2017

PM INDUSTRY ROADMAP

Technology Update
for the Powder Metallurgy Industry

METAL POWDER INDUSTRIES FEDERATION
Powder metallurgy (PM) is a state-of-the-art metal-forming process for producing high-quality net-shape components for a wide variety of important applications. The PM process can be broken down into four categories: conventional or press-and-sinter; metal injection molding (MIM); hot or cold isostatic pressing (HIP/CIP); and metal additive manufacturing (AM). PM’s high material utilization promotes efficient use of raw materials, reduces energy consumption, and improves labor efficiency. These attributes have enabled PM to firmly establish itself in applications for the automotive, electrical, energy, aerospace, medical, defense, industrial, and consumer markets. To continue to grow, the PM industry must respond to the changing needs of existing and potential customers within these markets.

The PM industry’s growth has been facilitated by addressing the technology challenges identified in the *PM Industry Vision and Technology Roadmap*, which was originally published by the Metal Powder Industries Federation in 2001 and updated in 2012. Since 2012, the PM industry has made significant progress in the processing of lean ferrous alloys, aluminum, titanium, magnesium, and metal matrix composites. Component densities continue to rise with improvements in powders, lubricants, tooling, warm compaction, high-tonnage compaction presses, and sintering technology. The most visible advance since the 2012 update is the rapid emergence of metal AM, but MIM has also grown significantly, as it has advanced in material options, process control, and standardization. These material and process developments have enabled new PM applications, such as variable valve timing sprockets, electronic power steering pulleys, turbocharger vanes, and jet engine fuel nozzles.

Due to the significant advancements over the past five years, the PM industry came together again in 2016–2017 to assess and update the Technology Roadmap. This 2017 update reviews current and future demands of key markets and identifies the technical barriers, challenges, opportunities, and priorities that will drive the PM industry’s continued growth. The main topics identified are:

- High-density PM components
- Processing of lightweight materials
- Improvements in precision, accuracy, and variation control
- Metal AM

This update also reviews the achievements made by the PM industry between 2012 and 2017, provides an overview of the PM industry, and describes the four main categories of PM processes. The original 2001 Technology Roadmap is still valid and relevant. It should continue to serve as a reference for the PM industry’s long-term vision to be the preferred source of net-shaped metal-based components; however, this 2017 update is expected to help guide the development of the PM industry over the next few years.
The current powder metallurgy (PM) industry is driven by applications in the automotive market. Growth opportunities for PM technology over the next 10 years include energy, aerospace, medical/dental, electrical and electromagnetics, defense, and industrial and consumer products.

Environmental concerns will significantly alter the focus of the automotive sector, the industry’s largest customer. Higher fuel efficiency through improvements in engine performance, weight reduction, and alternative or supplemental power systems will be key drivers.

The need for alternative energy sources will drive new markets and applications for PM.

The aging population will continue to create a need for PM applications in the medical industry.

Global economic development and rising living standards will have a significant impact on PM in consumer products.

The refinement and acceptance of metal additive manufacturing (AM) as a viable manufacturing option will increase demand for new, unique metal powders, equipment, and products/applications.

MARKETS AND CUSTOMER DEMANDS

The industry must respond to the changing needs and demands of existing and potential customers with agility and ingenuity while maintaining higher value than competing materials technologies. Innovative design takes into account both the strategic advantages of sustainability and minimizing adverse environmental impact. PM’s sustainable value is primarily derived from its net-shape capabilities and its high material-utilization that minimizes energy inputs, reducing the impact on the environment.

Automotive

Legislation to improve fuel efficiency is a driving force. The Corporate Average Fuel Economy (CAFE) goal has stimulated efficiency technologies, i.e. lightweight design, lightweight materials, alternative energy sources, through metal injection molding (MIM), metal AM, powder forging (PF), and warm compaction. Fuel efficiency continues to be increased with the help of PM components. The following systems are good examples:

- Variable compression ratio piston/connecting rod
  - The variable compression ratio is achieved by raising or lowering the height the pistons reach within the cylinder, optimizing compression ratio depending on the driving conditions. Components required in the system offer opportunities for PM design, materials, and process technologies.

- Multi-speed automatic transmissions
  - The market potential for automotive transmission gears is a strong motivator for the PM industry. The gear market is believed to be nearly the size of the entire PM market. Fully dense PM gears, with mechanical properties and
surface finishes comparable with cut gears, would ultimately be preferred by the ground vehicle industry.

