Markforged

The Additive Movement Has Arrived

100+ industrial use cases
for today's modern manufacturer

Trends Report

markforged.com/additive-manufacturing-movement

Contents

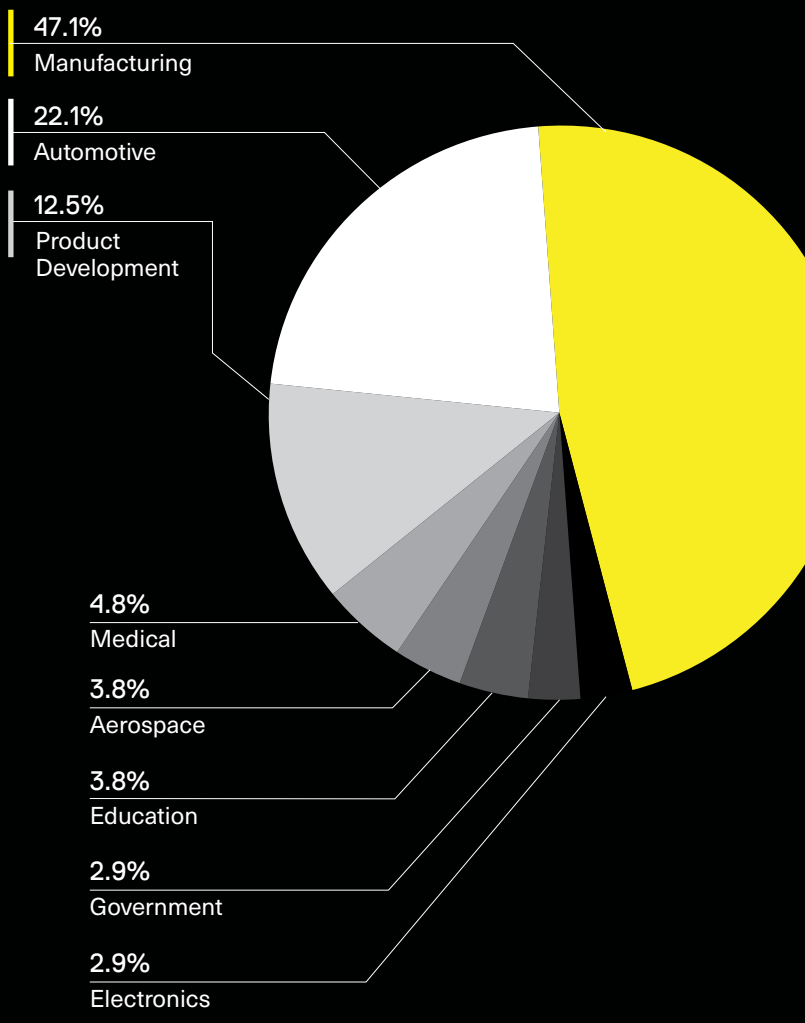
Public perception of additive manufacturing has been skewed for years. Industry monoliths have been obsessed over futuristic, vanity applications instead of practical use cases. But they've had it wrong. Today, 3D printing solutions are already transforming supply chains and manufacturers around the world.

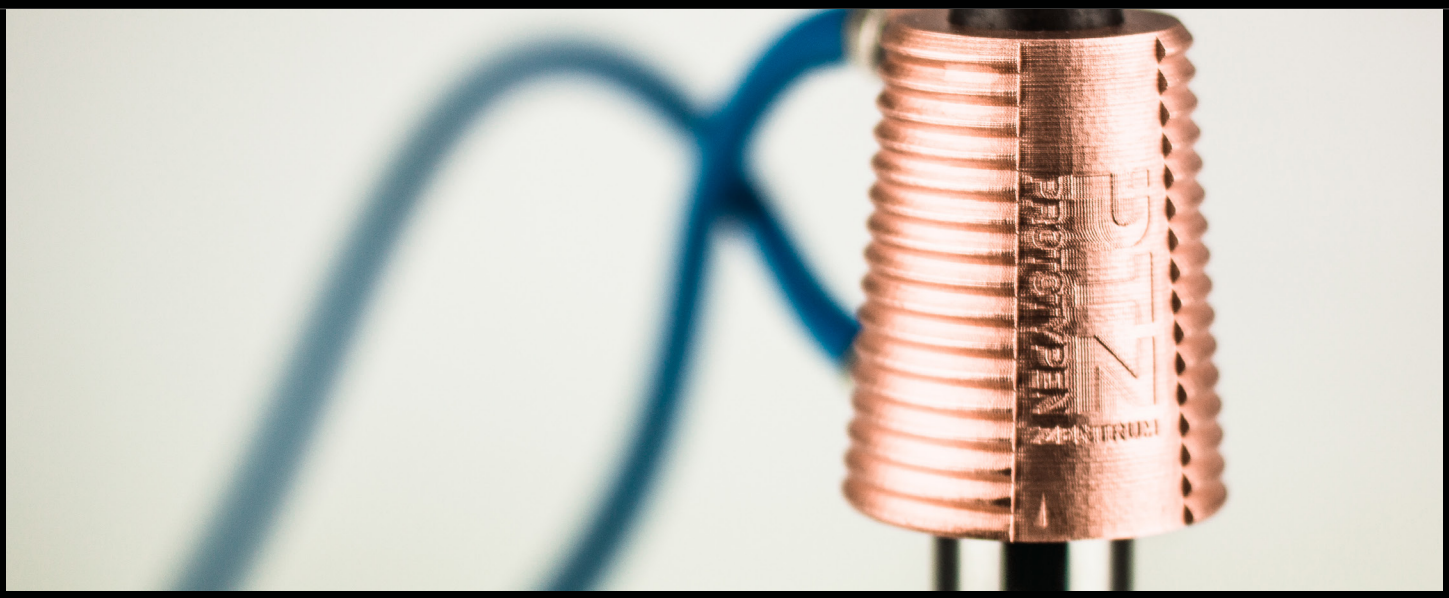
Industry experts have long predicted the advent of an "Additive Manufacturing Revolution." But the way they pitch it, 3D printing is as practical as flying cars. These experts may have to wait another decade for their unit economics and throughput capacity of 3D printing to make mass production and mass customization financially and physically viable. Moreover, many of the industries viewed by experts as "ripe for disruption" lack the business processes required to commercialize additive for mass production except for a handful of edge cases where more qualitative intangibles took priority over return on investment (ROI).

Against this decades-long backdrop of intense hype, Markforged set out to show how 3D printing is being used for supply chain optimization and manufacturing TODAY. Surveying customers across a broad range of industries, Markforged analysts identified the highest value applications, workstreams, and business processes made possible with current additive technology.

The customers surveyed submitted use cases that shed light on how the technology is actually transforming their businesses. The starting point for most was a predictable blend of tools, fixtures, and prototypes. As engineers and designers began to implement the technology, however, the quality of the parts coupled with the simplicity of the

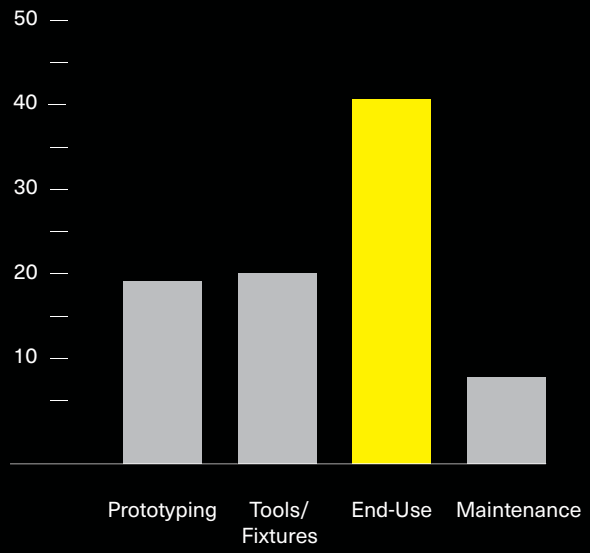
Industries Using Additive Manufacturing within Survey





process challenged their initial intuition. They found more and more places where printed parts could not only add value, but improve results. Prototypes and check fixtures became one-to-one replacements for machined metal in some of the most demanding engineering applications.

