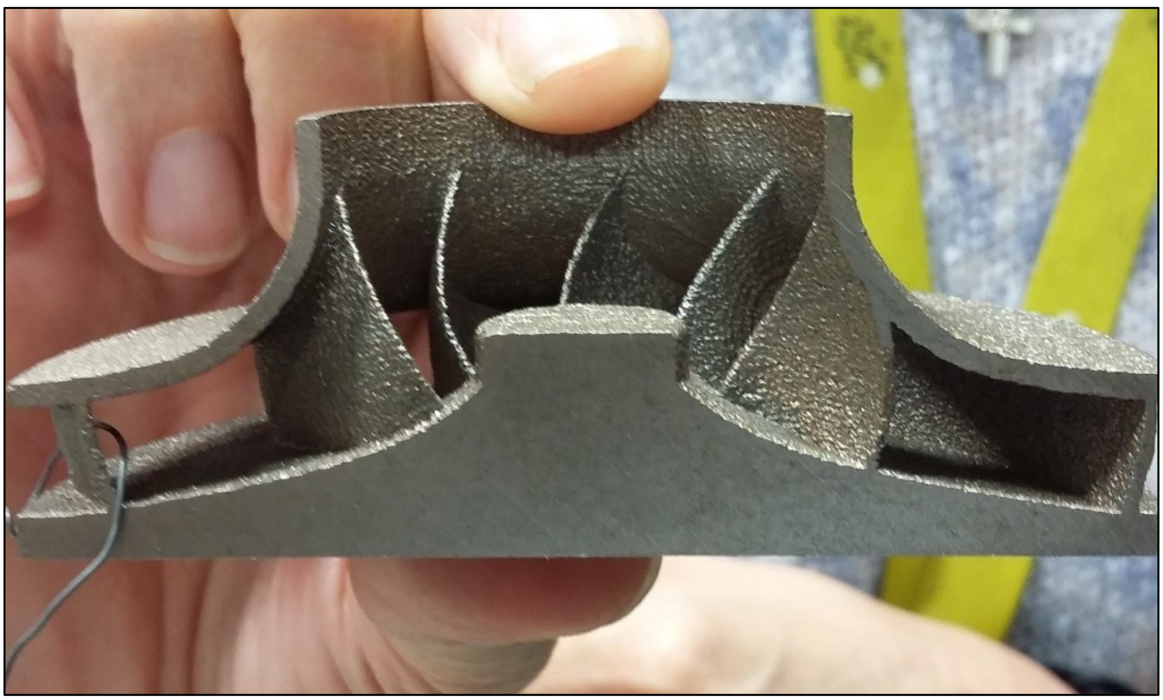
RECLAMATION
*Managing Water in the West*

# 3D Metal Printing

**Research and Development Office**
**Science and Technology Program**
**Final Report ST-2017-1737 (1)**



**U.S. Department of the Interior**
**Bureau of Reclamation**
**Research and Development Office**

**October 2019**

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Protecting America's Great Outdoors and Powering Our Future

The Department of the Interior (DOI) conserves and manages the Nation's natural resources and cultural heritage for the benefit and enjoyment of the American people, provides scientific and other information about natural resources and natural hazards to address societal challenges and create opportunities for the American people, and honors the Nation's trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities to help them prosper.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

### Cover Photograph:

Pump impeller printed using three-dimensional additive manufacturing technology.

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System downtimes could be reduced through means of 3D metal printing by allowing the production of parts onsite in a fraction of the time and costs. The adoption of 3D metal printing of large-scale components in other industries such as aerospace and automotive indicates the technology is proven and reliable.


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# Bureau of Reclamation

## Research and Development Office
## Science and Technology Program

## Mechanical Equipment Group, Technical Service Center, 86-68410

## Final Report ST-2017-1737 (1)

# 3D Metal Printing

*Retired*

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# Acronyms and Abbreviations

| | |
|---|---|
| 3D | three-dimensional |
| AM | additive manufacturing |
| ASTM | American Society for Testing and Materials |
| CAD | computer-aided design |
| CNC | Computer Numerical Control |
| DOE | U.S. Department of Energy |
| GE | General Electric Company |
| ISO | International Organization for Standardization |
| MDF | Manufacturing Demonstration Facility |
| OEM | original equipment manufacturer |
| ORNL | Oak Ridge National Laboratory |
| Reclamation | Bureau of Reclamation |

# Executive Summary

The Bureau of Reclamation (Reclamation) is faced with an increasingly aging infrastructure composed of many features and parts that require continual maintenance, upgrade, and replacement efforts and expenditures. Powerplant machine shops are backlogged with orders for everything from original equipment manufacturer (OEM) parts to custom parts where spares are no longer available and the tools and craftsmanship necessary to create them have all but vanished. (Some custom fabricated parts are seen in figure ES-1.)