➢ Turbochargers
  - Annual sales of vehicles with turbochargers are expected to increase 35% from 38 million in 2016 to 52 million in 2021.

Opportunities will arise for the PM industry to supply hybrid/electric vehicle components including fuel cells, electric motors, and gears.

Electrical and Electromagnetic

The development of applications for hard and soft magnetics will drive the demand for electromagnetic controls. The multitude of shapes that can be pressed or molded into stators and armatures using PM consolidation techniques and powders, without a loss in electrical performance characteristics, have modernized this sector. With the advent of hybrid/electric propulsion and continued electrification of systems for transportation, the design and weight advantages of PM create market opportunities for the technology.

Energy

The reduction of greenhouse-gas emissions and the realization that fossil-fuel reserves are finite will continue to be a global focus.

Energy industries are an opportunity for PM technology. Applications are increasing in the established energy sector such as oil-and-gas drilling, hydro-electric, nuclear, as well as sustainable energies, such as wind, solar and tidal energy. Fuel cells continue to be developed. Energy infrastructure requires bearings, gears, adaptors, clamps, electric motors, generators, storage, sensors, switches, interconnects, coatings, and powders—all prospects for PM.

Aerospace

Traditionally, the aerospace industry grows at a rate of 5% per year. Like automobiles, aircraft will become more fuel efficient to minimize fuel cost and respond to expected pressure to reduce greenhouse-gas emissions. PM hot isostatic pressing (HIP) and metal AM technologies should find opportunities in aerospace applications. The industry needs to develop materials and standards for non-critical parts to build confidence leading to flight critical parts. The need for more efficient engines will continue to drive development of higher-strength materials that can operate at higher temperatures. PM superalloys will continue to be used in extremely demanding applications. The industry needs to build upon this success by developing new materials and processes. Advances in repair technology, metal AM, and HIP processing of near-net-shape and net-shape components will continue to enable greater utilization of PM materials for aerospace applications.
The medical market encompasses a broad spectrum of sub-markets or segments that include products ranging from cosmetic enhancements, dental, diagnostic equipment, hospital furniture and equipment, implants, medical mobility equipment such as wheelchairs, prostheses, pharmaceuticals and surgical devices, to first-aid and wound-care products. Applications for MIM exist in three of the segments, which are identified as dental products, orthopedic products, and other medical devices and equipment. These three general market segments are further divided into product applications that comprise the medical device and diagnostics industries. Opportunities for metal AM exist in customized implants for both orthopedic and dental markets.

Within the medical device and diagnostics industries, two sub-categories or market segments have been identified that have product applications requiring the unique capabilities of the MIM process. These sub-market segments are surgical or procedural devices and implants. Within the surgical or procedural device sub-market segment, product applications for minimally invasive medical procedures can be found. These procedures constitute the greatest growth opportunity for MIM as the devices required to perform these procedures utilize components with high levels of sophistication, demanding material properties, and often are disposable, which drives significant increases in annual-production-volume requirements. Metal AM opportunities are primarily in the implant segment.

The North American medical device and diagnostics industries account for more than one-third of the estimated $350 billion worldwide market. Expected growth rate through 2020 is estimated to be 5% annually. As surgeries increase in number and complexity, there will continue to be a significant need for new medical devices, which is expected to support continued long-term growth of the market segment.

The orthopedic sector represents the largest portion of the medical device and diagnostic industries, with the highest revenues. Orthopedics also has the largest number of active companies within its sector. With these replacement surgeries, biomaterials demand will grow as patients become more knowledgeable and expect better-performing devices.
Continuing and emerging threats will drive development of new technologies to meet the detection, protection, mobility, lethality, and energy requirements for defense and homeland security. Advances in security screening, such as X-ray scanning, will continue to make use of tungsten-based collimators and shielding that are processed by PM. Refractory materials will continue to be used in kinetic-energy weapons and for maintaining proper weight distribution in missiles and aircraft. PM lightweighting is a solution to improve fuel efficiency and enhance mobility. Components with unique combinations of properties may be produced by emerging PM processes. Fabrication and repair of parts, both in manufacturing facilities and in the field, may be performed by metal AM technologies.