Additive Adoption of Survey Respondents



Where did this shift come from? The innovation spark was not printing metal. Additive manufacturing solutions have been capable of printing stainless steel and high-performance alloys for decades. The answer also doesn't lie in simplicity alone — desktop 3D printers give students and hobbyists with little-to-no prior expertise the ability to create any shape they can imagine.

The major breakthrough for manufacturers stemmed from accessible processes for producing parts that could hold up to the most demanding engineering challenges. This paradigm shift gave rise to a new way of thinking about not just 3D printing, but manufacturing as a whole.

The immediacy and repeatability of a cloud-based, end-to-end platform further extended the advantage, impacting every stage of the product development cycle. This innovation led to superior usability, which in turn, has spurred the industry to take a bolder approach to product development. As shown in the graph on the next page, 79% of the parts submitted in the customer survey were replacing either metal or composite fiber originals[1] with 3D printed parts. The companies that adopted the technology and the mindset enjoyed higher-performing

[1] Markforged customer survey

end products, superior customer experiences, greater market share, and entirely new and profitable business processes.

A 2019 report by EY found that an early majority of 46% of companies expect to use additive manufacturing for end-use parts by 2022[2]. While end-use part production does not paint a comprehensive picture of maturity with additive, it does serve as a proxy for how the survey respondents compare with the industry.

By contrast, the early majority has already arrived at end-use parts for Markforged users. But this does not represent the whole story[3]. A deeper look at how additive is transforming each phase of the product development cycle reveals maturity isn't just about printing end-use parts, but rather finding the components of the product development cycle most impacted by simple and robust part creation.

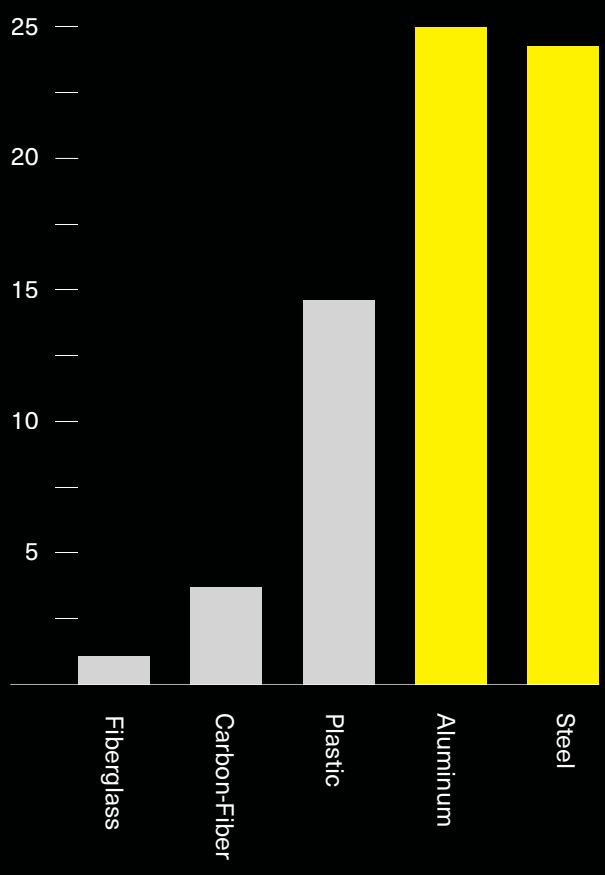
As additive manufacturing moves into mainstream adoption, its technologies are already delivering significant value today. Markforged solutions offer manufacturers unprecedented freedom in producing metal and composite parts with engineering-grade precision and durability. And with cloud-based 3D printing software, manufacturers can easily make any part, any time, anywhere on-demand.

After reviewing the exhaustive survey of 100+ additive use cases, Markforged analysts have found that these solutions are reliant on a platform built on four pillars: accessibility, design freedom, physical strength and durability, and reliability. These attributes combine to offer demonstrably improved workstreams relative to traditional manufacturing processes.

In the following report, you'll learn how these pillars apply to the use cases, but if you'd like to see the full list of applications we surveyed, you can visit: markforged.com/additive-manufacturing-movement.

