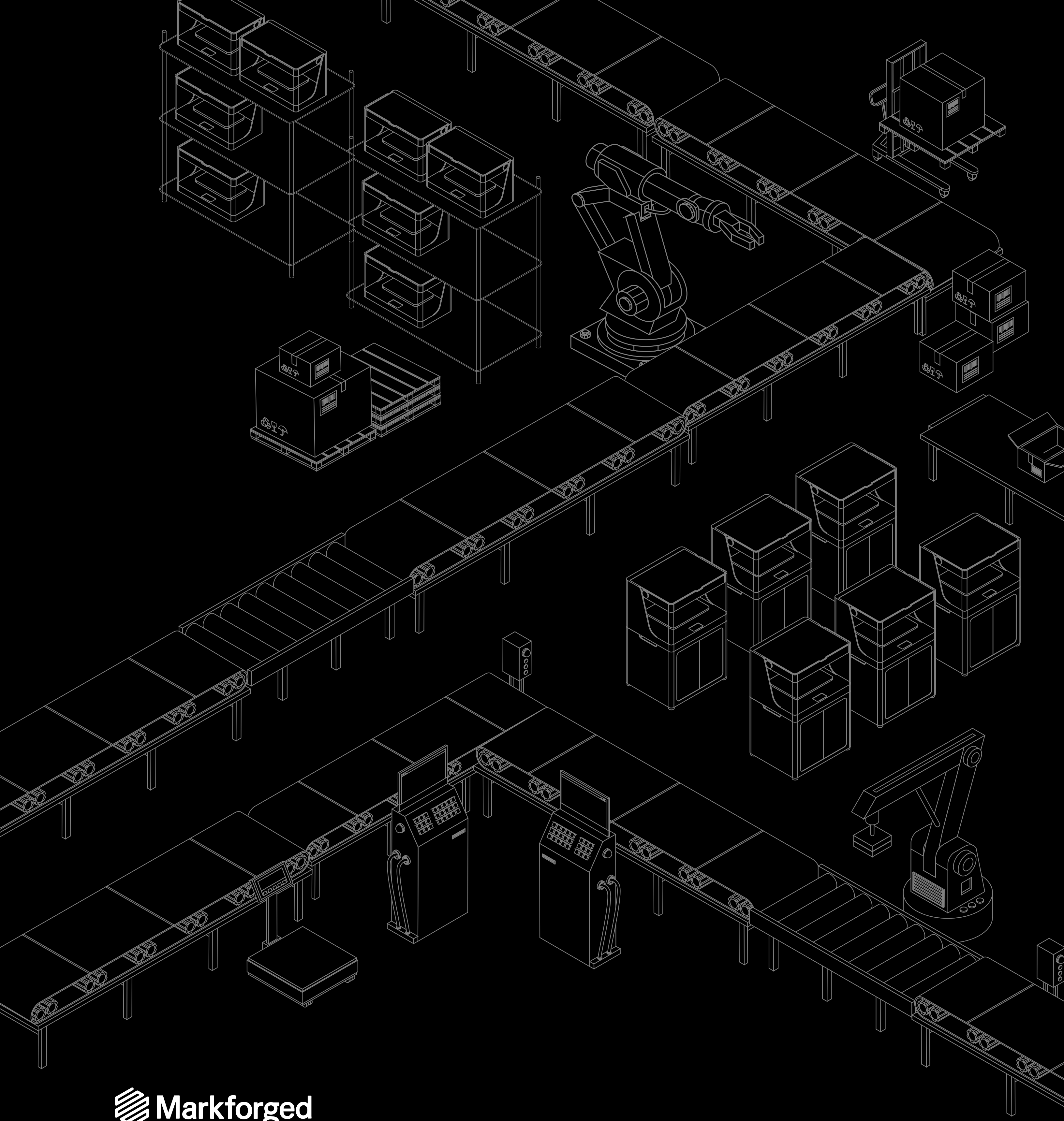

Markforged

Buyer's Guide to 3D Printing for Manufacturing

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1

Introduction

This buyer's guide serves as a source of information for engineers looking to add a 3D printer to their manufacturing process. The guide will concentrate on printers and printing technologies best suited for manufacturing applications. There are several options for printers and materials that offer the strength and chemical resistance necessary for manufacturing environments. The primary uses for 3D printed parts for manufacturing are prototyping, tooling and fixtures, and low-volume end-use parts.

2

What is additive manufacturing?

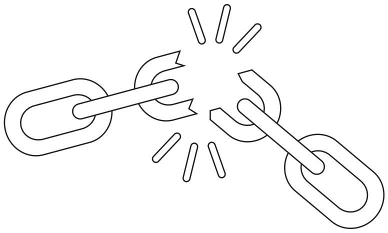
Additive manufacturing is a process in which a machine makes a three-dimensional object from a CAD (computer-aided design) file. In comparison, subtractive manufacturing methods involve removing material from a blank piece of stock. 3D printing is a subset of additive manufacturing, and is just one of the ways in which people and businesses fabricate 3D objects. Traditional subtractive manufacturing is notoriously slow, expensive, and has design limitations, whereas additive manufacturing is paving the way for quick, low-cost processes.