The second-largest combined market for PM encompasses a wide array of applications. New developments will open opportunities for industrial and consumer products. Applications such as telecommunications, computers, home appliance, lawn & garden, farm/off-road equipment, power and hand tools, recreation transportation, sporting goods, and firearms, as well as other high-tech industries, will need component solutions as they provide new products and services to consumers. Increases in living standards throughout the world are expected to expand consumer markets. As metal AM becomes more prevalent, aftermarket replacement part opportunities will develop.
Continued growth of the powder metallurgy (PM) industry depends on advancements in materials and material properties, processes and manufacturing efficiencies. The four main focus areas of technology priorities for the next decade are: high-density PM components; processing of lightweight-materials; improvement in precision/accuracy/variation control; and metal additive manufacturing (AM).

**HIGH-DENSITY PM COMPONENTS**

**CHALLENGES**

Density plays a significant role in mechanical properties. Achieving the highest density possible is normally the goal because, as density is pushed higher, the mechanical properties of the structure approach those of wrought metal, which is considered fully dense. As higher densities become feasible, a larger percentage of the overall fabricated-metal-products market can be captured by the PM industry, as the economic advantages of PM processing techniques are applied to high-density components.

**Materials:**

- **Development of new materials to replace wrought materials**
  Cost-effective high-density components manufactured from materials with mechanical properties comparable with wrought are required by engineers.

- **Enhanced compactibility of mixes**
  Material systems whose characteristics allow high compactibility that enables higher-density components to be formed in the green state are greatly desirable.

- **New lubricants**
  Typically, 0.5–1.0 weight percent of dry lubricant is added to the powder mixes to aid part ejection after mechanical compaction. However, the low bulk density of typical lubricants displaces valuable space preventing higher compacted green densities. More efficient lubricants will enable higher densities supporting the development of high-density PM components.

- **Implantable alloys**
  Development and standardization of PM processes for implantable materials will enable increased acceptance into the medical market.

**Processes:**

- **Die-lubrication technology**
  Refined die-wall lubrication technology will enable higher-density components.

- **Sintering optimization**
  Consistent with the development of high-density compaction technology, improved sintering-furnace capabilities are required. Optimum control of atmosphere and temperature, and the development of economical, long-life furnace fixtures/furniture, will enable improved higher-density components.
PROCESSING OF LIGHTWEIGHT MATERIALS

CHALLENGES

One driver for material selection in both the automotive and aerospace industries is weight savings/fuel efficiency. Substitution of lightweight materials for conventional steel and stainless steel components will depend on cost/benefit relationships, and the processing of aluminum, titanium, and other materials. The near-net-shape processing benefit of PM is desirable to the aerospace industry when stringent material requirements are met.

Standards, guidelines, and practices are required for the commercialization of both the high-density and conventional press-and-sinter approaches for lightweight metal powders. Additionally, lightweight metal powders are susceptible to contamination by carbon, nitrogen, and oxygen preventing greater acceptance.

Materials:

➢ **Cost-competitive lightweight powders**
  Lightweight metal powders for structural applications with specific material properties and processing methods have enabled lightweight PM to gain greater commercial acceptance. Continued demand will drive the supply chain to deliver consistent powder characteristics while reducing cost, increasing opportunities.

➢ **Metal matrix composites**
  Opportunities exist for metal matrix composites (MMC) for structural applications where reduced mass is required. Research and development are required to ensure uniform microstructures for optimum mechanical properties.

Processes:

➢ **Reduction of impurities**
  Processes to minimize/eliminate the contaminants affecting the mechanical characteristics need to be identified and developed.

➢ **PM consolidation of titanium**
  Production of titanium components requires development of a system starting with fully alloyed powders capable of being consolidated and sintered to acceptable mechanical properties, lubricants that do not contaminate, and identification of critical sintering variables that ensure the structural integrity of the final parts.
CHALLENGES

Competing metal-forming processes such as cold forging, fine blanking, stamping, casting and precision high-speed machining continue to improve their process capabilities and are a threat to PM. The demand for high-precision components will continue, and PM must take advantage of its near-net-shape advantage. The reduction of dimensional variation in PM components will have a positive effect on the cost of quality and open new business opportunities.

Materials:

➢ **Understanding raw materials**
   Interactions between elemental materials, alloys, and additives are required to optimize particle size, shape, and distribution, chemistry and surface tension at the interface. Thorough understanding of these relationships is key to dimensional variation reduction.

➢ **New lubricants**
   Development of lubricants that will enable good ejection properties and surface finish with minimal effects on dimensional variation will provide new opportunities.

➢ **Powder handling and storage**
   Improve powder packaging and shelf life to reduce lot to lot variations of current materials.

Processes:

➢ **Part design**
   Optimize part geometry and material choice with respect to dimensional precision.