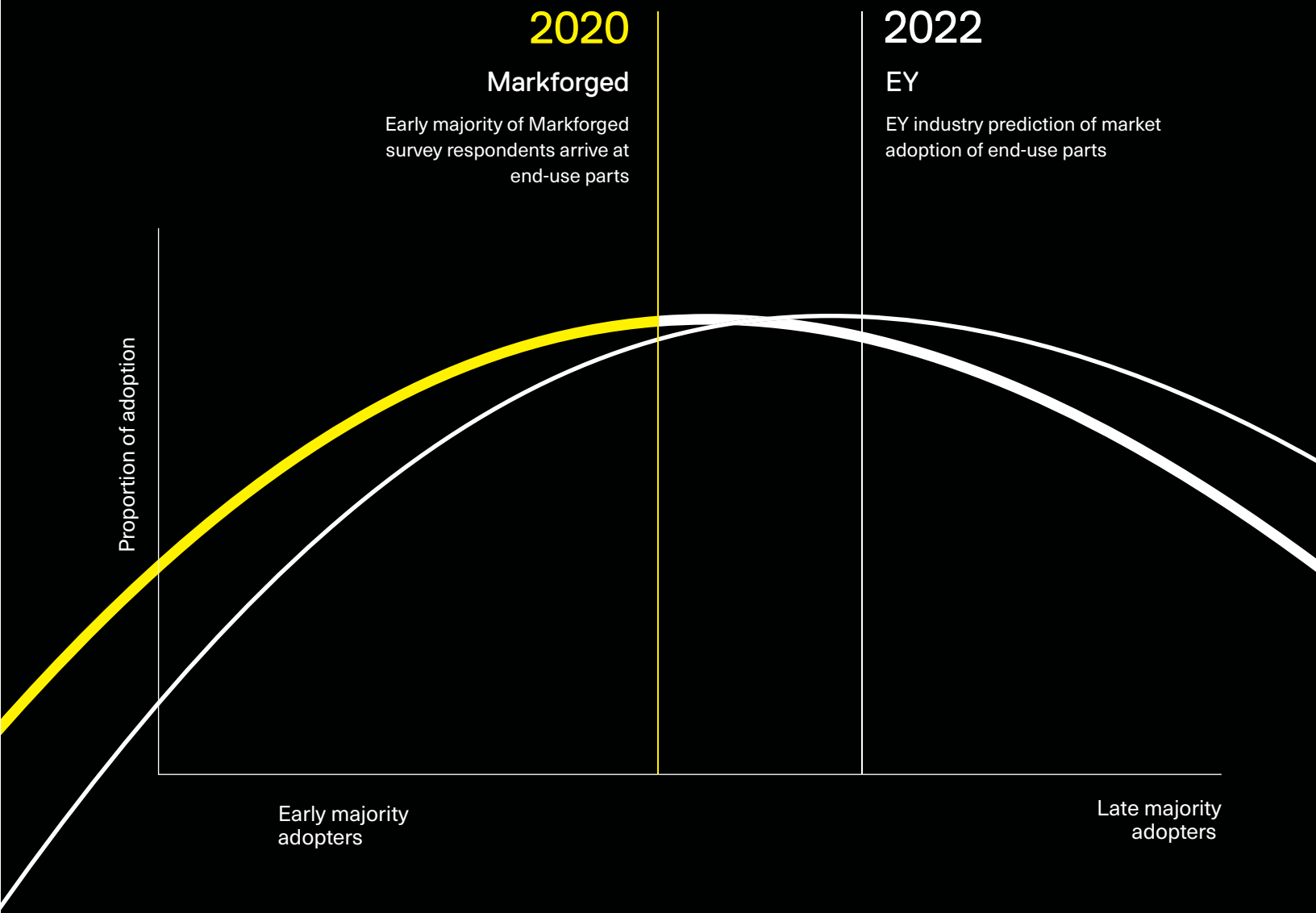
Original Materials Replaced

Frequency by Survey Respondent Application



[2] EY, *3D printing: hype or game changer? A Global EY Report 2019*
[3] Markforged customer survey

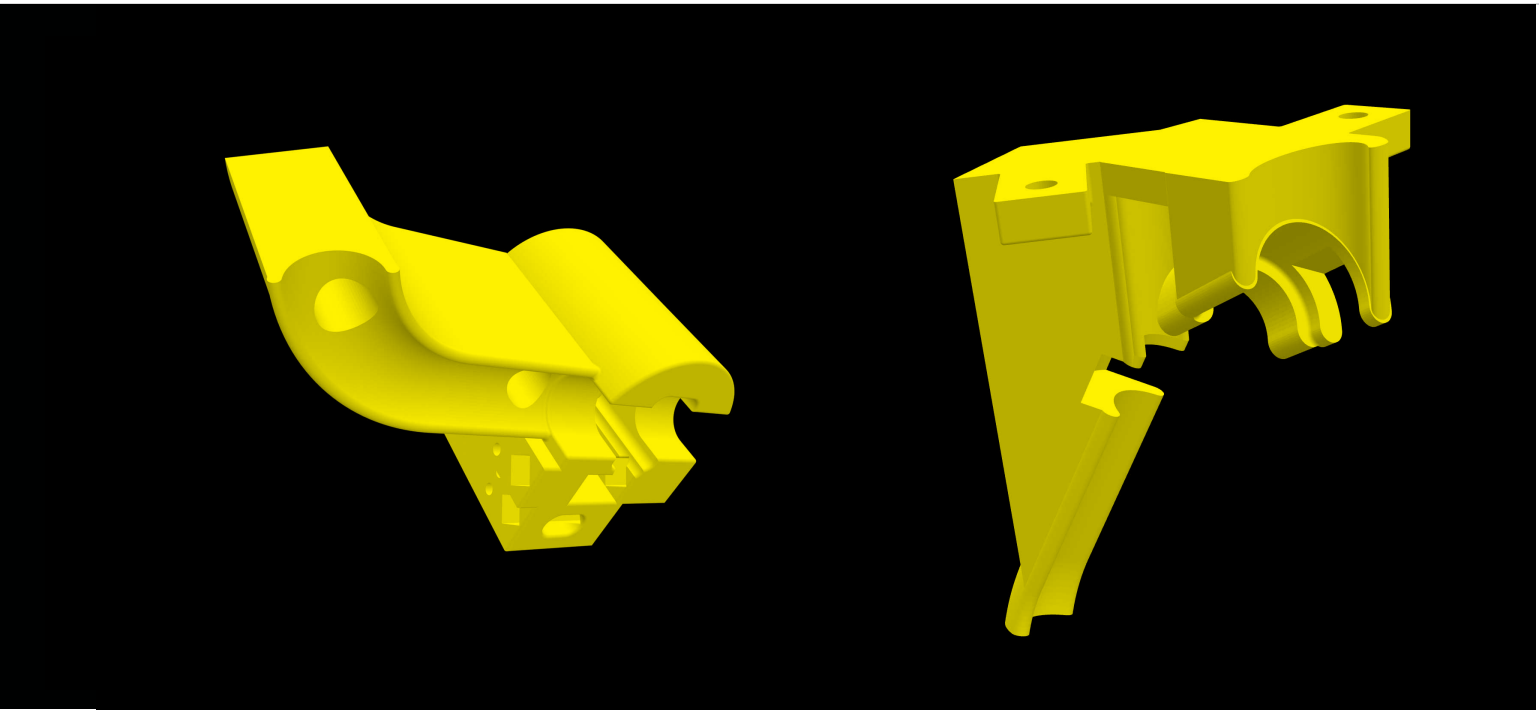
Current Markforged Customers vs End-Use Adoption Prediction



1

Peak Performance Through Unparalleled Design Freedom

DESIGN FREEDOM



Using 3D printing to free design complexity from price — Dayco

As consumer preferences for immediacy and variety in products increase, manufacturers must adapt to reduce operational costs and streamline workflows through simplifying their supply chains. Additive manufacturing provides unparalleled design freedom to meet these challenges in ways conventional methods simply cannot.

The flexibility of additive manufacturing is already playing a key role in production for companies like Dayco, a leading global systems solution provider for electric vehicles. One component of their offering is aftermarket vehicle drive systems, which require complex under-the-hood assemblies. These assemblies are configured using a complex series of tools and jigs that are fully-bespoke to these one-off builds.

The challenge is maintaining high-mix, low-volume production of aftermarket automotive tools while keeping skilled labor focused on designing creative engineering solutions for revenue-generating parts. Rather than use CNCs to machine gauges, Dayco 3D printed them in Onyx. The 3D printed material is a low-cost, high-strength thermoplastic made up of nylon and chopped carbon fiber. The surface finish and accuracy of Onyx gave Dayco's engineers the freedom to efficiently create complex routing scheme designs.

Dayco automated the production of complex engineering-grade composite parts, freeing up skilled CNC machining labor to focus on manufacturing high-value production processes.

70%

Savings

Costs reduced from $3,500 down to $1,500

2x

Faster

Reduced overall production time from 200 to 100 hours

Expanding capabilities with practical 3D printing materials — PTZ

Prototypenzentrum GmbH (PTZ) specializes in low-volume production and prototyping using casting, mechanical production, and additive manufacturing methods. PTZ's CNC production requires regularly replacing tools from tool chucks with other machining tools or cycling outworn and broken tools.

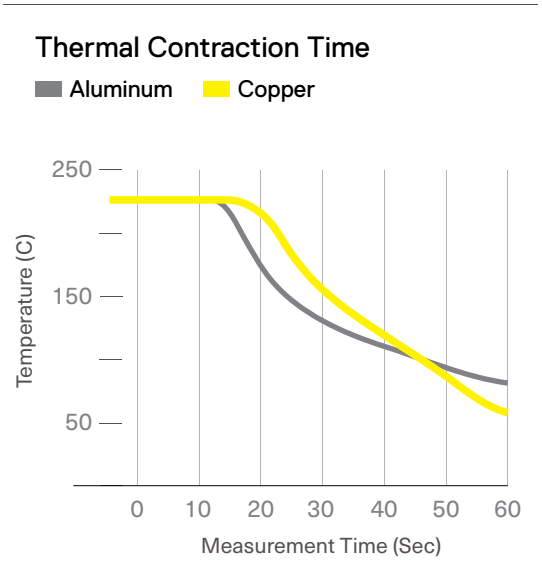
On average, PTZ does 40 tool changes per CNC machine a day. The speed of installations directly affects their bottom line, with faster changes leading to reduced operating costs and improved profitability. The speed of these changes is defined by the time required for the tool cooler to bind a cutting tool to the tool shank.

