Revolutionizing Metal AM Economics:

HIGHER PRODUCTIVITY & LOWER PART COST

Tritone
Industrial Additive Manufacturing

CONTENTS

INTRODUCTION

Metal Additive Manufacturing (AM) use has emerged over the past decade and its growth rate is projected to continue for years ahead. New design freedom, elimination of tooling and costly CNC setups are compelling advantages that early adopters are enjoying as they build competitive advantages. However, the major impact of AM to date has been limited to high value applications found in Aerospace, Medical, and Energy Production fields.

This narrow focus has been driven by the high costs associated with first generation Metal AM technologies. Individual part costs of $2,500 to $25,000 or more are acceptable in these low volume, super high performance applications. However, the opportunities are simply not available in most other industries.

New technologies have emerged in recent years that improve process economics and ease of operation so that any relevant manufacturer can enjoy their benefits.

EMBRACING THESE NEW TECHNOLOGIES, FORWARD-THINKING MANAGERS ARE SEIZING THE CHANCE TO SECURE A LASTING COMPETITIVE EDGE

Meanwhile across a wide range of “other” industries, there is a massive need for more efficient production for metal components in the **$2 - $200/part range**. Low and moderate volume production runs of these components are challenging for suppliers and end users alike on a global basis.

This paper will present a compelling new technology that brings these cost saving targets into focus. Over the following pages we will share how Tritone's cleaner, safer and less costly approach is poised to help manufacturers overcome the challenges they face in their adoption of Metal AM.

WHY METAL AM?

Metal AM is an important technical advancement that offers several advantages over traditional manufacturing methods for producing metal parts. These advantages include:

1. DESIGN FLEXIBILITY

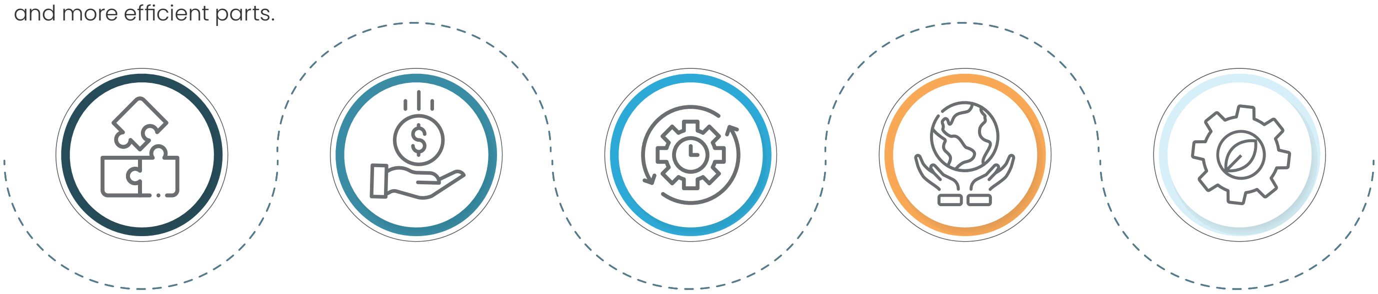
With Metal AM, it is possible to create complex geometries and internal structures that are not possible using traditional manufacturing techniques. This can result in lighter, stronger, and more efficient parts.

3. TIME EFFICIENCY

Metal AM can reduce lead times for producing parts, as the technology allows for rapid prototyping and fast production of parts.

5. SUSTAINABILITY

Metal AM reduces waste and environmental impact by using less raw material, producing less scrap, and reducing energy consumption compared to traditional manufacturing processes.



2. COST EFFICIENCY

Metal AM can be more cost-effective for small production runs or for producing parts with complex geometries that would be difficult or expensive to machine or tool up for casting.

4. MATERIAL EFFICIENCY

Metal AM can reduce lead times for producing parts, as the technology allows for rapid prototyping and fast production of parts.