➢ **Development of advanced mixing techniques**
   Refinement of mixing techniques to optimize homogeneity will reduce variation. Advanced mixing techniques like full bonding of the base material and additives will continue to reduce segregation and improve dimensional stability and precision.

➢ **Press and tooling design**
   Optimized powder delivery systems, compaction parameters, and tooling materials will normalize the compaction cycles reducing part to part variation.

➢ **Sintering furnace**
   Better understanding of the sintering cycle is required to control the variability in dimensional control. Intelligent sintering furnaces with real-time reporting will enable the optimization of atmosphere quality and flow, temperature profiles, and cooling capabilities. Ideal furnace loading practices need to be developed to reduce variation.
The legitimacy of metal AM continues to evolve and has the potential to go down in history as one of the most revolutionary technologies for metal-forming. The required design software, build equipment, and materials for metal AM have set the stage for the future of the industry. Aerospace, nearly always an early adopter of bright technologies, has grabbed the reins to charge ahead with the use of metal AM, along with the medical market segment. Companies that are proactive, provide solutions to existing obstacles, and capitalize on the demand for manufacturing requirements, will be positioned to advance this developing technology. Significant challenges include: safety and regulations; understanding the rapid growth of the industry; limited production volumes due to equipment constraints and build-times; limited commercially available metal powders; the need to develop best practices, specifications, and standards for acceptance by broad industry segments.

Materials:

- **Development of powder specifications**
  Powder characteristics that affect build machine optimization will need to be identified and specifications developed for use by design engineers.

- **Test methods standardization**
  Standardized test methods are required to ensure uniform testing by powder suppliers and parts producers.

- **Recycling of powders**
  The metal AM process typically generates non-sintered surplus powder during the build process. Best practice guidelines are required to determine the extent of recycling.

- **Development of materials standards**
  Development of materials standards is required to enable increased acceptance into the aerospace, medical/dental, automotive, and industrial markets.

Processes:

- **Understanding powder requirements**
  A better understanding of the precursor materials impact on the metal AM process is required. Traditionally, precursor materials have been existing thermal spray powders that have not been refined/tuned to the AM process limiting optimization.

- **Increase processing for available materials**
  Metal powders provide unlimited alloy combinations that open a broad range of opportunities for the AM process. However, limited material processing is currently available.
In addition to the four main focus areas outlined on the preceding pages, the following technology and manufacturing improvements and marketing initiatives were deemed critical to the industry’s continued growth.

➢ Improved machinability techniques (enhancers and additives)
➢ Means of green-crack detection
➢ Continued material standardization and global coordination efforts
➢ Mold-flow simulation for MIM
➢ Promotion of industry needs to universities, government, and national labs
➢ Integration of PM material properties into FEA selection list
➢ Promotion of modeling efforts to the end user
➢ Utilization of electronic media for communication, marketing, and market education
➢ Enhanced promotion of Global PM Property Database
Appendix I

ROADMAP ACHIEVEMENTS

Numerous priorities identified in the 2001 and 2012 Roadmap were achieved during that decade. Several of the achievements between 2012 and 2016 are listed below. The proceedings of the annual Metal Powder Industries Federation (MPIF) conferences are a source of reference for information regarding such achievements. Visit www.mpif.org for more information.

MATERIALS

Ferrous
- Lean alloys
- Powders <10 micron
- Strain-based fatigue data
- Powder forged material standards
- Guide to PM Microstructures
- Lubricants for higher-density components
- Machinability enhancers

Nonferrous and Non-Traditional Materials
- Titanium powders
- Metal matrix composites
- Functionally graded materials
- Tungsten-heavy alloys for kinetic penetrator applications
- Graphite-metal foams
- Cobalt-chromium alloys
- Magnesium powder
- Powders <10 micron
- Strain-based fatigue data
- Aluminum material standards

PROCESSES

Conventional
- Robotics/automation
- CNC controlled processes, control improvements in pressing, material handling and machining
- Surface modifications for improved performance, shot peening
- Tool coatings to improve machinability
- Compaction modeling

High-Density
- Lubricants & die-wall lubrication
- Warm-compaction/warm-die compaction
- Forged helical gears
- Spark plasma sintering

Metal Injection Molding (MIM)
- Process and binder systems for titanium alloys
- Standardization
- Micro MIM advancements
- MIM over-mold
- Functionally graded materials

Metal Additive Manufacturing (AM)
- Material jetting
- Powder bed fusion
- Directed energy deposition
- AM modeling
- AM standards