As the initial tool cooler was painstakingly machined out of aluminum, its cooling effects were less than optimal. To improve the part's efficiency, PTZ experimented with incumbent metal laser sintering technology coupled with the most conductive material available — ALSi10M. The process proved too complex, dangerous, and expensive to sustain.

Markforged solutions afforded PTZ the ability to produce their cooling designs in pure copper, which was twice as conductive as the best material available on the previous technology platform. This material improvement, coupled with the ability to access previously impossible features like channels, allowed PTZ to produce a more efficient cooling tool at a lower cost.

The performance improvements courtesy of the new material and design space netted a 38% improvement in changeover times. PTZ effectively used Markforged solutions to shorten turnaround times while increasing their capacity for inbound business with the same amount of equipment.

The freedom of design innate to 3D printing technologies enables what was previously impossible by conventional standards. This paired with the growing list of available metal printing materials sets the stage for endless performance gains.

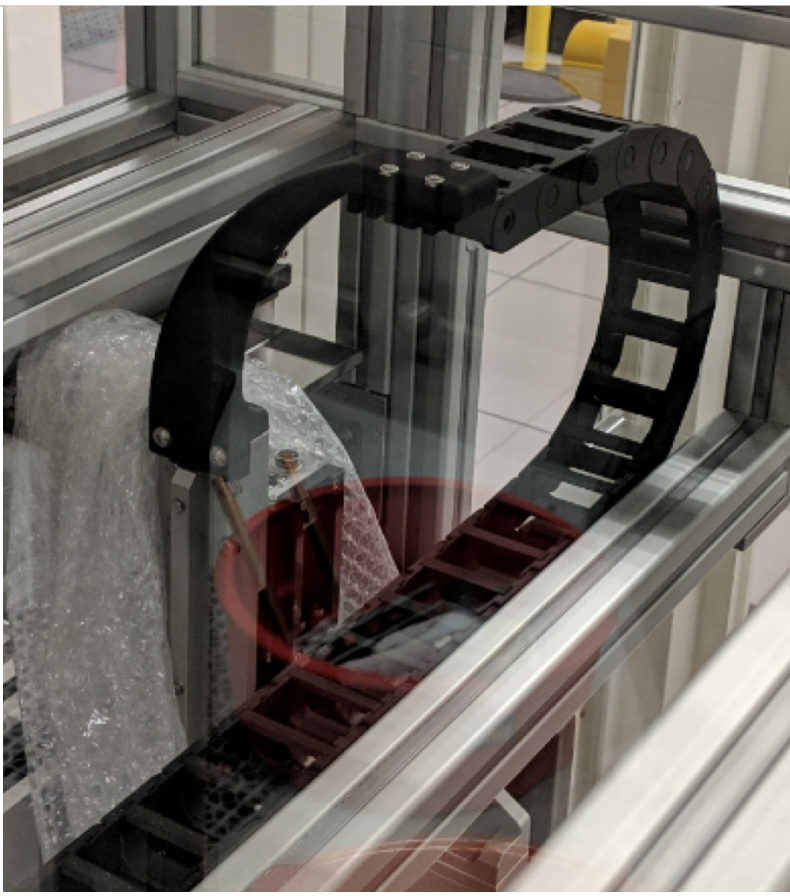


2

Engineering-Grade Durability with High-Strength Parts

PHYSICAL STRENGTH AND DURABILITY

Preventing downtime with 3D printing — Alcon



Additive manufacturing has clear advantages for replacing obsolete processes, but its value in modifying old solutions can be just as fruitful. As a major manufacturer of contact lenses, Alcon uses Markforged to upgrade automated inspection processes to guarantee their products meet high industry standards.

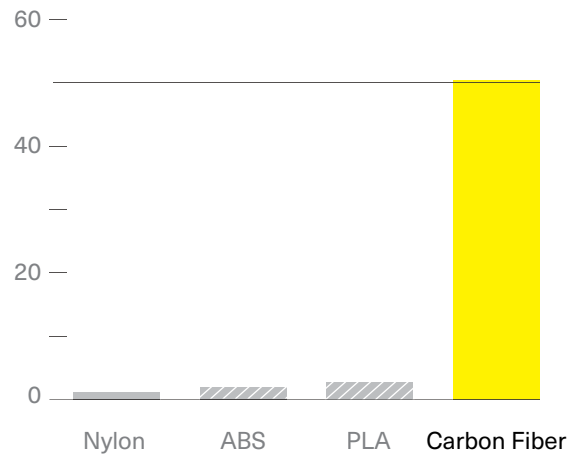
Automation upgrades to Alcon's inspection process require custom bracketry to retrofit old cable system equipment to new solutions. Due to imperfect specifications, the brackets became wear items resulting in line changeovers of cables every two weeks. Machining a one-off bracket requires 4–6 weeks of lead time at $250 per part.

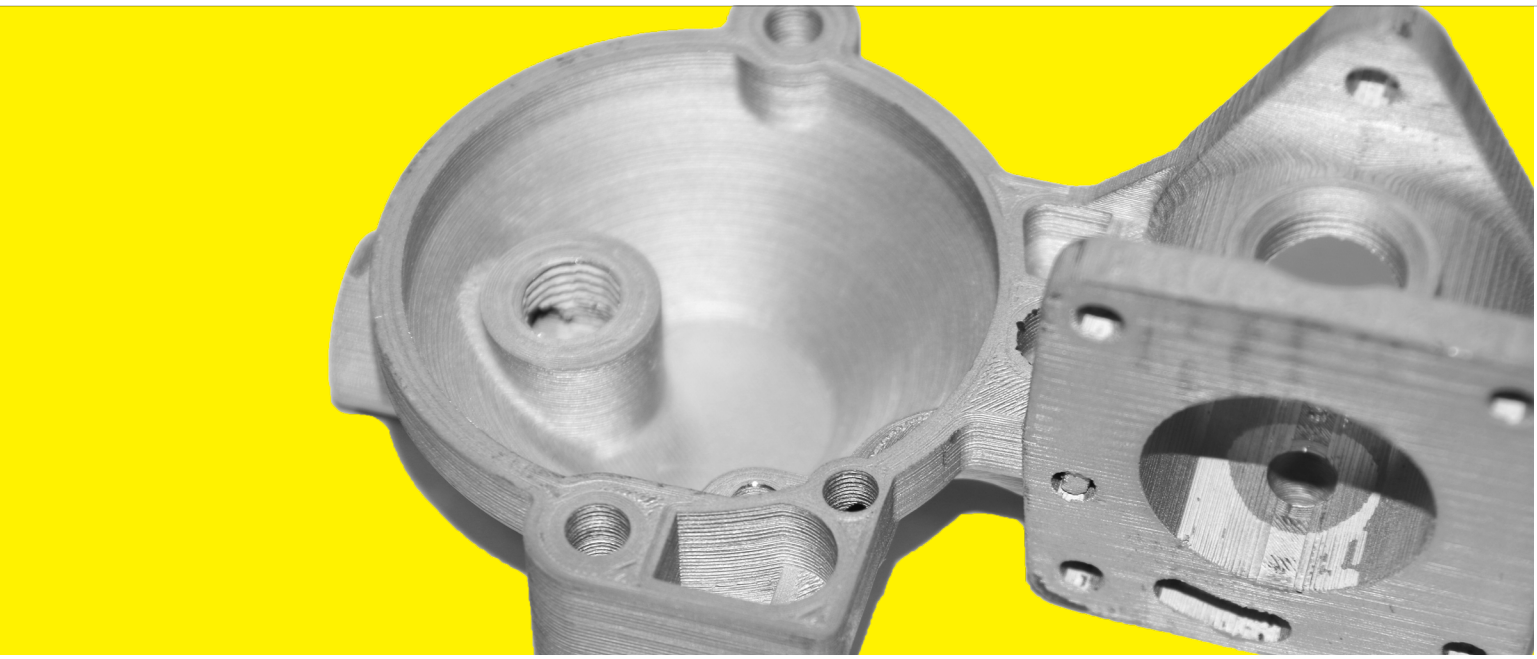
Alcon was able to produce engineering-grade components made from high-strength carbon fiber at a fraction of the cost and turnaround time relative to outsourcing the parts. The ability to design and print composite parts in-house reduced Alcon's reliance on expensive third-party services and empowered its engineers to create cost-effective solutions.

