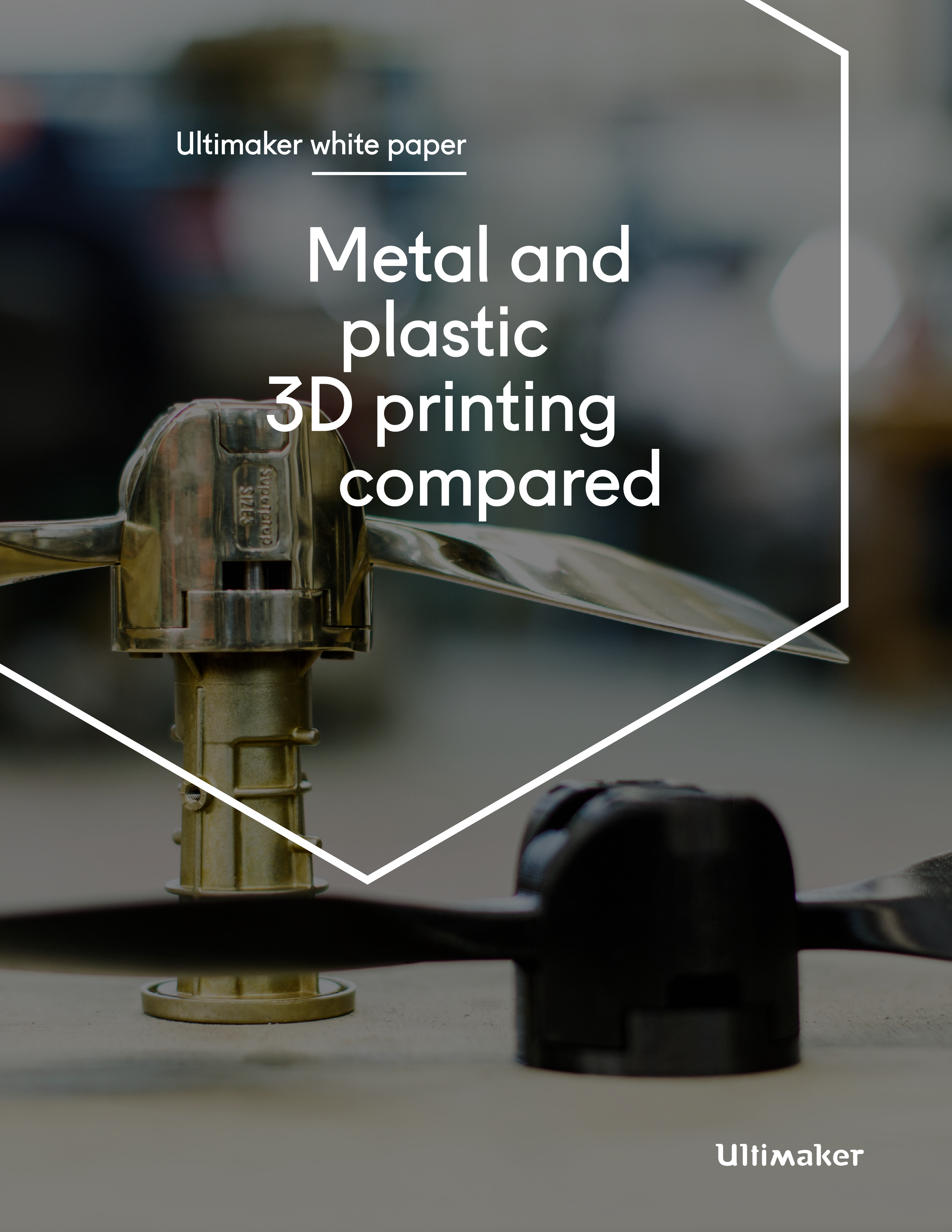
Ultimaker white paper

Metal and plastic 3D printing compared



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Introduction

You're probably thinking it…How could plastic 3D printing ever hope to compete with metal? Metal is often thought of as stronger than plastic, more durable, higher quality – to name a few. So isn't the battle of metal vs. plastic 3D printing already over before it starts?