3

Common misconceptions about 3D printers

Although 3D printing has been around since the 1980s, it has often been misrepresented — both positively and negatively. Unfortunately, 3D printed parts are often synonymous with figurines, hobbyist parts, and cosmetic prototypes. However, thanks to innovations in technology and materials, there's so much more that companies can achieve with a printer built for manufacturing floors.

Some people shy away from new technology when misinformed, while others criticize it. The following common misconceptions about 3D printers and their materials should uncover the truth about how this technology is aiding the industry, not hindering it.



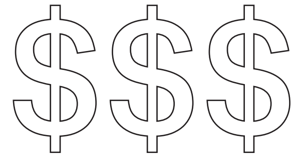
Myth: Plastic 3D printing materials are too weak to be used in a manufacturing environment

Before 3D printers built for manufacturing were introduced, many low-cost machines were printing plastics not suitable for a manufacturing environment. The parts they made were not only weaker, but also not durable enough nor chemically resistant.

In the last five years, 3D printer manufacturers have created machines capable of printing more robust materials. The addition of composites such as continuous carbon fiber has introduced the ability for customers to print parts that are both chemically resistant and durable, and when reinforced with continuous carbon fiber, parts are as strong as 6061 aluminum, a commonly used material in manufacturing applications fit for 3D printing.

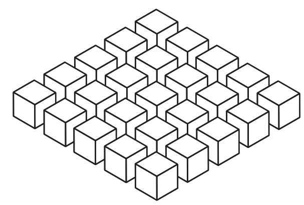
Myth: 3D printers are hard to use

3D printers for manufacturing purposes often have unintuitive software that requires expert knowledge, while most hobby-level 3D printers are built without software. As a result, these machines require considerable expertise — such as how to design a part for the process, how to orient and position a part, which material to use — to yield a viable part. 3D printer companies now produce integrated, purpose-built hardware, software, and materials, resulting in predictable machine performance. This means engineers and machinists can focus more on creating quality parts and less time focusing on figuring out how to operate their printer.



Myth: 3D printers capable of printing parts strong enough for manufacturing are expensive

Some manufacturing-grade printers are expensive, however you can find a 3D printer for manufacturing purposes from $3,500. The ones costing over $100,000 are usually large format plastic printers or metal printers, which frequently require special facility requirements and safety equipment.



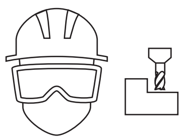
Myth: 3D printers will replace high-volume production

While some say that 3D printing is replacing high-volume manufacturing, the time and cost required to 3D print parts at high volume is often far greater than that of traditional manufacturing. Producing at scale has been optimized for decades, so 3D printing is currently not fast or cost-effective enough to replace processes like injection molding or casting. However, many companies find that adding several printers to its manufacturing processes can significantly reduce time spent fabricating complex parts in-house.

3D printers are able to create parts faster and at a low cost for custom low-volume parts. Businesses are able to focus on revenue-making end use parts, instead of focusing time, effort, and money on low-volume parts that may not generate any revenue for the business. With a 3D printer, you can rapidly iterate designs without wasting resources waiting for parts that may not meet quality standards. This makes 3D printers perfect for low-volume, custom-made prototypes, tooling, and fixtures that are often complex and hard to machine, but are critical for an efficient production process.

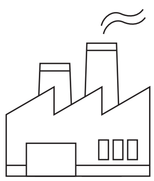
4 Let’s talk ROI

A 3D printer is a large investment that lacks the institutional maturity that suggests it will fit in as well as traditional manufacturing capital expenditures. If you haven’t used a 3D printer for manufacturing purposes previously, you may have not calculated the potential ROI. However, the addition of a 3D printer is capable of drastically reducing manufacturing costs for parts like prototypes and tools. Below we will compare 3D printing to machining in-house and third-party suppliers, as they are the most common processes.



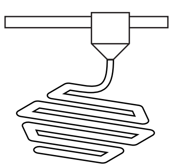
Machining in-house

Machining a part in-house requires money spent on equipment, material, and a machinist’s time. If you value your machinist’s time at $70/hour, and it takes them five hours to set up, program tool paths (CAM), and machine the part, that’s $350 of labour towards a part. Material costs also add up, and iterations and revisions contribute extra costs.



Sending out to a third-party supplier

Sending a part out to a third party is an easy way to fabricate a part without setting aside internal manufacturing resources. It is, however, quite costly when making low-volume parts. If you’re sending out a part to be made, you need to wait for it to be made and shipped. If you find you need to make some iterations, you will have to pay for each iteration plus shipping, and can’t make further modifications until you receive your part.



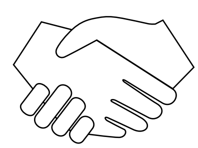
3D printing in-house

3D printing a part in-house includes a one-time machine cost and ongoing material costs. Your machinists can manage each print via cloud-connected software and focus on creating important parts instead of overseeing the machine while it works. Some 3D printers come with software that will tell you how much the part you’re designing costs to print, meaning you can monitor the second part of your cost (the material cost) through software.