METAL AM 1.0 – LASER POWDER BED FUSION (LPBF)

Over the past few decades metal AM applications and markets have grown dramatically, mostly driven by the Laser Powder Bed Fusion (LPBF) process. With this technique a high-powered laser is used to weld metal powder particles together, layer-by-layer, to build up a three-dimensional (3D) metal part.
This "direct" metal fabrication process is widely used in industries such as aerospace, medical, and energy where the production of complex, high-value parts is required.
While this process has been proven with many commercial successes, the technology is just too slow and expensive for most industrial applications, including prototypes production.
LPBF is also limited to materials that are weldable.

In these high value applications, performance improvements like more efficient fuel delivery systems for jet engines and longer low volume medical implants can justify:

- Costly and slow manufacturing processes
- Significant and ongoing investment in engineering resources
- Years or decades of process development and validation

LBPF PROCESS OVERVIEW

The Laser Powder Bed Fusion (LPBF) process is also called Selective Laser Melting (SLM) or DMLS. Some additional acronyms are trademarked by equipment manufactures but all these processes follow the same general steps and system architecture described here:

1

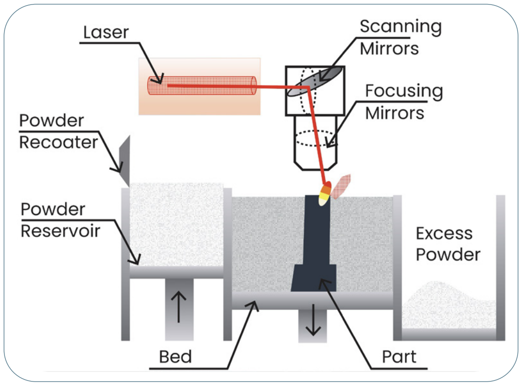
DESIGN AND BUILD LAYOUT

The process begins with the creation of a digital 3D model of the desired part using computer-aided design (CAD) software. The digital model is sliced into thin, 2D cross-sectional layers. Part orientation must then be optimized taking many complex interactions into account. During this design step, a support structure for each part is also designed.

2

BUILD PREPARATION:

Fine metal powder is supplied from a feed reservoir and spread in a thin layer (35-100 microns typically) over the entire build platform. The layer is then formed as described in steps 3 -5 below. This layer spreading and point-by-point melting process is repeated hundreds or thousands of times until the full build height is reached.



The schematic diagram of LPBF process.
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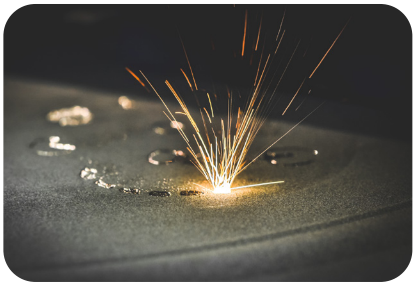
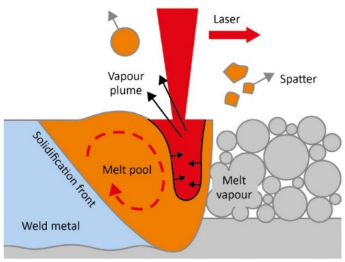
LAYER-BY-LAYER MELTING:

The LPBF machine selectively fuses the metal powder point by point using a high-powered laser. The laser path is precisely controlled as it scans the cross-section of each layer, melting/welding the metal particles together.



An observer of the LPBF process can see the sparks and smoke plume as the laser works its way across the powder bed.

The complex interaction of the laser and fast-moving pool of molten as shown in the image on the right. Soot/vapor and spatter from the melting process are a constant challenge to laser focus and the overall integrity of the build process. Any small upset to this process can result in inclusions and flaws to the part being printed. Just one significant flaw can result in the scrapping of an entire part or build.



Source: Saunders, M. (2018). How process parameters drive successful metal AM part production, Available from Metal AM Magazine Vol. 4 No. 2, Summer 2018

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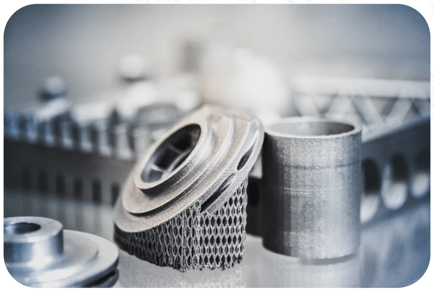
COOLING AND SOLIDIFICATION:

As each of region of the part is melted and fused, the metal rapidly heats and cools on each pass of the laser. This rapid thermal cycling imparts stress as parts build which must be factored into the support design and post processing. The layer-by-layer welding process also results in anisotropic material properties in horizontal and vertical axes.