Advanced Technologies
- Highly porous materials
- Layered nanolaminates
- Metal powder cladding
- Net-shape processing of refractory metal alloys
- Cold spray
APPLICATIONS

➢ VVT – variable valve timing systems
➢ EPS – electronic power steering
➢ Fuel nozzle for jet engines
➢ Transmission planetary carriers
➢ Mechanical diode/one-way clutches
➢ Powder forged helical planetary gears
➢ Powder forged differential gears
➢ Soft magnetic fuel injector solenoid cores
➢ Variable displacement oil pumps
➢ Turbocharger vanes
➢ Dental implants
➢ Jewelry
➢ Sputtering targets
➢ Braking system compressor clutches
Appendix II

INDUSTRY OVERVIEW

Powder metallurgy (PM) is a state-of-the-art metal-forming process used to produce net-shape components. PM comprises several different technologies for fabricating semi-dense and fully dense components. Generally, the PM process can be broken down into four categories: conventional or press-and-sinter; metal injection molding (MIM); hot or cold isostatic pressing (HIP/CIP); and metal additive manufacturing (AM).

The processes are capable of producing simple to complex alloys and components not capable of being manufactured with other technologies. In addition, porous bearings, filters, and many types of hard and soft magnetic components are also produced exclusively by the PM process.

One of the key attributes of the PM process is high material utilization. PM’s value is derived from its near-net-shape process that helps reduce energy consumption; promotes efficient use of raw materials, typically more than 97% of the starting raw material in the finished part; is less labor intensive than other competitive metal-working industries; and has thus been long-recognized as a sustainable technology.

PM applications fall into three main groups—structural, powder, and refractory metal:

➢ Structural applications consist of components in which PM is a preferred solution to machined components, castings, and forgings. Key markets in this group include automotive, electrical and electromagnetic, energy, aerospace, defense, medical/dental, firearms, and industrial and consumer products.

➢ Powder applications consist of loose powders or powder mixtures used for welding, joining, and spray coating for the fabrication, repair, and surface texturing industries.

➢ Refractory metal applications consist of components difficult to make by any other production method, such as cutting tools and other components made from tungsten, tungsten carbide, or molybdenum.

Estimated sales from all three sectors in North America total over $7.0 billion, with employment exceeding 25,000 people. The majority of PM companies are small; 90% of the firms are classified as small businesses by U.S. government standards.

**Conventional PM Sales by Application (Dollars)**

![Pie chart showing PM sales by application](image)

- **Automotive OEM:** 28%
- **Automotive Suppliers:** 45%
- **Off-Road Vehicles:** 4%
- **Outdoor Power Equipment:** 7%
- **Industrial Motors/Control/Hydraulics:** 3%
- **Household Appliances:** 4%
- **Hardware:** 2%
- **Recreation/Hobby:** 3%
- **All Others:** 5%

Source: Powder Metallurgy Parts Association, 2015
The success of the PM industry is directly related to the health of the automotive industry. Currently that sector consumes 70+ percent of all ferrous PM components produced. It has been estimated that there are approximately 350 PM automotive component applications totaling about 1,000 discrete pieces. The number of applications is steadily rising as PM is increasingly viewed as an effective alternative to machined or cast parts. Meeting automotive needs is critical to the continued success of the PM industry and is central to the industry’s vision.

PM’s value has been derived from its net-shape capabilities, high material-utilization rates, and minimal energy-input requirements. Coupled with environmentally friendly operations and use of scrap for the source of powder materials, the sustainable nature of PM technology provides a positive contrast to other metal-forming technologies. Often the manufacture of a PM component requires fewer steps and offers greater material choices, as well as unique properties unavailable with other metal-processing techniques. PM can provide sustainable manufacturing benefits from the point of view of either a value-added product feature, such as part complexity without additional machining, or process efficiency, such as sinter hardening which eliminates traditional heat treatment.