Working out ROI

Use the table below to work out the number of parts it will take to pay off a 3D printer. In this example, we’re using Markforged’s X7 Industrial Series printer ($69,000) as the benchmark printer, and three different parts (gripper jaws, CMM fixture, welding fixture) for benchmark parts. Take your current manufacturing method costs and subtract the cost of the printer to get cost savings per part. Take the price of the printer and divide by the cost of the savings to work out how many parts you need to print to pay off the machine. For example, using the results in this table, you would only need to print 55 CMM fixtures to pay off the X7.

	Traditional	3D Printed	**Savings**
Gripper Jaws	$290	$9	**$281**
CMM Fixture	$1590	$330	**$1260**
Welding Fixture	$800	$10	**$790**



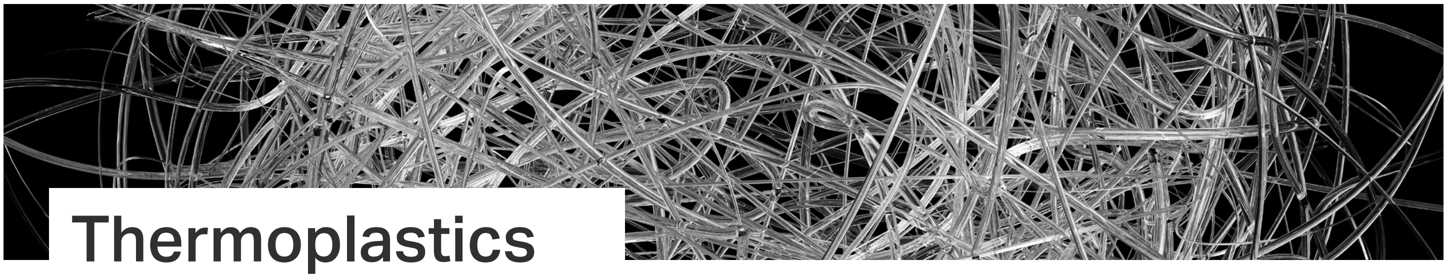
Business Impact

Business benefits spread far further than reduced costs and time related to part production. Here are a few areas where manufacturers have benefitied by utilizing 3D printers:

- **design flexibility** — make parts that were otherwise unable to be fabricated traditionally
- **faster time to market** — ship products faster by running your 3D printer 24/7
- **greater agility** — achieve more flexibility for small modifications, reducing turnaround time
- **less machine downtime** — continuously innovate with minimal downtime

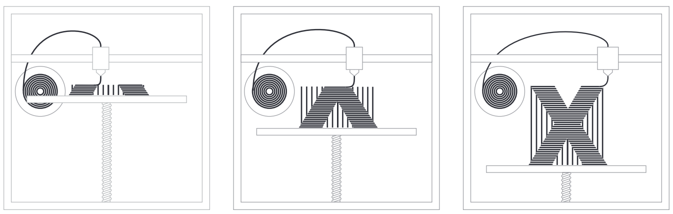
5 Types of 3D technologies

There are plenty of different technologies to choose from, and different materials that apply those technologies. The following is a guide to those materials and the technologies associated with them.



Thermoplastics

Thermoplastics are one of the most common material groups in additive manufacturing. Thermoplastic 3D printing processes involve heating a plastic material to just below its melting temperature where it is semi-formable to create a shape. Thermoplastics are tough but weak, deforming rather than fracturing under stress. They have relatively low melting points, and low chemical and abrasion resistance.



FFF

Fused Filament Fabrication

Best applications: Low-fidelity prototypes and models.

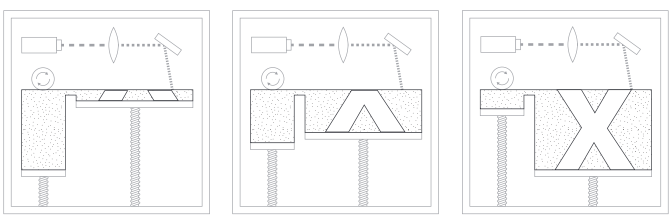
How it works: FFF is the most widespread 3D printing technology. In this process, thermoplastic material is heated and extruded through a nozzle. As the nozzle moves, it deposits a cross-section of the model being printed. This is repeated layer by layer, until the model is completed. FFF parts are generally not fully dense.

PROS

+ simple
+ affordable
+ lightweight parts

CONS

- weak parts
- parts prone to wear



SLS

Selective Laser Sintering

Best applications: High-precision end-use parts.