In addition, procurement and contracting for these aging components is also becoming increasingly more difficult. Being reliant on traditional procurement sources for some of Reclamation's key parts and materials puts Reclamation at risk of being incapable of maintaining and repairing equipment in a timely and economical fashion.

Research in the area of three-dimensional (3D) metal printing, as it relates to the hydropower industry, is limited at best, if not altogether lacking. Thus, a research project was proposed and sought to identify if Reclamation can benefit from 3D metal printing technologies and answer one of many questions: Can Reclamation build on the successes seen in other industries to improve performance and reduce system downtimes?

**Figure ES-1.—Examples of custom fabricated parts requiring multiple manufacturing steps and, subsequently, long lead times to create.**

System downtimes could be reduced through means of 3D metal printing by allowing the production of parts onsite in a fraction of the time and costs. The adoption of 3D metal printing of flight-critical components in aerospace indicates the technology is proven and reliable. The growing use of large-scale 3D-printed components in aerospace, automotive, appliances, and biomedical industries shows the technology is quickly adapting to the diverse needs of industry.

However, the hydropower industry presents unique challenges compared to those of other industries thus research was needed to determine if this technology could be leveraged both safely and effectively. Working with hydropower owners, operators, and industry partners, such as the U.S. Department of Energy's (DOE) Manufacturing Demonstration Facility (MDF) at Oak

Ridge National Laboratory, could begin to advance awareness of how this technology may be used within the hydropower community.

Hence, this research consisted of a site visit to DOE's MDF at Oak Ridge National Laboratory, the largest DOE science and energy laboratory, where scientists are conducting state-of-the-art applied research in the field of 3D additive manufacturing (AM) to determine which technologies, if any, would be suitable for implementation at Reclamation facilities (see figure ES-2).

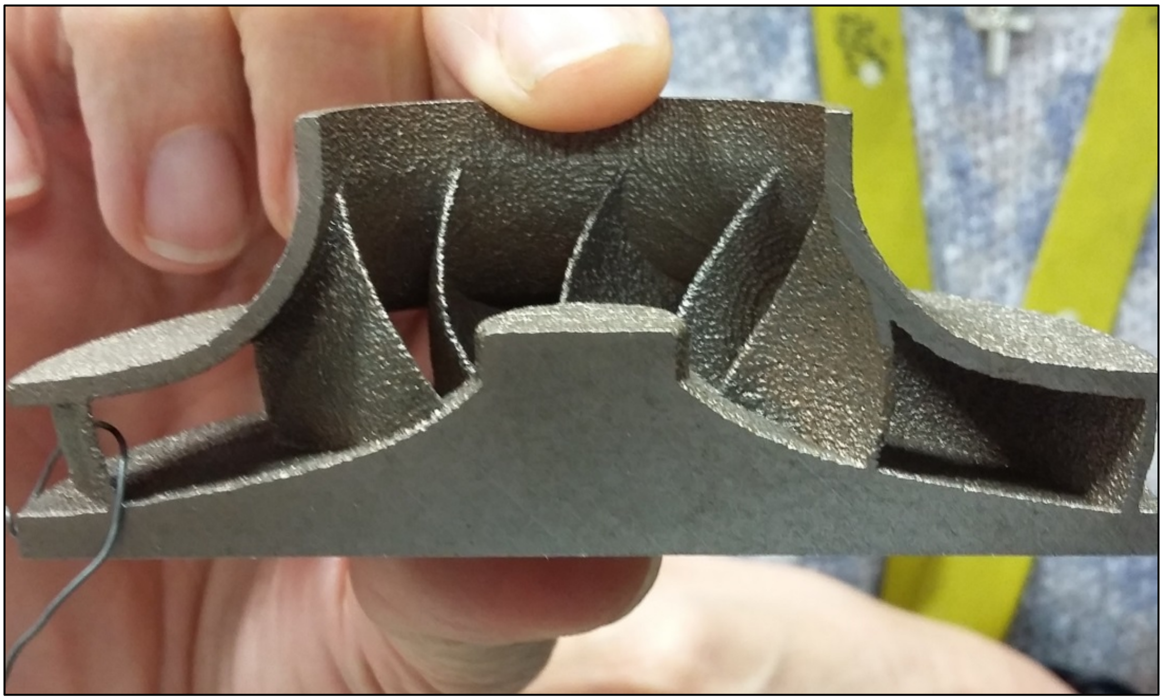

**Figure ES-2.—Pump impeller printed using 3D AM technology. Note the curved impeller blades created in situ during parts creation.**

A thorough literature search and review were also conducted to uncover current industry trends and how Reclamation may play a role in the development of this burgeoning field of manufacturing.