**Structural-Component Segment of the North American Conventional PM Industry**

<table>
<thead>
<tr>
<th>Segment</th>
<th>Annual Sales</th>
<th>Employees</th>
<th>No. of Companies</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Powder &amp; Materials</strong></td>
<td>$750 million</td>
<td>1,500</td>
<td>30</td>
</tr>
<tr>
<td>(Powder, lubricant, industrial-gas, and raw-material producers)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Tooling &amp; Equipment</strong></td>
<td>$187 million</td>
<td>1,000</td>
<td>85</td>
</tr>
<tr>
<td>(Tooling, process-equipment, and service suppliers)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Components Production</strong></td>
<td>$3 billion</td>
<td>9,000</td>
<td>140</td>
</tr>
<tr>
<td>(Contract and in-house component fabricators)</td>
<td></td>
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</tr>
</tbody>
</table>
Conventional Powder Metallurgy (PM) Process

Also known as press-and-sinter, the process consists of mixing elemental or alloy powders with lubricants or additives to produce a homogeneous mixture. Additives may help improve machinability, wear resistance, or lubricity of the part. The mixture is compacted in a die at pressures typically as low as 138 MPa (10 tsi) or as high as 965 MPa (70 tsi) depending on the density requirements of the part and the compressibility of the powder being compacted. In the typical sintering step, the green compact is conveyed through a controlled-atmosphere furnace. The parts are heated to a temperature below the melting point of the base metal, held at the sintering temperature, and then cooled as the part exits the furnace. Sintered parts have the strength levels to meet functional requirements of the components. Many PM parts are ready for use after sintering. Value-added properties or features can be obtained through repressing, forging, impregnation, machining, vibratory finishing, plating, shot-peening or heat treatment.

Most conventional PM parts weigh less than 5 pounds (2.27 kg). While many of the early PM parts, such as bushings and bearings, were very simple shapes, today’s sophisticated PM process produces components with complex contours and multiple levels.
Metal Injection Molding

Metal injection molding (MIM) offers a manufacturing capability for producing complex shapes in large quantities. The process utilizes fine metal powders (typically less than 20 micrometres) that are custom formulated with a binder (various thermoplastics, waxes, and other materials) into a feedstock. The feedstock is fed into a cavity (or multiple cavities) of a conventional injection molding machine. After the “green” component is removed, most of the binder is extracted by thermal or solvent processing, and the rest is removed as the component is sintered in a controlled-atmosphere furnace. The MIM process, like plastic injection molding, can produce highly complex, intricate three-dimensional shapes that otherwise would require extensive finish machining or assembly operations if made by other metal-forming processes.

Advantages of the MIM process lie in its ability to produce net-shape components with good dimensional control, excellent mechanical properties, and high-production rates through the use of multi-cavity tooling.

Flowchart of the Metal Injection Molding Process utilized to make high volume, complex parts

Diesel Leak-Off Union

Front Sight Base
Isostatic Pressing
Isostatic pressing is a consolidation process that applies equal pressure in all directions on a powder compact, thus achieving uniformity of density and microstructure.

Isostatic pressing is performed "cold" or "hot." Cold isostatic pressing (CIP) is used to compact powder at ambient temperatures to create green parts. Hot isostatic pressing (HIP) is performed at elevated temperatures to compact and sinter powder to full density. HIP can also be used to eliminate residual porosity from sintered PM, MIM, metal AM parts, and castings.

Examples of the isostatic pressing processes utilized to achieve full density

**COLD ISOSTATIC PRESSING**

- "Green" Compact
- Flexible Mold
- Gas Pressure Inlet

**HOT ISOSTATIC PRESSING**

- Water-Cooled Jacket
- Gas Pressure Inlet
- Heater
- Pressure Vessel
- Canister or Workpiece

Examples of the isostatic pressing processes utilized to achieve full density
Metal Additive Manufacturing (AM)
Metal additive manufacturing, or metal 3D printing, has the potential to change the production, time-to-market, and simplicity of components and assemblies. Unlike conventional or subtractive manufacturing processes, such as machining which creates a part by removing material, metal AM builds a part using a layer-by-layer process directly from a digital model, without the use of molds or dies. Metal AM has been used as a design and prototyping tool for decades, but the focus of metal AM is now shifting to the direct production of components for the aerospace, medical/dental, and jewelry industries.

There are multiple metal AM systems. All systems employ a common layer-by-layer approach and use a wide variety of technologies, materials, and processes.

Metal AM technologies utilizing metal powders include, but are not limited to:
- Material jetting
- Directed energy deposition
- Material extrusion
Appendix IV

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The process of updating this PM Industry Roadmap was made possible through efforts on the part of many industry individuals over a period of 12 months.

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MPIF is a federation formed by the PM industry to advance the interests of the metal powder producing and consuming industries. It is a federation of trade associations, all concerned with some aspect of powder metallurgy, metal powders, or particulate materials—Powder Metallurgy Parts Association, Metal Powder Producers Association, Powder Metallurgy Equipment Association, Metal Injection Molding Association, Refractory Metals Association, and Isostatic Pressing Association.