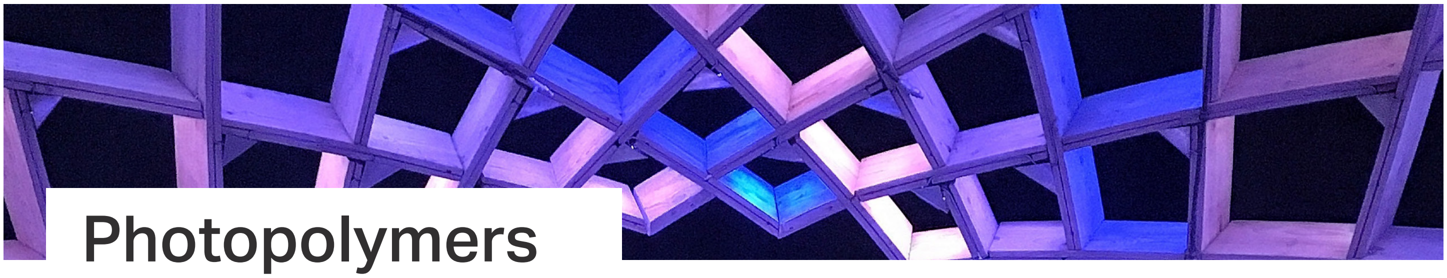
How it works: SLS utilizes a laser to sinter powdered thermoplastics into any given shape. The parts are printed in a chamber of plastic powder. For each new layer, a roller sweeps new powder over the chamber, and a laser selectively sinters a cross-section of the part. The chamber then moves down to make room for the next layer of powder. By using SLS, you can create incredibly high-quality parts with high-strength plastics like PEEK and ULTEM.

PROS

+ high detail
+ wide range of materials

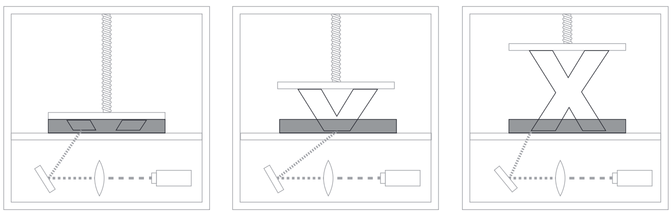
CONS

- expensive
- respiratory protection required



Photopolymers

Photopolymer materials are liquid polymers that change structure when exposed to a light source. When catalyzed with UV radiation, these liquid resins solidify. Unlike thermoplastics, photopolymers cannot be melted. Due to the specific properties that enable photopolymerization, resins are often brittle and not as long-lasting as thermoplastics, because they degrade over time from continued UV exposure.



PROS

+ highly detailed
+ smooth surface finish
+ isotropic

CONS

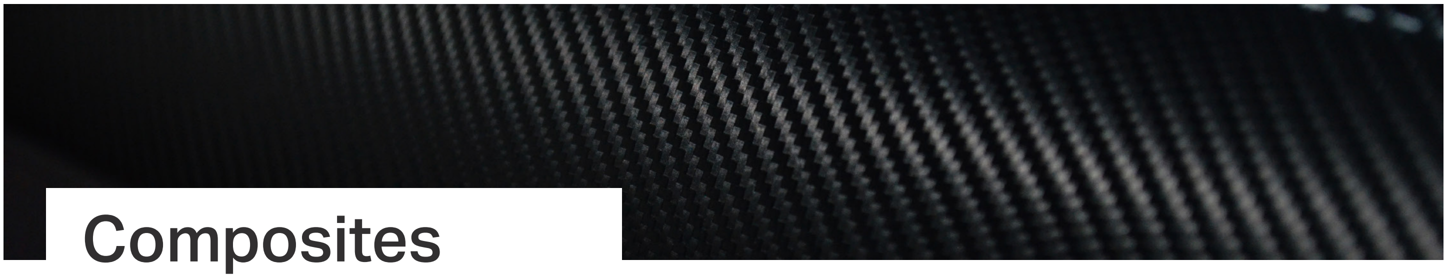
- brittle parts
- small build volume
- chemical protection required

SLA

Stereolithography

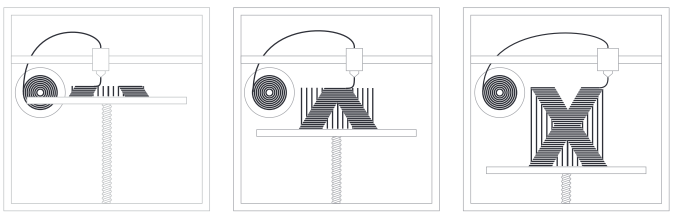
Best applications: High-precision detailed parts such as form prototypes or models.

How it works: The SLA process selectively cures photopolymers with a UV laser. The laser cures the resin to form a hardened layer, then repeats the process layer by layer until complete. As the chemical bonding process is induced by photopolymerization, printed parts are dense and isotropic. SLA 3D printers often have a relatively small build volume, but can achieve exceptional detail and surface finish through the precision of the laser beam.



Composites

Composite materials are highly valuable because of their material properties. Well-known and heavily utilized composites like carbon fiber reinforced resins traditionally deliver high strength-to-weight ratios for industries such as automotive and aerospace. With the recent innovation of 3D printable composite materials, parts can be made strong enough for use in engineering applications in which the material properties of more common printing methods would not be sufficient. In 3D printing, a thermoplastic reinforced with continuous carbon fiber can effectively replace traditionally machined aluminum components, because it combines the strength and stiffness of metal with the ease of additive manufacturing.



FFF

Fused Filament Fabrication

Best applications: Functional prototypes, customized end-use parts.