At first glance that might seem true. In 2018, Gartner made the following industry prediction:

"By 2020, 3D printed metals and alloys will become a critical element in supply chains for replacement parts."

Despite this, you'd be mistaken to think that plastic 3D printers will no longer have a place in the additive manufacturing industry. In fact, the number of industry applications that can truly benefit from in-house metal 3D printing is fewer than you might think. And many application opportunities exist where a plastic 3D printed alternative can perform the same function or better – at a lower cost.

That's not because plastic can always outperform metal (although in some situations it does). But because engineers and designers automatically choose to make parts from metal, without taking into account the mechanical properties required. While the reality is that, for many applications, choosing metal by default is overkill.

To keep this white paper a manageable length, our discussion will be limited to three additive technologies:

- Direct metal laser sintering (DMLS) metal 3D printing
- Bound metal deposition (BMD) metal 3D printing
- Fused filament fabrication (FFF) plastic 3D printing

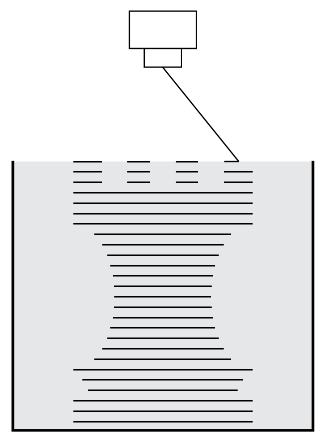
Metal 3D printing technologies

In recent years, metal 3D printing has gained increased interest. While there are many different technological approaches, each manufacturer has coined or patented its own variant. The resulting cocktail of names and acronyms can be confusing, so we'll look at two here:

1. Direct metal laser sintering (DMLS)

Sometimes referred to as selective laser melting (SLM), this technology uses a powder bed fusion build process similar to selective laser sintering (SLS). A poweful laser melts a 2D shape on a bed of powdered metal. This bed then moves down and is recoated by a fresh powder layer, ready to be melted. Layer by layer, a metal part is produced directly by the 3D printer. Unlike SLS, however, all printed parts must be attached to the build plate via support structures to avoid warping.

After 3D printing DMLS, the part requires heat treatment to relieve residual stress. It is then removed from the build plate, using a wire electrical discharge machine (EDM).



To achieve the right finish for functional surfaces, a combination of CNC milling, media blasting, belt sanding, or manual tools is often needed.

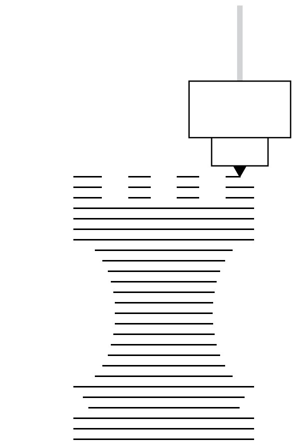
DMLS and SLM 3D printers use a powerful laser to build up layers of melted metal powder

2. Bound metal deposition (BMD)

Also known as metal material extrusion, this technology is similar to FFF plastic 3D printing. It creates a metal part in three distinct stages.

Instead of using pure powder like DMLS, the metal is bound in rods of sacrificial wax or polymer. This mix behaves like a thermoplastic material. It can be melted at a lower temperature and extruded through a nozzle layer by layer. This creates a metal-polymer object – also known as a 'green part'.

After 3D printing, the unfinished part requires further post-processing. It is washed or debound to remove the binder and then sintered in a furnace. This process fuses the material, leaving a finished metal part.



BMD printers extrude metal-polymer rods in layers to form a 'green part', which must be debound and sintered

Initial investment cost comparison

This table compares a DMLS and BMD 3D printer with the cost of owning an Ultimaker S5.