Now capable of making more design adjustments with less design collateral, Alcon 3D printed a custom bracket that cost $40 in materials and was available 24 hours after finalized design. The ability to quickly implement high-strength solutions eliminated Alcon's need for bi-weekly preventative maintenance for the Vision System. This ultimately allows them to produce more for less while maintaining the level of quality their customers have come to expect. As additive manufacturing makes formerly cost-prohibitive solutions possible, manufacturers will have unprecedented opportunities to eliminate the need for preventative maintenance.

Comparing Flexural Stiffness to Common 3D Printed Plastics

(GPa)





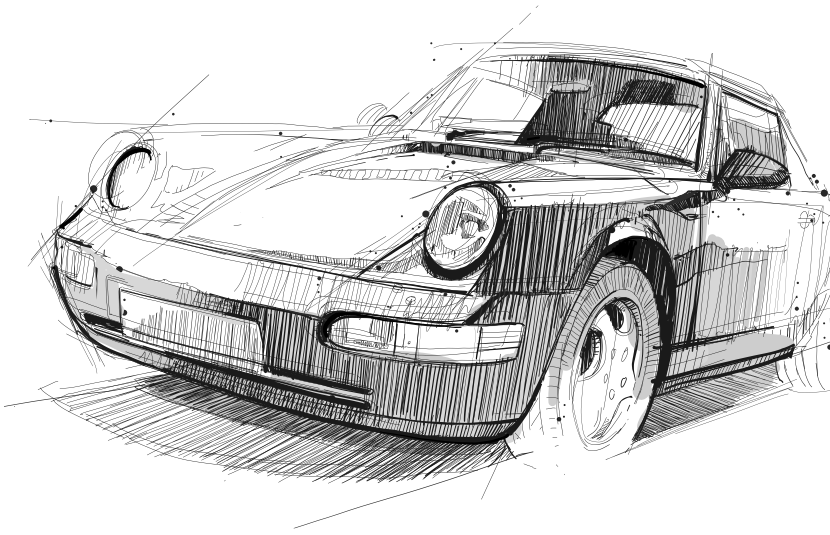
Raising parts from the past with today's technology — Tecron

Tecron provides manufacturing and engineering services to a wide range of automotive companies across the EMEA and APAC regions. The business serves the automotive industry through engineering consulting and custom manufacturing.

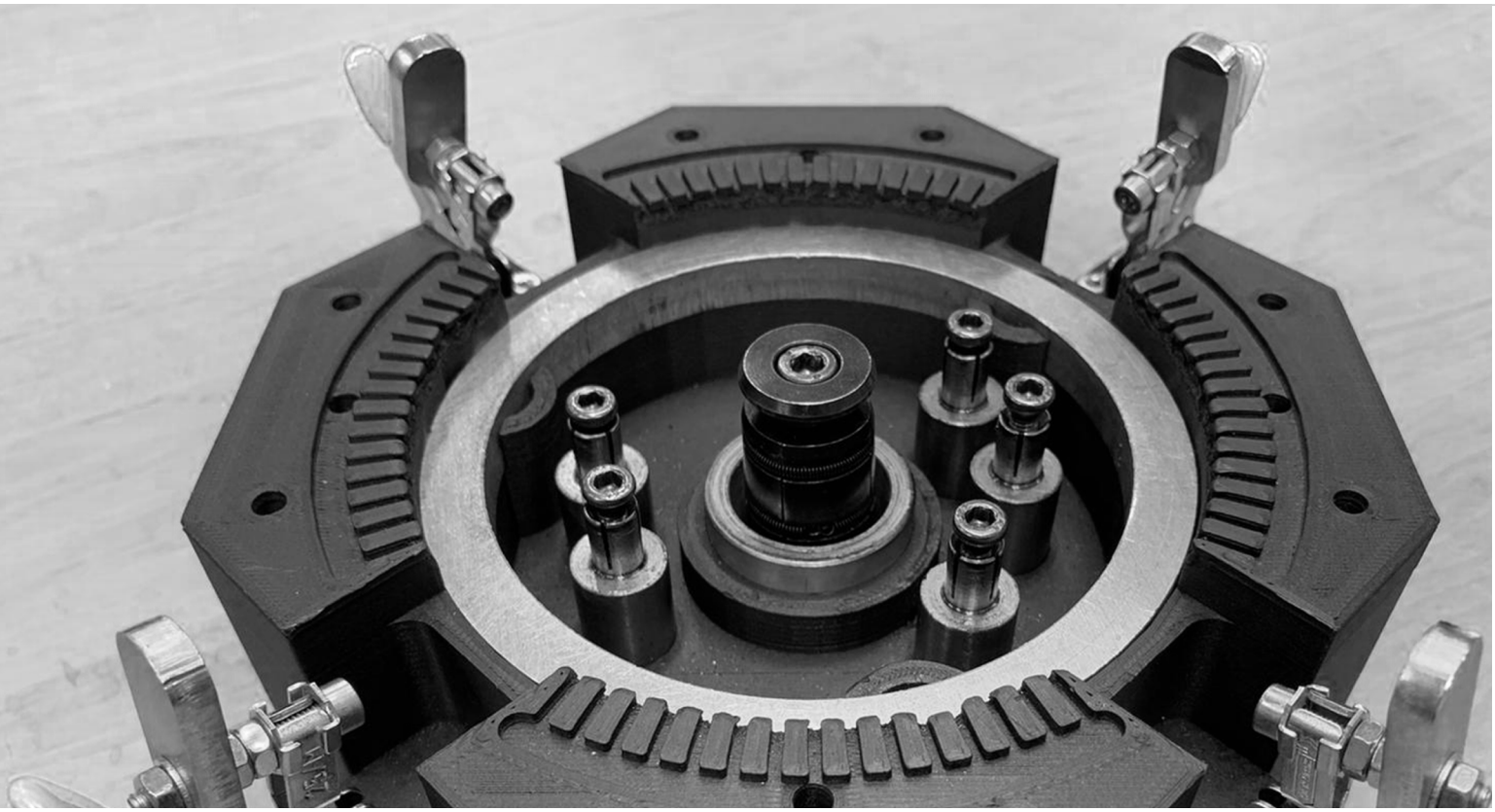
Among the many challenges Tecron faces, they are often tasked with producing replacement and restoration parts, whose original designs are unavailable. The painstaking process of developing the toolpath to machine a like-for-like replacement made producing the spares on a CNC mill very complicated. Tecron instead needed a cost-effective additive solution that was easy to use and free from the design constraints of traditional manufacturing, while delivering the strength and durability their customers had come to expect from their conventionally produced parts.