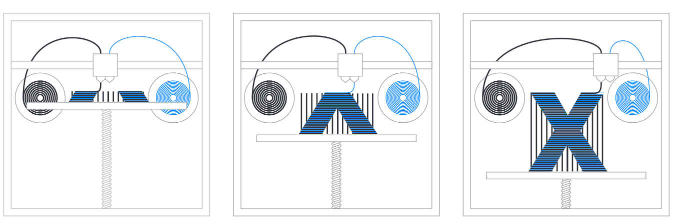
How it works: Composites FFF uses materials composed of traditional thermoplastics like nylon and PLA mixed with chopped fibers (usually carbon fiber). While the FFF process remains unchanged, the chopped fibers increase the strength, stiffness, and surface finish of the model.

PROS

+ heat deflection
+ precision
+ strength

CONS

- limited range of materials
- medium-strength parts



CFF

Continuous Filament Fabrication

Best applications: Functional prototypes, long-lasting parts, strong end-use parts, tooling and fixtures.

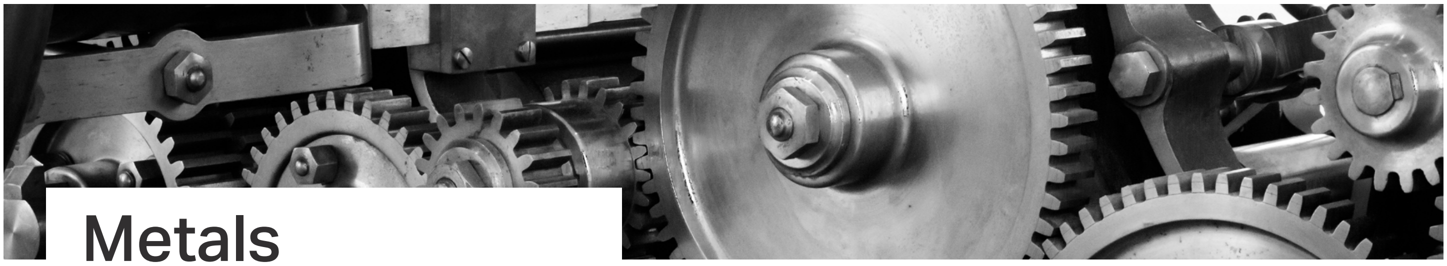
How it works: CFF is a cost-effective solution for replacing metal parts with 3D printed composite parts. Printers use a second nozzle to lay continuous strands of composite fibers (such as carbon fiber, fiberglass, or Kevlar®) within FFF-extruded thermoplastics while printing. The reinforcing fibers form the backbone of the printed part, resulting in strong, stiff parts.

PROS

+ metal-strength parts
+ customizable fiber pathing

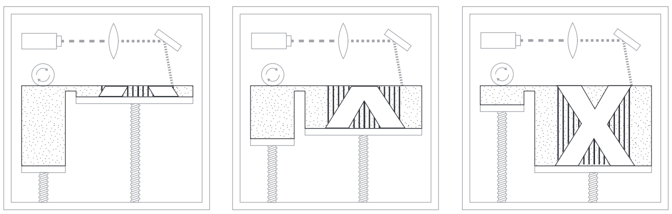
CONS

- inter-layer adhesion
- lower surface hardness and corrosion resistance vs. metal



Metals

3D printing metal has been limited by cost, complexity, and material constraints until recently. Metals cannot be extruded as easily as thermoplastics, and require high heat and power to achieve a formable state. In order to implement metal additive manufacturing, most solutions start with the metal in powder form and use various heating techniques to fuse the powders together. Many metal printing methods include post-processing steps to fully strengthen or finish the printed parts.



SLM / DMLS

Selective Laser Melting / Direct Metal Laser Sintering

Best applications: High-precision parts requiring great dimensional accuracy.

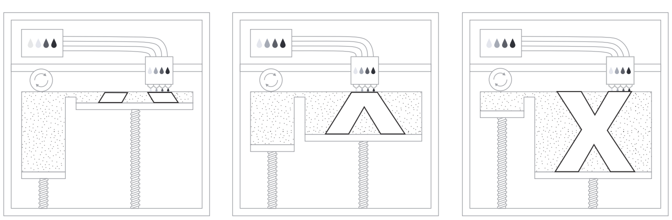
How it works: SLM is achieved by precisely melting fine metal powders in an inert gas chamber to build up a metal part. Layers of the metal powder are distributed and then selectively melted with a high-power laser to fuse the powders together. High heat concentrations within the chamber can deform or warp the parts, so the process has some geometry limitations. However, the process can be used for functional metal parts that would be too expensive or complex to machine (such as medical implants and weight-optimized parts). There are also multiple post-processing operations to remove supports and clean the part, so specific facility requirements are necessary.

PROS

+ strong parts
+ intricate detail
+ excellent surface finish
+ wide range of materials

CONS

- expensive
- part failure
- extensive post-processing steps



Binder Jetting

Binder Jetting

Best applications: Complex large parts such as cooling systems, housings, and aerospace parts.

How it works: Binder Jetting is a process where a layer of powder is deposited on a build platform. A liquid bonding agent is applied, which bonds the particles together. The print head drops alternating layers of the material and the binding material layer by layer. Binder Jetting does not require any support structures, meaning the build volume can be filled with several parts. Binder Jetting is a cheap and fast process, and can work with almost any material that comes in a powder. After printing, the part needs to be washed and sintered in an oven to make it a fully dense metal part.