5

SUPPORT STRUCTURES:

Each part within the build box must be “anchored” to maintain its position and shape through the build process. Supports are built along with the part and prevent part distortion or collapse during the printing process. These supports naturally add to the build time and material cost.



6

POST-PROCESSING:

After the printing is complete, the build platform with parts attached is typically removed from the machine. The platform goes through a stress relief step and then parts can be cut from the platform before removing the additional support structures. This is followed by additional machining, surface finishing, and other steps to achieve the desired mechanical and aesthetic properties.

After decades of maturation, this complex powder fusion process has been proven with commercial success in many niche and high value applications. Reliable results can now be obtained under tightly controlled conditions.

However, significant economic challenges remain that prevent widespread adoption. The technology is simply too slow, expensive, and complicated to extend to more general industrial applications for serial part production.

AS A “WELD-BASED” PROCESS, ONLY WELDABLE MATERIALS CAN BE CONSIDERED. A MUCH WIDER RANGE OF MATERIALS ARE AVAILABLE WHEN A SINTER-BASED TECHNOLOGY LIKE MOLDJET IS SELECTED

LPBF KEY CHALLENGES

MANAGING LOOSE POWDER
Powder Bed processes require large supplies of loose metal powder, which must be carefully handled, stored, and recycled.
There are significant cost and safety concerns to outfit a manufacturing facility to handle tons of this fine metal powder.
Additionally, as powder is recycled the quality degrades and must eventually be disposed of before part quality suffers.
With thousands of pounds of powder across multiple pieces of equipment, changeover of materials can be a daunting or completely impractical task.

PROCESS COMPLEXITY
From job preparation, through the printing and post processes, LPBF process are complex.
Each part requires a custom designed support structure to keep the part located and stable during the print step.
Optimization of this support structure is a critical task.
Laser toolpaths and process parameters are often optimized as well for each geometry and material type.
This is high skill labor and all tracks along with the high value nature of the output of these machines.

LABOR INTENSE POST-PROCESSING
After printing, parts must be excavated from the mass of metal powder in the build box.
This is followed by a heat treat step to relieve stress from the weld/build process.
Then comes the most challenging step. Each part must be cut free from the solid metal support structures. All attachments.
Then each part must be cut off the build tray, followed by careful removal of the solid metal support structures. All attachment points must then be ground smooth.
After all these steps, there will typically be some final machining steps for critical dimensions.
These labor intense steps all contribute to final part performance – and overall part cost.

TRITONE'S MOLDJET PROCESS EASES THESE CHALLENGES BY ELIMINATING LOOSE POWDER AND SUPPORTS, SIMPLIFYING MACHINE SETUP AND OPERATIONS

METAL AM 2.1 – A NEW COST MODEL FOR VOLUME PRODUCTION

For Metal Additive Manufacturing to reach its potential for broad adoption, customers need dramatic improvements **in ease of Productivity, Adoption, and Process Economics.**

Tritone Technologies was established in 2017 with an ambitious mission to solve this challenge for industry on a global basis. Tritone's founding team followed a completely different path from LPBF. These innovators looked to proven industrial technologies from the Metal Injection Molding (MIM) and screen print industries for inspiration and invented the MoldJet process.

We will review how the MoldJet process address each of these key concerns from a high level.
In the next section we will then take you on a deep dive into the MoldJet process – step by step.