Tasked with manufacturing a legacy carburetor for a vintage racing car, Tecron used its Markforged solution to 3D print the intricate carburetor in 17-4 PH Stainless Steel faster and more affordably by a significant order of magnitude. The precision and accuracy allowed engineers and designers at Tecron to make the final part to spec, continuing their tradition of superior customer satisfaction.

The opportunities that modern-day additive manufacturing technologies offer for producing high-value, low-volume replacement parts are infinite. 3D printing solutions make it possible to accurately recreate high-strength legacy components with powerful cloud-based design software.



christophkadur - stock.adobe.com



Printing stability in tooling — Primetall

Headquartered in Germany, Primetall GmbH offers a comprehensive range of trailer truck manufacturing solutions fabricated out of stainless steel. Defined by high-quality service delivered through combined know-how, Primetall brings consulting, design, and production under one roof to deliver precise, durable, quality parts.

Primetall 3D prints lightweight fiberglass parts that are durable enough to withstand the high-speed axis rotations of their laser welding apparatus. The fiberglass component is an extremely affordable alternative, costing 88% less than the original machined aluminum part.

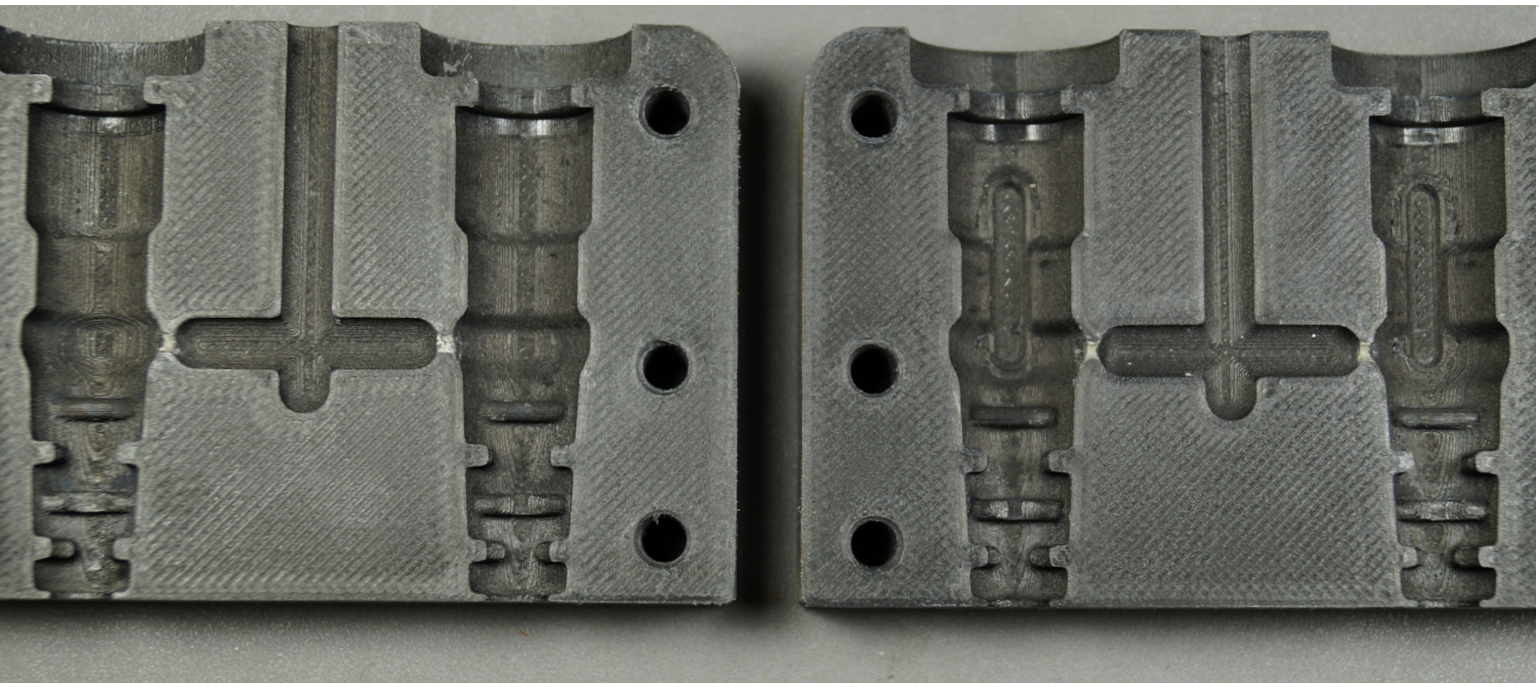
"The fact that it is possible to print continuous fibers was an absolute knockout criteria. This is absolutely unique."

Raphael Willgenss
Plant Manager, Primetall GmbH

3

Accurate, Reliable, and Repeatable Parts

RELIABILITY



The survival of the fastest — Fischer Connectors

Precision and accuracy aren't only crucial for end-use parts. For manufacturers like Fischer Connectors, reliable and agile prototyping is key for business success. Fischer designs, manufactures, and distributes rugged connectors for high-performance electronic devices requiring faultless precision and extreme durability.

Fischer's challenge lies in maintaining agile manufacturing processes to win highly competitive contracts from key customers in military and medical industries. To win contracts, Fischer must rapidly iterate on and deliver a viable proof of concept (POC) faster than competitors in order to win contracts. These POCs usually take the form of prototype quantities of finished connector assemblies, components of which are injection molded. A set of these molds typically require 2–4 weeks of lead time and cost at least $5,000 per mold — with no guarantee that it will win Fischer the contract.

The durability and resistance of Markforged's Onyx and HSHT fiberglass materials allow Fischer to 3D print molds to produce the POC batches in 24–48 hours for 97% less[4] than industry average costs — ultimately helping them deliver POCs that win contracts valued as high as $1M.

The reliability and accuracy of carbon fiber 3D printing help Fischer get POCs to market faster, providing a key advantage in winning medical and military contracts that boost Fischer's overall revenue.