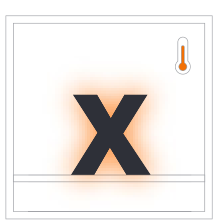
PROS

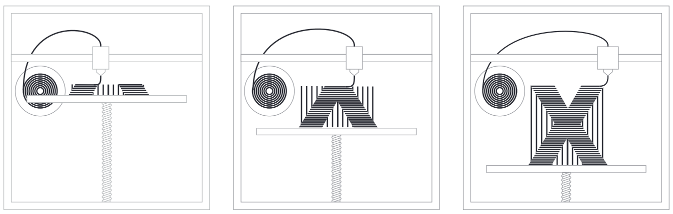
+ fast
+ cost-effective
+ many materials available

CONS

- fragile parts
- extensive post-processing time

POST-PROCESSING





PROS

+ custom infills
+ cost-effective
+ wide range of materials

CONS

- not fully dense
- can't produce small, precise features

POST-PROCESSING

ADAM

Atomic Diffusion Additive Manufacturing

Best applications: Metal tooling and complex parts.

How it works: ADAM is a unique and cost-effective metal 3D printing process that combines concepts from FFF 3D printing and Metal Injection Molding (MIM). Metal powder (common to SLM methods) is encased in a plastic binder, which gets deposited layer by layer on a print platform by an extruder. After a part is finished printing, it needs to be washed and sintered in an oven, melting away the binder and allowing the metal powders to fuse into an isotropic metal part. ADAM is also useful for building custom internal geometry.

6 How to choose a 3D printer for your company

When choosing a 3D printer, ask yourself these questions:

1. What are our biggest manufacturing challenges?
    - prototyping (number/time of iterations, lead time/cost)
    - tooling (time/cost to tool up, custom tooing)
    - end-use parts (cost, quality, lead time)
2. What are my current costs for outsourcing or machining parts in-house?
3. How important is it to have strong parts?
4. Do my parts need to be resistant to heat or chemicals?
5. Do I have speciific material restrictions? (thermoplastic, composites, photopolymers, metal)
6. Am I currently missing deadlines because of time spent machining or outsourcing parts?
7. Is the company losing revenue due to reduced production?
8. Are our engineers relying too heavily on expensive equipment for non-revenue parts?

If you get the chance to speak to a few 3D printer companies, ask them these questions:

1. What's makes this company's technology unique?
2. What are the facilities requirements for machine operation (health, safety, power, and ventilation)?
3. Is it possible to get samples to test quality?
4. What is the process from design to part in hand?
5. What are the specific steps involved to get to a functional part ready for my factory floor?
6. How does your system assure great print quality?
7. What materials can I work with on each machine and how will these support my application?
8. What does the setup process look like, including training, and how quickly am I printing?
9. Who typically operates printers in-house and what kind of training/expertise is required?
10. Can you test software in advance?
11. Does the printiner come with its own software?
12. What's the learning curve for the software?

Once you have the necessary information, you'll be able to make an informed decision about which printer works best for you.

7 3D printing for manufacturing with Markforged

At Markforged, we've introduced new materials and technologies that have helped companies change their processes and achieve greater outcomes. Here are some of the ways in which our customers have utilized Markforged technology in creating prototypes, tooling and fixtures, and end-use parts.

COMPANY
Centor

INDUSTRY
Architecture

PRINTER
Onyx One

MATERIAL
Nylon

90%
CHEAPER

92%
FASTER

Integrated Doors

Centor used to rely on three machinists who would machine 3D parts on demand, which proved to be costly. David Chappell, Group Manager of Product and Engineering at Centor, would also outsource 3D printing for prototypes, resulting in inconsistent parts that did not meet quality standards. David knew he needed to look into other options, and found Markforged 3D printers.

David said it’s the first time he’s seen “a 3D printer promise what it could do in a real life design studio factory,” which is why the team runs the printer almost 24/7 to produce functional prototypes.