EASING ADOPTION WITH PRODUCTIVITY, SAFETY, AND SIMPLICITY:

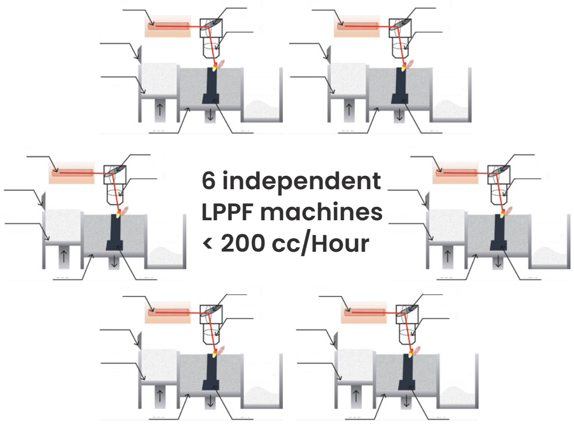
PRODUCTIVITY - SIX JOBS IN PARALLEL

Equipment, OPEX and plant floor space are closely watched expenses. Productivity is one key to maximizing the return on these investments. Most AM equipment is built around one build box, with jobs running sequentially. A lot of time and effort is placed on "fast turnover" between jobs. It's so common in fact that no one questions that philosophy.

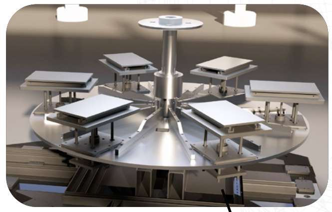
Tritone's founders had a different vision. They had the breakthrough idea to process build jobs in **parallel**. MoldJet machines are designed using a rotary workstation concept. With this approach, up to 6 print jobs run **at the same time**. The print jobs are controlled independently so users have the flexibility to match output from the printer to the downstream processes.

IT'S LIKE HAVING SIX PRINTERS IN THE SPACE OF ONE. TRITONE REMAINS THE ONLY COMPANY IN THE INDUSTRY WITH PARALLEL PROCESSING CAPABILITIES

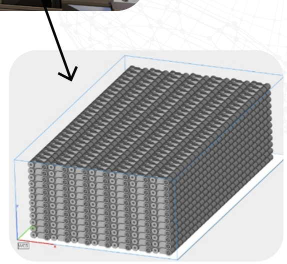
LPBF



MoldJet



Dominant system.
6 simultaneous and
independent trays
1,600 cc/hour



This single build tray holds 4,500 parts. One fully loaded Tritone Dominant can process 27,000 of these components simultaneously by parallel processing.

SAFETY - NO LOOSE POWDER

One major step Tritone has taken is the elimination of loose powder from the process. This brings a “Triple Benefit” that impacts product quality, plant safety, and overall CAPEX requirements.

With MoldJet’s paste feedstock:

1. Material is fully contained and safe making storage and transport trouble free.
2. Users only need to stock material for specific parts being produced (with powder bed processes, a minimum of 10X material is needed at various stages of the process).
3. Site safety expenses and inventory carrying costs are greatly reduced (especially with expensive alloys like Ti64 and copper.

MoldJet

A completed printed tray, ready for demolding processes.
Use of minimal PPE (latex gloves)

VS.

LPBF

Working with the LPBF process requires breathing apparatus, as well as protective clothing to ensure no contact with hazardous powders.

SIMPLICITY

1. From job setup, through print and post processing and even machine maintenance, the MoldJet process is designed for use by operators in a manufacturing environment. Preparing jobs for MoldJet Additive Manufacturing requires only basic computer skills and training as there is no need to design complex support structures for each part. Support is automatically provided by mold material during the print process. Tritone provides design guides and training to learn the basics of job setup.

2. Training for system operation is completed within a comprehensive program after installation. MoldJet Systems have a large graphic touchscreen user interface with diagnostics and troubleshooting. Operators need only minimal PPE (safety glasses and latex gloves).

3. MoldJet employs advanced AI monitoring algorithms to detect and repair print errors in real time.

4. Post-processing of parts is a hands-free operation which is designed to interface with plant automation systems as your production volume grows. After parts are cleaned, they are sintered using the same industrial furnaces that are used as a standard across the MIM industry. These processes are well understood and highly reliable.

5. With MoldJet's paste feedstock system, powder and binders are mixed continuously prior to deposition. This process ensures homogeneous, dense, consistent green parts in all regions of the build box, run after run.