This research project identified Reclamation can indeed benefit through using 3D metal printing and AM technology by leveraging commercial businesses to supply its legacy parts faster than traditional methods. There are existing service bureaus that rapidly manufacture complex metal parts by simply uploading a 3D computer-aided design (CAD) model of the part.[1] Furthermore, industry-driven businesses like GE Additive, a part of General Electric Company (GE), are making enormous investments to industrialize AM technologies.[2] However, due to material and capital equipment costs, onsite parts creation at Reclamation facilities, at least in the realm of 3D

[1] As one such example, see https://www.shapeways.com/
[2] https://www.ge.com/additive/

metal printing, would benefit from further research efforts with DOE's MDF at Oak Ridge National Laboratory (in collaboration with stakeholder within the hydropower industry such as manufacturers and hydropower facility owners and operators). For new equipment and parts supplied by manufacturers, using AM may provide reduced manufacturing costs and, consequently, faster lead times and lower costs to the Government. However, while AM provides an alternative means of parts creation for contractors supplying Reclamation, it is important to note that parts certification will remain a priority over means and method of production. The U.S. Department of Defense and the aerospace industry are leading efforts to certify and quality parts, through data analytics, immediately as they leave the machine (i.e., "Born Qualified"). These efforts are only a few years away, not decades, so the timing is right for Reclamation to understand the rapidly evolving AM industry.

Future research efforts could focus on 1) procuring AM components and demonstrating those products at a facility to prove their performance and 2) working with stakeholders within the hydropower industry to determine suitability of components for potential AM technology and identifying Reclamation facilities willing to demonstrate their use. This will require assembling both internal and external experts to further these research efforts.

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# Background

Since the 1980s, the field of AM has been filled with new process developments, bold entrepreneurs, and daring business ventures. In the past several years, the field of 3D printing has grown exponentially as new technologies, methods, materials, applications, and business models are introduced. Figure ES-3 illustrates the demand of 3D-printed parts by industry as of 2017.

International Standard ISO/ASTM 52900, "Standard Terminology for Additive Manufacturing – General Principles – Terminology," defines 3D printing as "the fabrication of objects through the deposition of material using a print head, nozzle, or another printer technology." In the past, this has been associated with low-end machines of little cost and overall capability. The standard also defines AM as "a process of joining materials to make objects from 3D model data, usually layer upon layer." However, today these words have become synonymous and are collectively used to describe the process of building physical models, prototypes, patterns, tooling components, and production parts in plastics, metals, ceramics, glass, composites, and biomaterials from 3D computer models.

**Table 1.—AM Parts Demand by Industry. Source: Wohlers Associates, Inc. [1].**

| Industry | Demand (percent) |
|---|---|
| Industrial Business Machines | 19 |
| Aerospace | 18 |
| Motor Vehicles | 15 |
| Consumer Products/Electronics | 13 |
| Medical/Dental | 11 |
| Academic Institutions | 8 |
| Other | 7 |
| Government/Military | 6 |
| Architectural | 3 |

The list of metal materials available for use in 3D printing is expanding each year. New processes are producing metal parts nearing 100 percent density (no porosity) with many that exceed the properties of cast parts in the same material and some that approach the properties of wrought materials. However, certification remains an important element in the future adoption and integration of 3D-printed parts into critical service, especially considering the effects of reduced fracture toughness and fatigue properties in less than full density 3D-printed metal parts.

# Conclusions and Recommendations

Metal AM parts can reduce material, waste, and weight and are ideal for both rapid tooling and low volume production of complex parts making AM a potentially good fit for many of Reclamation's manufacturing needs. Many industries (aerospace, automotive, appliances, biomedical) are already using AM for low-cost rapid tooling. Where full parts creation is not possible, leveraging 3D printing of metal parts to get near-net-shape parts could significantly reduce the overall time required to build a part.

While this applied research project has focused on the implementation of 3D metal printing, as it relates to legacy parts, it should be noted that detailed consideration in designs should be given to AM manufacturing process requirements such as parting lines, draft angles, and wall thicknesses in order to take advantage of AM in the future.

AM technologies suffer more from lack of consistency than lack of capability and without a sufficient body of supporting data, parts certification is very costly and time intensive. ASTM International, formerly known as American Society for Testing and Materials, established a standards committee, "ASTM Committee F42 on Additive Manufacturing Technologies," to help address these and other issues related to the AM realm.

With regard to onsite printing of metal parts, while possible, the costs of initial setup are exceedingly high. Estimates for initial startup costs could easily exceed $1 million, potentially $2 million. Added to that are operating costs such as gas rental and use, gray water disposal, software licenses, and maintenance/power costs. All totaled, these operating costs are estimated at $170,000 annually [1]. One technology that may enable lower cost, near term entry into AM part manufacturing, is the Binder Jetting process by the ExOne Company.[3] While AM parts using laser or electron beam processes are typically very expensive, the Binder Jetting process is relatively simple and low cost (the part in figure ES-2 was manufactured using the Binder Jetting process). Shapeways, Inc., manufactures customized jewelry using the Binder Jetting metal AM process.