97%

Cost Reduction

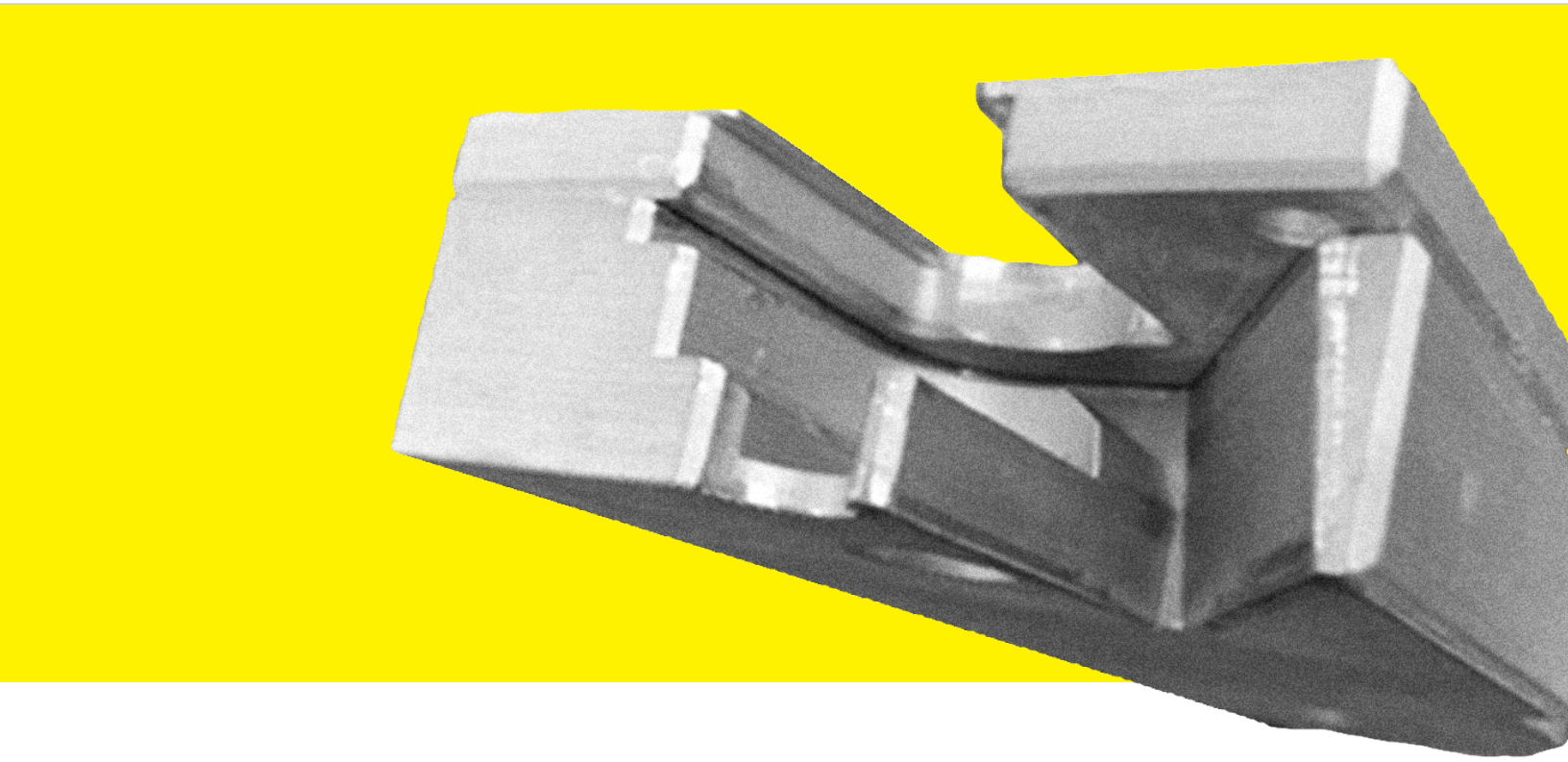
When compared with current industry standard

1-2 Days

Production Time

Compared to 4–6 weeks of traditional manufacturing

[4] Markforged customer study



Prototype to production with additive manufacturing — Nichirin

With a wide variety of composite and metal materials, Markforged customers like Nichirin are printing cost-effective carbon fiber and steel parts that are strong enough for engineering-grade applications yet robust enough to replace machined metal.

As a leading global manufacturer of automotive hoses, Nichirin was in search of methods to mitigate their inventory expenses and skilled labor cost for secondary parts, such as bracket assembly jigs for precisely bolting brackets to brake hoses. These brake hoses typically need between 1-5 bracket jigs. Each assembly jig requires 2–4 weeks of lead time and can cost anywhere from $800 to $4,000.

Nichirin uses 3D printing to prototype bracket assembly jigs in high-strength Onyx filament — an affordable and time-saving alternative to metal prototyping. After checking the Onyx jig's fit and form, Nichirin then prints the part in durable 17-4 PH Stainless Steel.

With Markforged's portfolio of plastic, composite, and metal printing materials, Nichirin can agilely iterate on and perfect jig components without significantly raising operating costs to deliver final parts faster. This versatility lets them 3D print jigs on demand, rather than carry additional inventory and dedicate skilled labor to machining low-value parts.

4

Print from the Cloud — Anywhere in the World

ACCESSIBILITY

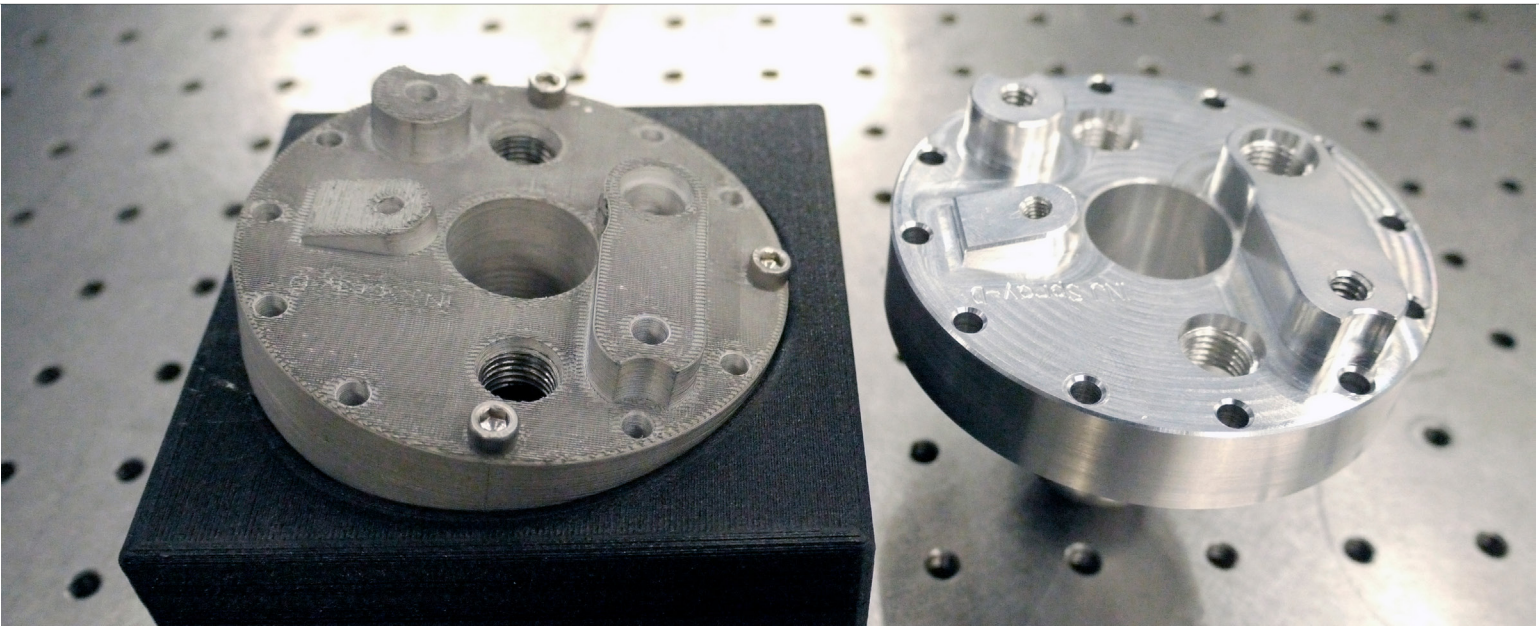
Business built around additive manufacturing — BMF

As more manufacturers improve existing production processes with additive manufacturing, others like Bernstein Mechanische Fertigung GmbH (BMF) are restructuring their business models around 3D printing technology.

BMF is an industrial post-processing equipment manufacturer primarily focused on automatic blasting machines. Their Twister and Tornado machines, part of BMF's Smart Surface Control technology, produce homogenous and repeatable surfaces through automatic blasting processes.

These machines use a wide array of components with severe demands in mechanical strength and reliability. These parts drive exorbitant supply chain and inventory management costs due to the complex processes and long lead times required to produce them. When they recognized that carbon fiber 3D printing was a viable method to replace machined components, BMF was able to make drastic improvements in their business and manufacturing processes.