MATERIAL CHANGES / EQUIPMENT FLEXIBILITY

Another critically important factor, especially early in each customer's technology adoption curve, is flexibility. The ability to use equipment to process different materials for specific projects is a "given" with most manufacturing technologies (machining, injection molding, etc.). With powder-based metal AM systems however, this changeover can take up to 1 to 2 full days. In some cases, it is so cost prohibitive that machines sit idle waiting for a project to run with the material that is in the machine. With MoldJet's systems, **the material changeover process takes approximately 30 minutes, ensuring a seamless transition between materials.**

MATERIAL REMOVAL
Remove the empty tube from the system.
7 min

CLEAN THE APPLICATOR
Proper cleaning is essential for a smooth material changeover. To prevent any contamination, the applicator is thoroughly washed with water and then returned to its original position within the system.
15 min

INSTALL THE NEW MATERIAL
Insert the new material tube into the material cartridge.
8 min

PROCESS ECONOMICS

While ease of use and productivity are key ingredients to successful implementation, business cases are built on ROI. When comparing economics, the need to match process economics to "part value" becomes quickly evident. As stated earlier, there are many high value parts that can (and should) only be made using a LPBF process. In most other cases, MoldJet is a compelling option.

PRODUCTIVITY COMPARISON

	TECHNOLOGY PLATFORM		
	MoldJet Dim	**MoldJet Dominant**	**LPBF Twin Laser 280 mm Build Box**
Total Average Investment for Printer + powder handling and plant safety modifications	**$395,000**	**$690,000**	**$750,000**
Productivity Comparison			
Productivity	200 cc/ hour	1,600 cc/hr	70 cc/hour
Cost of Productivity (Investment per CC)	**$1,900** per CC of Capacity	**$575** per CC of Capacity	**$10,715** per CC of Capacity

LOWER COST, HIGHER PRODUCTIVITY EXAMPLE (A CASE STUDY EXAMPLE)

This example demonstrates how the MoldJet process can provide an application "win" over a part that would have otherwise been made with by machining and assembling multiple components. The LPBF process was deemed too expensive for the application.

The component is a bracket that aligns a precision extruder assembly.
Material: SS 15-5PH

The cost to fabricate the component by CNC was estimated at over $200 per assembly in lots of 90-100 units. Lead time for the project was quoted at 6 weeks.

The cost to fabricate by LPBF was estimated at over $1,000 per unit as only 9 parts could be built per machine run. Each fabrication run required 30+ hours of machine time.
This is a total of over 300 hours (almost 2 full weeks of runtime) to complete 90 parts.

The total cost to fabricate the component using MoldJet Technology was **$70** and an entire lot of 90 units could be **printed in just 23 hours.**

MOLDJET PROCESS OVERVIEW

The first step is creating the first layer of the component mold from a wax-like polymer using an **inkjet printing process.** In this process, the mold material is heated in a reservoir and jetted accurately onto the substrate by the print heads to form a mold layer.

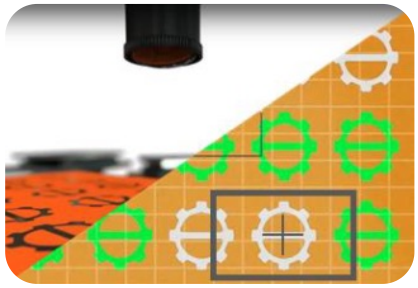
The entire layer of mold cavities is then filled with metal paste. The paste consists of metal powder, an aqueous carrier, and an organic binder system. A proprietary applicator design ensures a homogeneous transfer of paste into the mold cavities, eliminating density gradients. Hundreds of cavities can be filled in a single pass of the paste applicator.

After the mold cavities are filled on each layer, a series of drying and hardening steps remove the water based carrier. This step prepares the build substrate for the next layer of mold material to be applied.

After all layers are printed the complete build tray is removed from the machine for secondary processing. At this stage, the print is a solid block of mold with parts embedded inside. The tray can be handled without PPE.