Note: All prices accurate at the time of publication. However, they are subject to change.*

	DMLS	**BMD**	**FFF** (Ultimaker S5)
3D printer cost	$550,000 (€493,000)	$49,900 (€50,000)	$5,995 (€5,495)
Other required and optional equipment	• Heat treatment furnace $17,000 (€15,200) • Wire EDM $50,000 (€45,000) • 5-axis CNC machine $120,000 (€108,000) • Optional media blast cabinet $10,000 (€9,000)	• Debinder $9,000 (€10,000) • Furnace $59,900 (€60,000)	• Optional reinforced print core $349 (€295) • Optional manual post-processing tools $100 (€89)
Contracted service program cost	• Installation and training included in purchase price • $20,000 (€18,000) maintenance per year	• $5,000 (€5,000) installation and training	• Not required
Most affordable material cost per unit	• From $110 (€100) per kg (but 75 kg required to fill the powder bin)	• From $425 (€376) per cartridge	• From $50 (€33) per 750g spool
Other equipment and consumables	• Build plates, from $200 (€178) • $500 (€448) for rakes and filters • House argon or nitrogen	• Consumable start kit $7,000 (€7,000) – includes media, gas, debinder fluid, furnace effluent filters, build plates	• None required
Software cost	• $20,000 (€18,000) per license • $30,000 (€27,000) for additional material settings (optional) • $80,000 (€72,000) product lifecycle management software (optional) • $20,000 (€18,000) enter-prise resource planning software (optional)	• $550 (€500) per year	• Free (Ultimaker Cura)
Total investment cost (excluding materials)	**$777,700 (€698,000)**	**$131,350 (€132,500)**	**$5,995 (€5,495)**

** While most price conversions are calculated using currency exchange rates, some are based on regional MRP.*

Should you consider CNC machining?

Why is computer numerical control (CNC) machining relevant to this discussion? Simply because if you can afford to own an in-house metal 3D printer, you can afford a CNC-milling machine.

For this reason, CNC machining remains a cost-effective way to produce a wide range of metal prototypes. Of course, this comes with some caveats. While part designers must observe design for additive manufacturing guidelines for 3D printing, design for subtractive manufacturing guidelines must be followed for CNC machining.

These rules are based on two limitations: tool shape and tool access. Wall thickness, cavity depth, internal corner radius, hole diameter all must be considered to reduce the time and the cost of CNC machining. In addition, internal geometries are limited to T-slot or dovetail shapes at specific angles. Small cavities and holes are limited to a 2.5 mm (0.1 in) diameter.

If your metal part design can remain within these limitations, CNC machining from a solid metal block is cheaper and faster than metal 3D printing. Parts retain the blank metal's isotropic mechanical properties and can be made with higher accuracy: up to ±0.025 mm, compared to the ±0.100 mm of DMLS. To begin to compete with the design freedom that metal 3D printing brings, a 5-axis CNC machine is required. Prices start at around $120,000 (€100,000).

5-axis CNC machines are cheaper than metal 3D printers, but subtractive manufacturing limits geometric freedom

Technology comparison

Each 3D printing technology has its own strengths and weaknesses. Because of this, they are suitable for different manufacturing applications. First, let's look at the advantages and challenges found in each system.

DMLS

Advantages

- Geometric complexity carries no extra cost
- Allows the creation of stiff and lightweight parts
- Repeatable and consistent results
- Can achieve the highest metal density in metal 3D printing
- Features more in-depth process simulation and reporting than other technologies

Challenges

- Metal powder is volatile and requires an oxygen-free build chamber
- Higher cost-per-part than traditional manufacturing
- Post-processing tasks can take up to 50% of the fabrication time. These include heat treatment (annealing), cutting from build plate, unsintered powder removal, surface treatment
- Slow printing process
- Some part geometry angles must be avoided to avoid collision with the recoating arm
- Struggles to print fully enclosed hollow parts to allow powder draining
- Expensive to remake a failed print
- Parts are welded to build plate due to residual stress
- Changing materials requires decontamination with a wet separator vacuum
- Recommended to use one machine per metal alloy family

