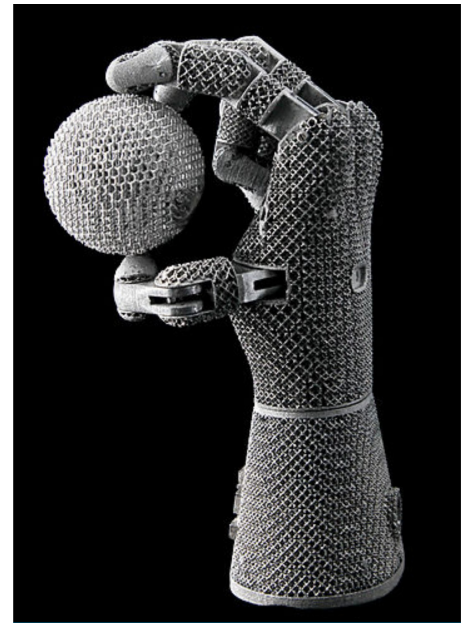
The healthcare industry is investing in tailored prosthetics, dental implants, hearing aids, and other types of medical devices and tools. Manufacturers of many consumer products may soon be using additive techniques in their production processes to embed electronic components and circuits in substrates, reduce device weight and volume, and improve electrical performance.⁵

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.



A titanium prosthetic hand produced via additive manufacturing.

Photo courtesy of Oak Ridge National Laboratory.

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.

4 *The Economist*, "Solid Print: Making Things with a 3D Printer Changes the Rules of Manufacturing," 21 April 2012. www.economist.com/node/21552892

5 Alberto Pique et al, "Laser Direct Write of Embedded Electronic Components and Circuits," Princeton University.

Manufacturing converts a wide range of raw materials, components, and parts into finished goods that meet market expectations. The Advanced Manufacturing Office (AMO) partners with industry, small business, universities, and other stakeholders to identify and invest in emerging technologies with the potential to create high-quality domestic manufacturing jobs and enhance the global competitiveness of the United States.