A printed mold layer prior to filling with paste

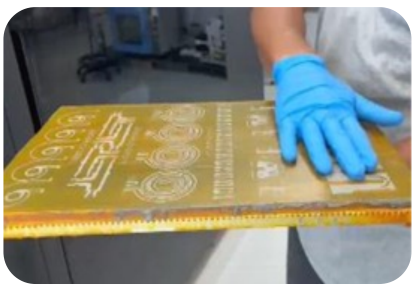
Paste being applied into mold cavities, b: the build layer after cavities are filled and dried.



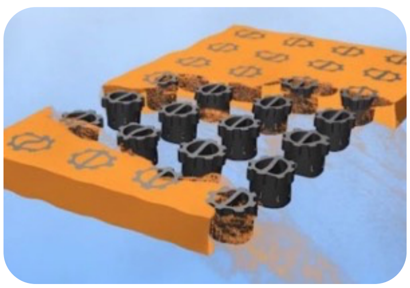
Camera based inspection provides for real time defect detection and repair

DEMOLDING

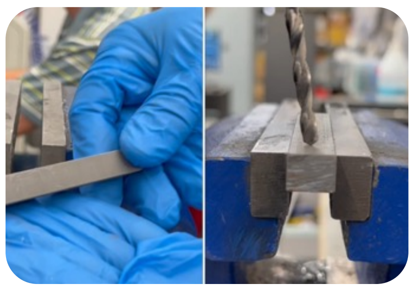
The next process is removal of the mold material to reveal the green parts. This is a 2-step, hands free operation. First the bulk mold material is melted away in a low temp oven, then any remaining material is dissolved with solvents. A range of standard industrial equipment is available “off the shelf” for use in these steps depending on the scale of production required. There is no “de-powdering” step required as there is no loose powder to remove.