BMD

Advantages

- Geometric complexity carries no extra cost
- No safety concerns with volatile metal powder
- Faster than DMLS
- Non-metal interface layers allow for easier post-processing
- No residual stress on printed or sintered parts
- Office-friendly

Challenges

- Less strength and density than DMLS
- Requires extra post-processing stages such as washing, drying, sintering, surface treatment
- Parts shrink when sintered by roughly 20%, requiring software scaling
- Green parts are fragile (the same density as a crayon)
- Changing materials requires separate material feed trays, print heads, nozzle brushes

FFF

Advantages

- Geometric complexity carries no extra cost
- Minimal post-processing
- Scalable due to affordable hardware
- Plug-and-play operation
- Requires no dangerous chemicals
- Use of water-soluble supports for geometric design freedom
- Open material systems that match injection molding portfolios
- Office-friendly

Challenges

- Most thermoplastic properties are more limited than metal
- Manual post-processing required for some prints
- Print orientation is important because of inter-layer anisotropic mechanical properties
- Software does not have the same print simulation features as DMLS systems

CNC machining

Advantages

- Larger milling area than additive build volumes
- Tight tolerances (up to ±0.025 mm or ±0.001 inch)
- Parts have fully isotropic physical properties
- Most materials can be machined
- Fast process when part geometry is optimized for subtractive manufacturing

Challenges

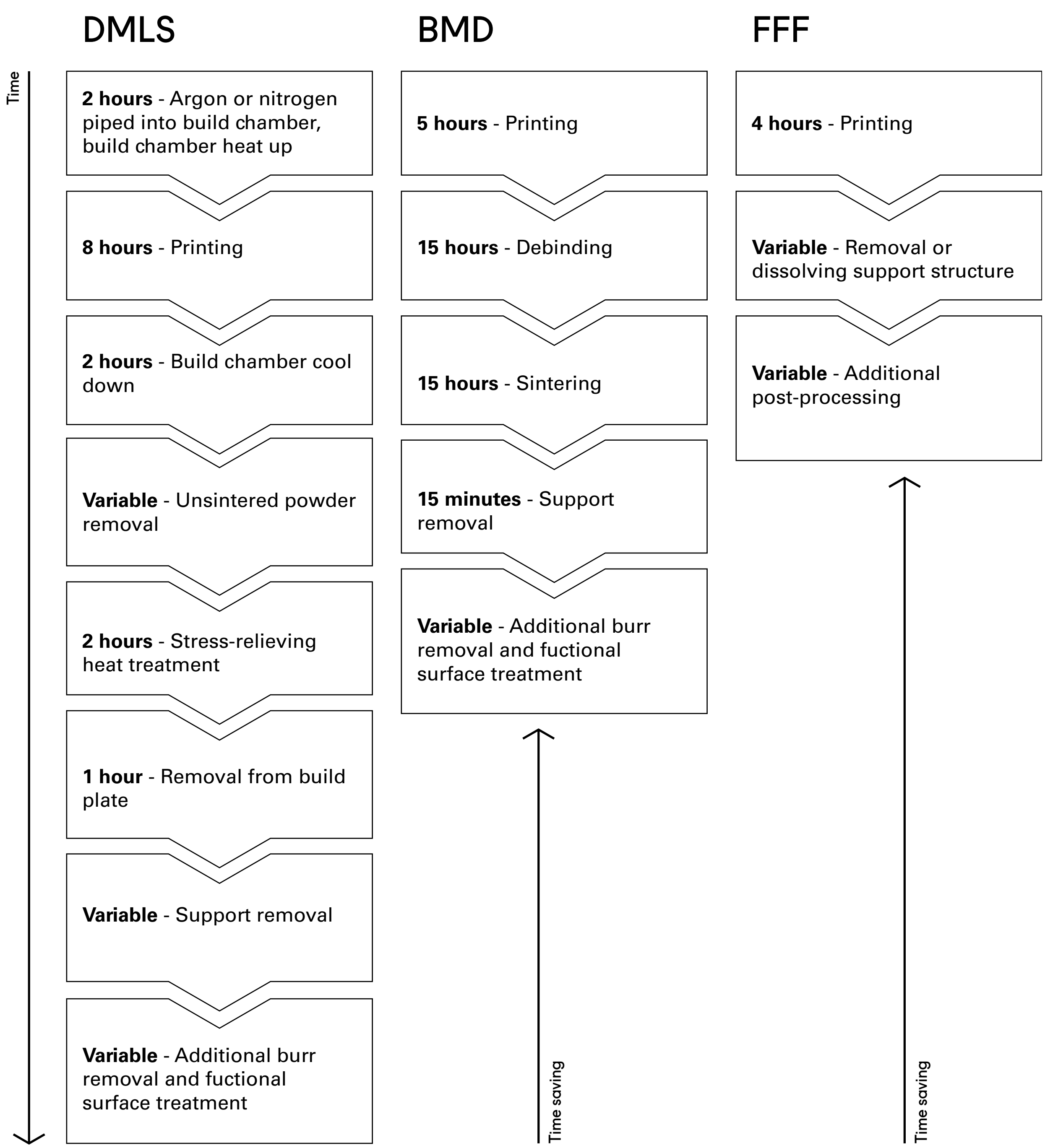
- Geometric complexity takes longer and costs more
- Results in wasted material
- Some internal geometries are impossible
- Parts cannot be light-weighted with reduced infill
- Noisy and messy compared to 3D printing
- Geometric features are limited to specific tool geometries