COMPANY
Autometrix

INDUSTRY
Textiles
Equipment

PRINTER
Mark Two

MATERIAL
Onyx

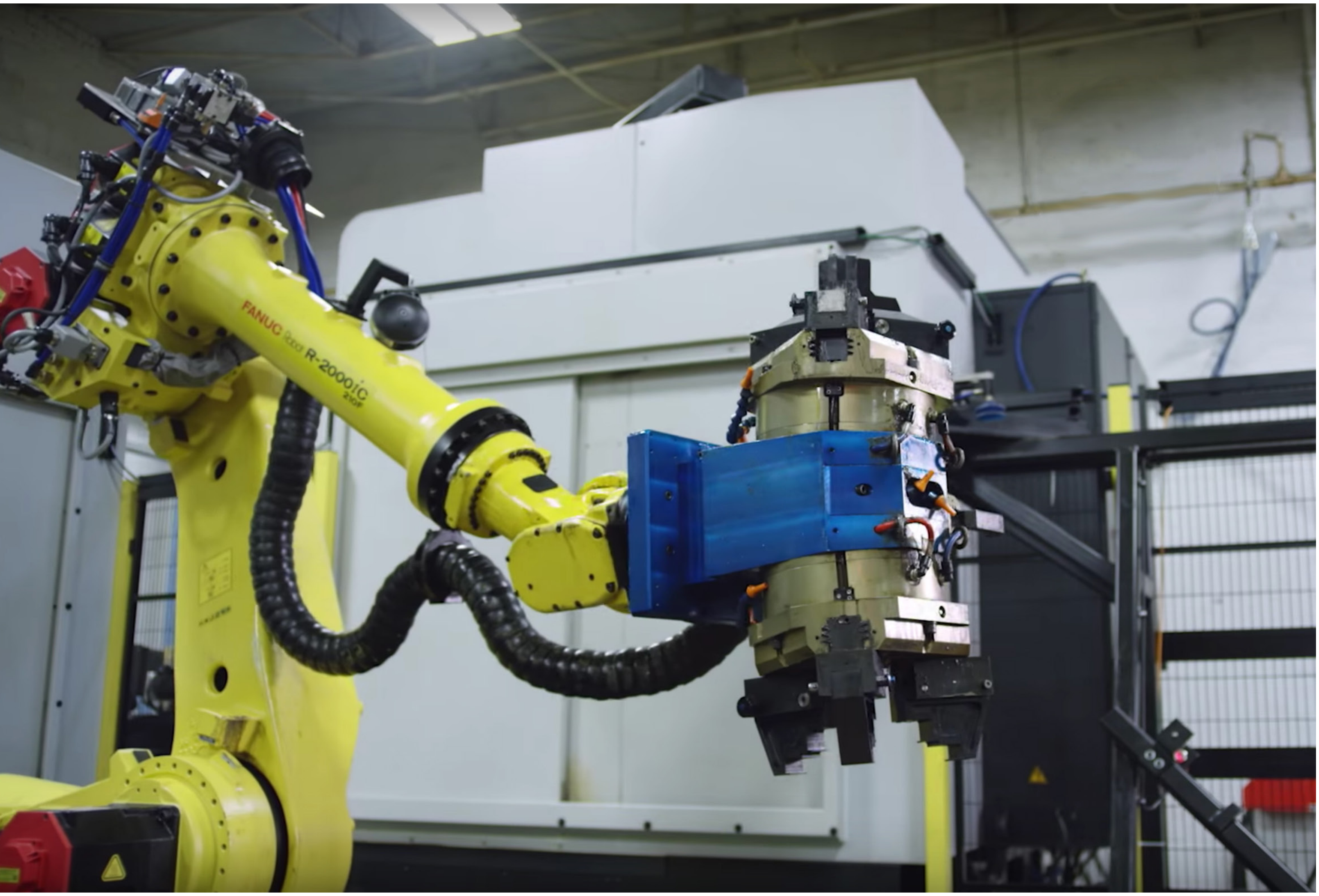
93%
CHEAPER

78%
FASTER

Precision Cutter

Autometrix, a cutting equipment designer and manufacturer, needed a new way to prototype parts for its machines. The company had previously machined prototypes out of aluminum, which was prohibitively expensive for low-volume custom parts. The added costs came from custom tooling, which had to be machined each time a new prototype was needed.

When the company started looking into other options to offset their high costs, they found that a 3D printer "was able to produce stronger parts in a shorter amount of time for way less money than anything else we had found out there," according to Chief Technical Officer Jonathan Palmer. Autometrix now quickly tests new ideas by printing prototypes instead of paying third-party manufacturers for high-cost single parts.