A completed build tray, ready for demolding operations

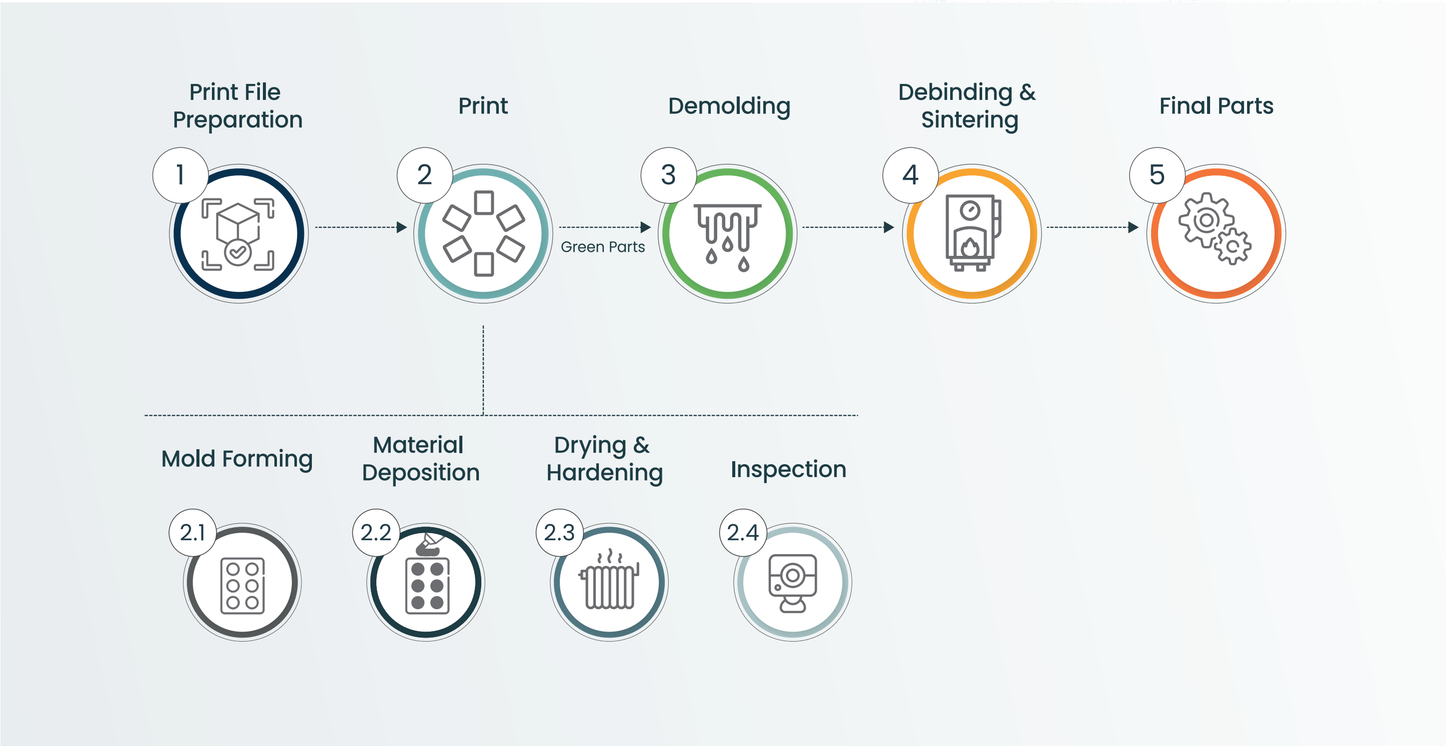


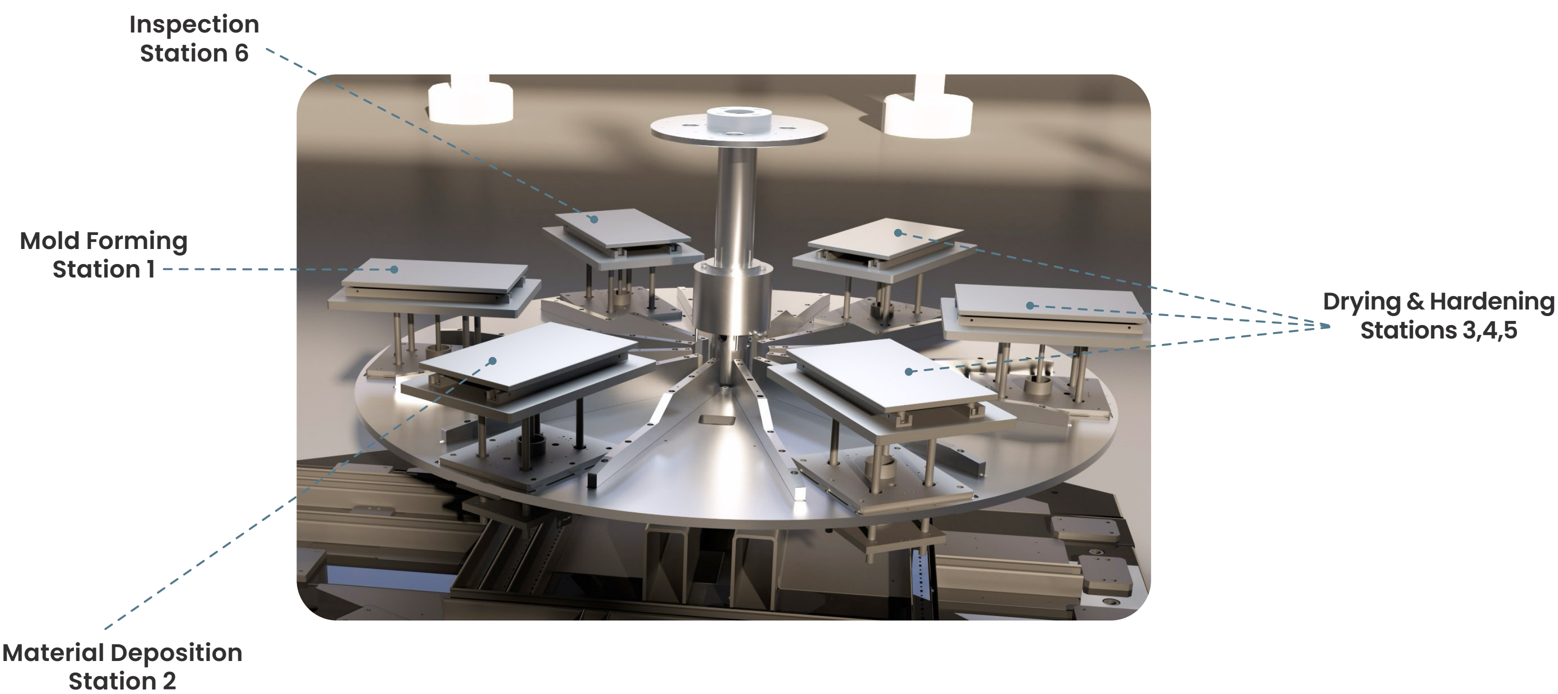
Mold is removed to reveal green parts ready for thermal debind and sintering