Below is a comparison of each manufacturing system's key features:

	DMLS / SLM	BMD	FFF	CNC
Usable build volume	250 x 250 x 325 mm (9.85 x 9.85 x 12.8 in)	254 x 170 x 170 mm (10 x 6.7 x 6.7 in)	330 x 240 x 300 mm (13 x 9.5 x 11.8 in)	2,000 x 800 x 100 mm (78 x 32 x 40 in)
Typical build speed	~ 2.0 mm^3/s (depending on powder recoating speed)	Up to 4.4 mm^3/s	Up to 24 mm^3/s	Too many variables to compare (material machinability, tool velocity, cut continuity, tool and block vectoring)
Materials	Various, including grades of stainless steel, aluminum, titanium Ti64, Inconel, bronze, copper, precious metals	Stainless steel 17-4 PH (other stainless steel grades, titanium, and Inconel are in development as MIM alloy ports)	Various engineering grade polymers filament, including glass and carbon fiber reinforced, and metal-filled	Nearly all engineering materials, machined from a blank block
Material system type	Closed material system	Closed material system	Open material system (2.85 mm thermoplastic filament)	Not applicable
Additional facilities / equipment	Floor space, ventilation inert house gas supply (nitrogen or argon), oxygen sensor, HAZMAT for unused powder disposal, wet vacuum, dry powder (class D) fire extinguishers, personal protective clothing (including respirator), flammable storage cabinet	Floor space, optional external / house gas connection for sinter furnace	Optional ventilation	Floor space, storage for blank material, coolant supply, flammable oily waste disposal, safety gauntlets, chip scoop, refractometer for measuring coolant solution
Training	Five days for three operators, learning one material	One training day	Recommended: 30 minutes to three hours	Two days for two operators
Applications	High-end functional prototyping, low-volume end-use parts, customized products, spare parts	Functional prototyping, low-volume end-use parts, customized products, spare parts	Rapid prototyping, functional prototypes, low-volume production, spare parts, metal casting mold cores	Functional prototyping, low to mid-volume end-use parts, customized products, spare parts with simple geometries

Workflow comparison

Please note that the times shown below are estimates that assume the same part size and part geometry across the three technologies. They represent the various production processes required by each system, taking into account the difficulty of post-processing metal compared to plastic.



Application opportunities for plastic to replace metal

Given the cost of creating metal parts with 3D printing or CNC-machining, there are opportunities for a plastic part – 3D printed in-house and on-demand – to replace a metal one. This is especially true since plastic 3D printing technology has become more affordable and its material science has advanced. We increasingly see this in customer applications, where a plastic part offers a cheaper, lighter, and more ergonomic alternative to metal.