COMPANY
Dixon Valve

INDUSTRY
Manufacturing

PRINTER
Mark Two

MATERIAL
Onyx +
Carbon Fiber

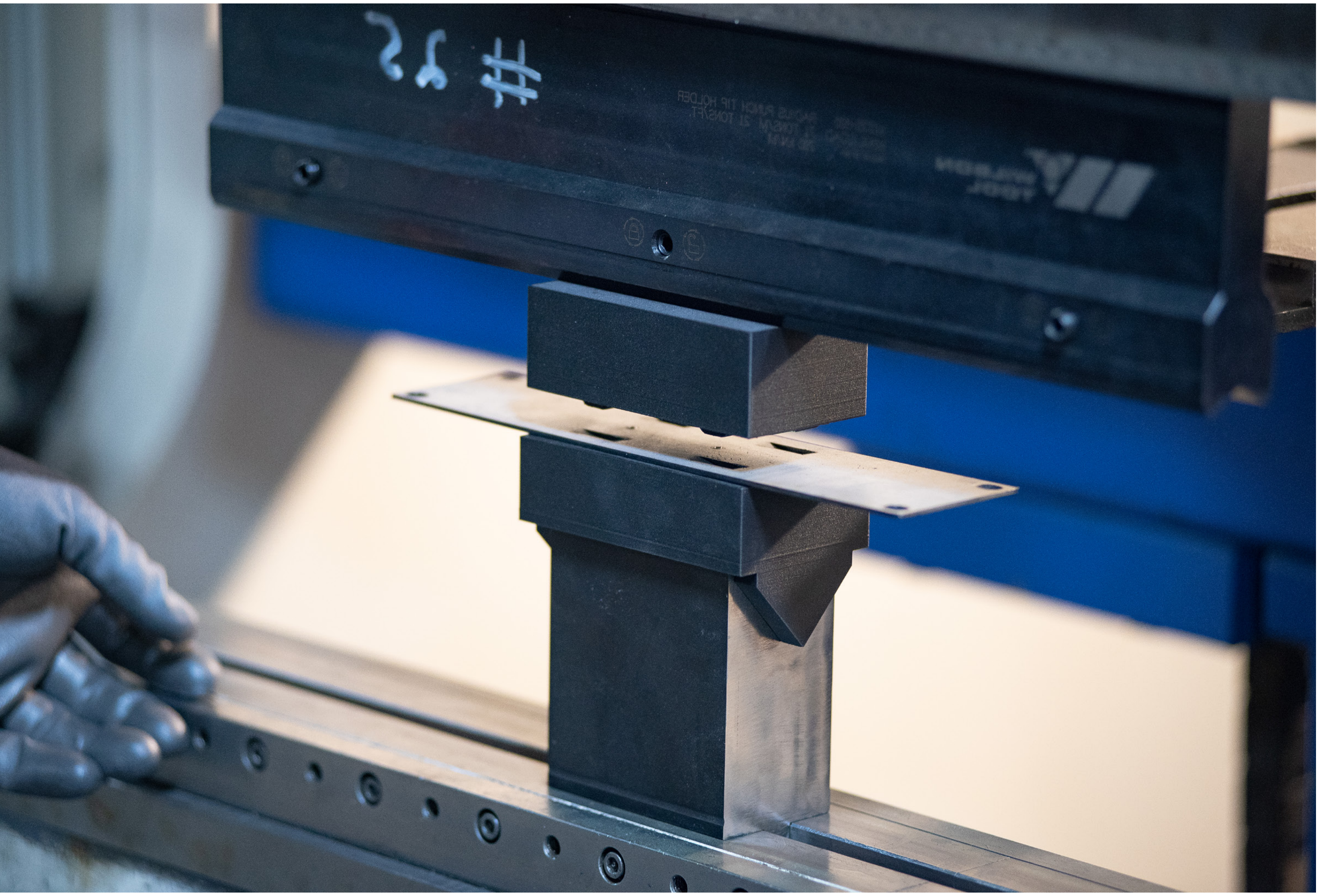
97%
CHEAPER

93%
FASTER

Gripper Jaws

Dixon Valve needed gripper jaws to transfer parts between machining centers. The company found that they were expensive to machine, and took a week to manufacture. After purchasing a Mark Two, engineers were able to retool a robotic arm in less than 24 hours.

System Engineer J.R. Everett describes the Markforged machines as "a critical component in our design process that's really changing the way we work to the point where we are actually altering our procedures and plans to accommodate it." With Markforged technology, Dixon Valve engineers produced durable, chemically resistant parts in Onyx and eliminated the need to outsource or machine the majority of its grippers.



COMPANY
Centerline

INDUSTRY
Manufacturing

PRINTER
Mark Two

MATERIAL
Onyx

86%
CHEAPER

88%
FASTER

Press Brake Punch

Centerline Engineered Solutions (CES) is a contract engineering and fabrication business in Greenwood, South Carolina. The company had to turn down potential jobs because the customer's budget could not cover the tooling and fixturing costs required to make the parts, and struggled to find tooling solutions for low-volume parts.

A customer approached CES and requested a lanced and formed 14-gauge stainless steel piece. A laser cutter creates four formable regions, and then a press brake with a custom punch and die lances the regions outward. Phil Vickery, CEO and Founder of CES, 3D printed the press brake punch, pausing it midway to insert 14-gauge steel inserts into the printed part. This resulted in a reinforced 3D printed part that was capable of forming features of the die.

COMPANY
Radiant Images

INDUSTRY
Camera Equipment

PRINTER
X7

MATERIAL
Onyx + Carbon Fiber

77%
LIGHTER

63%
FASTER

360º Camera Frame

Radiant Images creates platforms to film high-quality 360-degree videos. The camera rig required a frame with high-strength polygonal brackets bolted together at an angle. Parts were initially being outsourced and machined from 7075 Aluminum. The original rig was heavy and time-consuming to produce, so the company purchased a Markforged 3D printer to ensure it could assemble a rig with a high strength-to-weight ratio.

By printing the frame in-house out of Onyx and Carbon Fiber using its 3D printer, Radiant Images could build lighter rigs faster than before. The company now has more than 30 printed parts on each camera frame, with the smooth surface finish of the parts being an added bonus.

COMPANY
MARTAC

INDUSTRY
U.S. Naval Technology

PRINTER
Mark Two

MATERIAL
Onyx

99%
CHEAPER

93%
FASTER

Seawater Intake

MARTAC (Maritime Tactical Systems) designs and manufactures high-performance unmanned aquatic vessels. The company was investigating the ability to create geometrically complex intakes that could help route seawater through cooling channels. The company 3D printed a complex, custom part that didn't need to conform to traditional machining constraints by utilizing a 3D printer.

According to Ian Weaver, Operations Coordinator at MARTAC, the printed parts are "fairly resilient with debris in the water." Parts are durable enough to withstand the high impact of water thrust at them. This result ensures the company won't have to go down the route of injection molding, saving money for additional creations.