Tough green parts can be handled and post processed

TRITONE MOLDJET MANUFACTURING SOLUTION

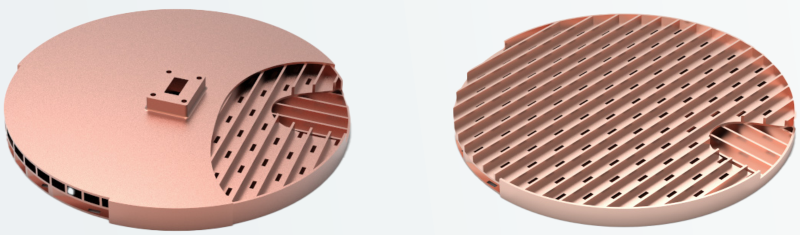




PROCESS COMPARISON

PROCESS	MoldJet	LPBF (Twin Laser 280mm Build Box)
Best Fit Use Cases	▶ Moderate to high volume production ▶ Complex, medium, and high-value parts components, including intricate details ▶ Under 15 cm / 6” ▶ Across many industries ▶ Hundreds to tens of thousands of parts	▶ Low to moderate volume production ▶ Big, complex, and high value components ▶ Aero, medical, and energy industries. ▶ Single to hundreds of parts
Feedstock/ Raw Materials	Safe, clean metal paste with low material inventory requirements	Hazardous Loose metal powder 10X inventory required
Build rate/ productivity	$575-$1,900 per cc of productivity	$10,715 per cc of productivity
Post Processing	▶ Hands free demolding ▶ Sintering ▶ Finish machining as needed	▶ Labor intense depowdering and support removal ▶ Heat Treatment ▶ Finish machining as needed
Plant Safety Requirements	▶ Minimal requirements for printer ▶ Sinter Furnace cover gas compliance ▶ < $20K	▶ Extensive/expensive compliance requirements for loose powder handling and storage ▶ Cover gas compliance ▶ $100-400K
Material changeover (Equipment Flexibility)	Under 30 minutes. Simple and contamination free	8+ man hours to change at lab scale. Practically impossible on production level
In process monitoring and corrective action	Can detect and confirm repair of flaws during the build process	Monitor only. Some systems have detection to stop and scrap a build

RF ANTENNA
Material: Copper



With MoldJet, any internal passages are filled with mold material, NOT powder. There is no powder to remove from these channels in post processing.

A SAFER, FLEXIBLE, COST-EFFICIENT AM PROCESS FOR METALS AND CERAMICS

SAFER
Eliminate the need to store and handle ultra-fine metal powder in your plant.

FLEXIBLE POWDER HANDLING
In addition to removing loose powder, MoldJet eliminates the need for manual labor.

ENHANCED COST EFFICIENCY
The massive gains in productivity with MoldJet technology result in saving of anywhere from 2 to 10X in most cases.

ABOUT TRITONE TECHNOLOGIES

Tritone Technologies transforms metal Additive Manufacturing to address the demanding standards and needs of industrial production. The company's innovative technology enables industrial throughput of accurate parts with a range of metal and ceramic materials, suitable for the Automotive, Aerospace, Medical and Consumer Electronics industries. Founded in 2017, Tritone is led by an experienced team of experts with a track record in driving technology and business growth. Backed by private equity firm Fortissimo, Tritone is a global company and is based in Israel with presence in North America and Germany.

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