Below are four key material properties where a plastic 3D printed part can replace a part that by default would be made of metal.

We also suggest advanced polymer filaments to use from leading materials companies. Each material has a preconfigured print profile downloadable from the Ultimaker Marketplace, which takes the guesswork out of 3D printing these filaments with Ultimaker machines.

Heat resistance and flame retardancy

While commonly 3D printed metals like stainless steel and aluminum can withstand temperatures up to 400 °C, they also conduct heat, making them unsuitable for many applications. The following polymer filaments perform well for heat-resistant applications:

DSM Arnitel ID 2060 HT is the first high-temperature copolyester thermoplastic on the market. It has excellent heat resistance: up to 175 °C for 1,000 hours and 190 °C for 500 hours. Applications include air-fuel management systems, engine shields, covers, gaskets, and seals for automotive. Due to this high performance, it can also provide a viable aluminum or rubber replacement for light-weighting applications under the hood.

Clariant PA6/66 GF 20 FR filament is a semi-crystalline thermoplastic reinforced with glass fiber. It achieves UL 94 V-0 flammability standards and outstanding wear resistance. Combined with the flame retardant Exolit®, it will extinguish a flame in less than ten seconds, rather than remain ignited. It also has reduced thermo-oxidative degradation, meaning its polymer bonds are slower to lose their mechanical properties when exposed to heat. These properties make it suitable for functional end-use parts and prototypes.

Chemical and corrosion resistance

Stainless steel 17-4 PH is known for its corrosion resistance. But depending on the specific chemicals your part will be exposed to, some thermoplastic filaments have excellent chemical resistance built in.

Arkema FluorX is made from Kynar® PVDF (polyvinylidene fluoride). It is chemical resistant to automotive fluids (oil, gas, and lubricants), fully halogenated hydrocarbons, alcohols, acids, and bases. It is also heat resistant, retaining its form up to a continuous 150 °C.

DuPont Zytel® 3D12G30FL BK309 is a specialty nylon that is able to resist most solvents, cleaning agents, automotive fluids, and fuels at room temperature. Reinforced with 30% glass fiber, it exhibits similar mechanical and chemical properties to well-known injection molding grades.

Wear resistance

For applications where a low-friction coefficient is a priority, polymers often outperform metal. Metal-to-metal contact requires lubrication to effectively reduce friction and wear. However, for applications that must work in dry or low-lubrication conditions, self-lubricating polymers can increase the service life of components and reduce their maintenance frequency. Such applications include plain bearings, toothed wheels, gears, piston rings, and seals.

Igus Iglidur I180-PF is a self-lubricating filament that's up to 50 times more wear resistant than other polymers. This means it is suited to applications that demand low friction and high abrasion resistance, such as lubrication-free bearings, moving assemblies, and complex wear parts, jigs, and fixtures.

Old and new: For many applications, 3D printed plastics can provide a more affordable alternative to metal

Strength and stiffness

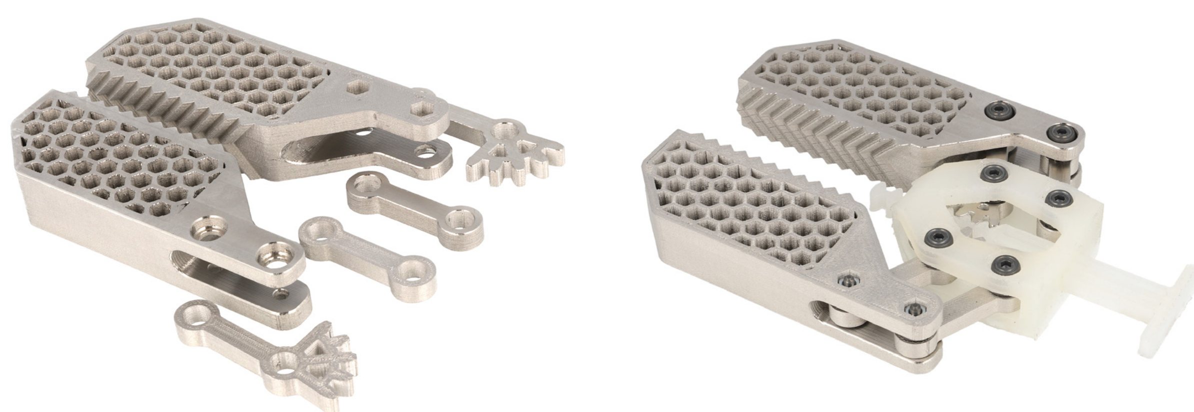
If tensile strength is a critical property for load-bearing parts, your default material choice will be stainless or tool steel – whether CNC-machined or 3D printed. However, thanks to polymers reinforced with either glass or carbon fiber, plastic printed parts can offer a low-cost and light-weight alternative with good strength and stiffness.