Many of Reclamation's manufacturing needs could be met by the technologies that AM has to offer. However, rather than attempting onsite creation of legacy parts through the purchase of 3D printer systems and equipment, it is far more economical to outsource parts that have exceptionally long lead times or cannot be reproduced due to lack of tooling and/or craftsmanship to 3D printing vendors (such as Shapeways, Inc.). Vendors can provide those parts at a fraction of what the startup costs would be to own and operate a 3D metal printing machine onsite. One area that likewise needs to be explored is the ability to rapidly reverse engineer-damaged parts where no CAD model exists, and purchase is no longer possible. With the growth of the AM industry, there has also been significant improvements in 3D scanning tools.

The future development of AM technologies will continue to free engineers and designers from the limitations of traditional manufacturing.

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[3] https://www.exone.com/

# References

[1] Wohlers Associates, Inc. 2017. *Wohlers Report 2017*. 3D Printing and Additive Manufacturing State of the Industry, Annual Worldwide Progress Report. Fort Collins, Colorado, 344 pp.

# Appendix A – Grand Coulee Power Office Site Visit (April 2018)

The Grand Coulee Power Office in Reclamation's Pacific Northwest Region hosted personnel from across Reclamation and experts from DOE's MDF at Oak Ridge National Laboratory to examine the current uses of their machine shop and the parts created in order to help Reclamation determine if AM technology would be feasible. Reclamation personnel included staff from the Mid-Pacific Region's Central California Area Office, the Lower Colorado Region's Lower Colorado Dams Office, the Technical Service Center, and the Research and Development Office.

The benefits of using AM are significantly shortened lead times, reduced fabrication costs, increased part quality, and failure-specific material upgrades on portions of an existing part.

The representatives from DOE's MDF at Oak Ridge National Laboratory briefed attendees on current AM technologies and their applicable materials that include:

- Metal Binder Jetting – Typically used to print metal matrix composites, stainless steel, bronze, tungsten, and titanium. The printers have large print beds, and are faster than other powder bed systems.

- Electron Beam Melting – Typically uses pre-alloyed metal powders or wire. The printer produces stress-relieved parts or structures that have better physical properties than cast components and can withstand high temperature applications.

- Selective Laser Sintering – Can be used with a variety of materials including metals, ceramics, and polymers. The process uses a laser to sinter powdered material together, thereby limiting any phase changes to the surface of the powders being used.

- Selective Laser Melting – Can be used with a wide range of materials, including stainless steels, tool steels, aluminum, titanium alloys, and nickel alloys. The process is similar in concept to Selective Laser Sintering, with the key difference being that the powdered material is melted, allowing the creation of parts with higher density. The printer has a large build volume and can produce complex shapes and designs.

- Laser Metal Deposition – Is a site-specific material addition for the application of advanced coating materials. Produces fully dense parts with strong metallurgical bonds to the base material. Ideal for refurbishing worn parts.

There are currently several prominent traditional manufacturers in AM. The Yamazaki Mazak Corporation is utilizing Laser Powder Feed and CNC machining hybrid tooling (Integrix-i400AM) in manufacturing cells, which are currently available for purchase. The KUKA Robotics Corporation and Wolf Robotics/Lincoln Electric Company are also exploring AM using large-scale wire feed welding technology.

When selecting parts for AM, consider wear parts with long lead times, no design drawings, complexities of tooling, and large numbers of operations to create.

Some parts identified for potential AM at Reclamation include:

- Saddle washers/bearings for grounding (micarta, G10-G11 fiber glass reinforced epoxy). AM of these parts would be highly advantageous because they are currently expensive to produce and require a large number of operations with difficult-to-clean machines

- Insulators

- Parts for 480-volt distribution panel

- Governor pumps (herring bone gears)

The Grand Coulee Power Office's machine shop identified parts that they might like to produce using AM. Figure A-1 shows examples of the parts selected; all can be produced using AM technologies.

**Figure A-1.—Parts identified by the Grand Coulee Power Office's machine shop as candidates for AM.**

**Starting in the top left and working clockwise: Innomag pump impeller (stator cooling water system, Third Powerhouse); Niles lathe gear (machine shop); two pump shaft couplings, (Right Powerhouse); governor unloader piston (Third Powerhouse); governor unloader (Third Powerhouse); ring seal gate roller chain roller (Left/Right Powerhouses); Innomag pump part; collector ring, saddle washer (John W. Keys Pump-Generating Plant); gear (unspecified origin); Niles lathe shaft (machine shop).**