XSTRAND™ GF30-PA6 from Owens Corning is an FFF-compatible filament strengthened by 30% glass fiber. It is an excellent all-rounder, providing high tensile and flexural strength at yield, a wide operational temperature (-20 °C to 120 °C), and good chemical and UV resistance.

DSM Novamid® ID1030 CF10 is a 10% carbon fiber reinforced polyamide. It can be used to 3D print durable parts with good mechanical properties, close to what is usually only achievable by injection molding. It is suitable for applications including, under-the-hood brackets, structural jigs and fixtures, and high-performance structural parts.

3D print metal with FFF

Ultrafuse 316LX from BASF is a metal-polymer filament that offers an easy and low investment entry into metal 3D printing. Compatible with 3D printers with an open material system, the filament is a metal-polymer composite comprising austenitic stainless-steel type 316L powder. Tailored to existing, MIM industry standard catalytic debinding and sintering, it produces high-quality final metal parts. Possible applications include tooling, jigs and fixtures, functional components, and small-batch parts.



This gripper demonstrates a light-weighted application unlocked by BASF Ultrafuse 316LX, using FFF technology

Conclusion: Metal vs. plastic 3D printing

Despite its high price, metal 3D printing has significant advantages. But those advantages only make financial sense for a handful of applications in industries that prioritize product innovation and performance to meet certified quality standards. For DMLS, these applications include light-weighting, assembly part reduction, and topological optimization for the aerospace and automotive industries.

BMD is more accessible, but a less developed technology. Its lower purchase price still carries a high cost-per-part because of the extra workflow steps of debinding and sintering. BMD's promised material portfolio will increase the technology's viability. But this has yet to be fully delivered and will still form an expensive closed material system.

Polymer 3D printers that feature an open material system offer the most cost-effective in-house solution. And because they support rapid iteration and validation, they also complement outsourcing designs to metal 3D printing bureaus. If the mechanical stresses on your application and part geometry demand a metal 3D printed object, such services remain the most affordable, low-volume option.

The Ultimaker S5 – in combination with Ultimaker Material Alliance Program – allows you to print with materials from more than 80 global brands like BASF, DSM, and DuPont. This unique collaboration ensures that this reliable and affordable 3D printer will align and provide a turn-key workflow with increasingly sophisticated material portfolios.

Put your budget to the best possible use

The biggest pitfall you could make is to assume that functional metal parts that you previously outsourced should automatically be 3D printed in metal.

With an easy-to-use and reliable plastic 3D printer, your investment in an in-house production method will be more often useful, more often used, and more quickly achieve ROI.

Read the buyer's guide to FFF 3D printing:

Download PDF

If you have any questions or would like to find a reseller:

Get in touch

About Ultimaker

Since 2011, Ultimaker has built an open and easy-to-use solution of 3D printers, software, and materials that enable professional designers and engineers to innovate every day. Today, Ultimaker is the market leader in desktop 3D printing. From offices in the Netherlands, New York, Boston, and Singapore – plus production facilities in Europe and the US – its global team of over 400 employees work together to accelerate the world's transition to local, digital manufacturing.

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