But that isn't even the most significant transformation BMF underwent. Due to the high demands placed on the components, BMF's customers, who are globally dispersed, require frequent replacement parts for wear items. The process of getting these parts to the right place not only presents a logistics nightmare but also leaves the customer deciding between stocking high levels of inventory or waiting on spares. By contrast, now that these parts can be directly printed, BMF has made the digital version of the spares available to customers who are also Markforged users. Since they are able to monitor where and how the digital files are processed they are able to easily apply a pay-per-use fee when applicable. This new process eliminates all supply chain and physical part costs of supporting customers, while also driving superior customer experience and value.



Impacts of in-house 3D metal printing — Sandia National Laboratories

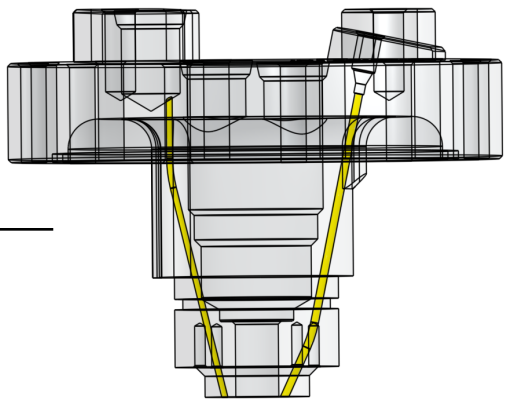
While some companies use additive manufacturing to improve existing production processes, Sandia National Labs implemented Markforged metal 3D printing solutions to bring entirely outsourced processes in-house.

Funded in combination with the Department of Energy and private sector contracts, Sandia focuses on improving internal combustion engine efficiency by testing optimal flows of diesel fuel injectors in different physical simulations. To test differences in the intricate internal geometries of diesel fuel injectors, Sandia relied on third-party Direct Metal Laser Sintering (DMLS) and CNC services. This multi-step process takes months of lead time at a cost of tens of thousands of dollars.

Sandia searched for cost-effective alternatives that could deliver stainless steel components in complex geometries with the precision and accuracy to find cutting-edge insights for next-generation engines. Markforged solutions enable Sandia to design and print geometrically complex parts in 17-4 PH Stainless Steel, with in-house post-processing that is less intensive and costly than third-party DMLS services.

Now capable of producing highly complex diesel fuel injectors, Sandia uses Markforged solutions to run more high-quality iterations and experiments that have broad impacts across major verticals utilizing internal combustion engines.

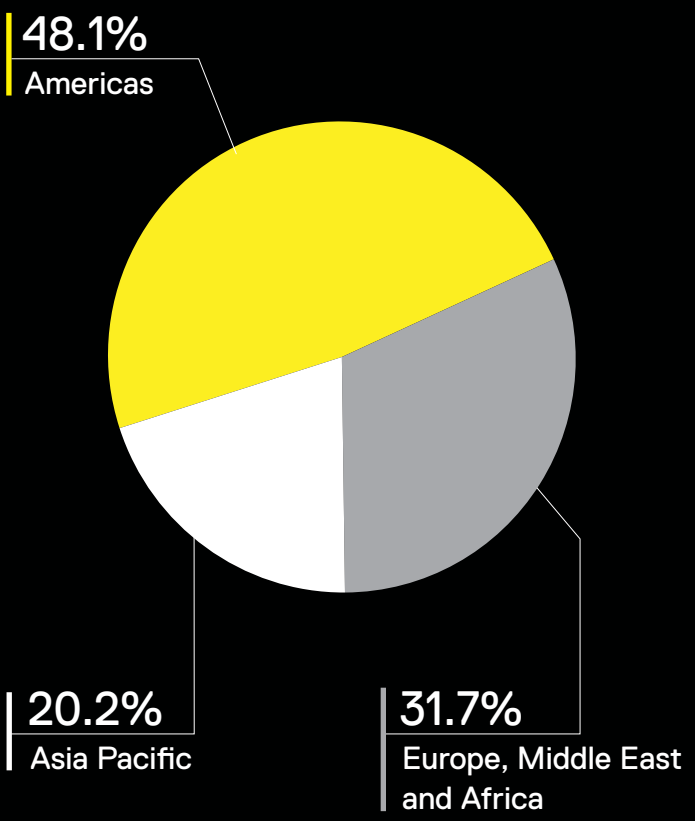
Design flexibility of additive allows Sandia to produce intricate geometries at no extra cost. These internal flow passages would be prohibitively complex to produce through traditional manufacturing methods



Summary: The Key Elements of Additive Manufacturing

Global Regions Using Additive Manufacturing

Survey Respondents



While industry experts hypothesize the benefits of additive manufacturing, Markforged customers are already leveraging 3D printing on every continent and delivering ROI in every stage of the development cycle. This report illustrates the four key ways they're using 3D printing to improve their supply chains, factories, and products.

1. Peak Performance Through Unparalleled Design Freedom

Additive brings a new set of capabilities to the concept of "Design for Manufacturing." While traditional manufacturing is limited by cutting processes, geometry, and tool access, additive allows engineers and designers to access complex geometries and infills never thought possible.

2. Engineering-Grade Durability with High-Strength Parts

Advancements in additive materials with high-strength properties open up an entirely new and more productive range of manufacturing applications. Markforged Onyx reinforced with continuous carbon fiber produces parts that have strength comparable to machined aluminum, but at a fraction of the weight. 3D printed metals allow for all the benefits of traditional steels and alloys, along with a newfound flexibility and accessibility.

3. Accurate, Reliable, and Repeatable Parts

The speed and repeatability of 3D printing allows users to rapidly and reliably iterate from prototype to final part. 3D printing empowers manufacturers to move faster than their competitors, whether it's to replace a part, create a proof of concept, or retool their factory line.

4. Print from the Cloud — Anywhere in the World

Additive cloud solutions empower on-demand part production through a digital inventory, reducing reliance on traditional inventory and supply chain costs. Users of 3D printing can restructure their business models to create parts whenever and wherever needed.

With all of these advantages available today, the question now is "what's next?"

While other players in additive suffer the sunk costs of investing in the wrong technologies to solve nominal problems, Markforged users are optimizing their supply chains and implementing practical, high-impact applications.

Looking to Tomorrow

Additive manufacturing is taking businesses to a completely new level of efficiency in manufacturing. Expensive physical storage is changing to digital inventories with on-demand parts. Manufacturing lines are being adapted on-the-fly with flexible, on-site tool production. Engineers are developing new products faster with better performance and optimized geometries.

The innate flexibility of 3D printing makes it easier for companies to adapt and accommodate new customer and industry demands. It lets manufacturers quickly respond to unpredictable environments, regulations, or shifts in the market. The agile tool allows engineers to respond creatively to any situation — whether there's a supply chain shock from a pandemic or demand spike from a new trend in consumer preferences.

The ease, versatility, and design freedom of 3D printing are here now. On the horizon is a world of full-scale adoption, optimized supply chains, and parts sold from digital inventories, but the stories outlined in this report mark the success of just how far 3D printing technology has come and serve as a precursor for what's next.

Markforged

Metal & Carbon Fiber 3D Printers

Markforged transforms manufacturing with 3D metal and continuous carbon fiber printers capable of producing parts tough enough for the factory floor. Engineers, designers, and manufacturing professionals all over the world rely on Markforged metal and composite printers for tooling, fixtures, functional prototyping, and high-value end-use production.

Founded in 2013 and based in Watertown, MA, Markforged has about 250 employees globally, with $137 million in both strategic and venture capital. Markforged was recently recognized by Forbes in the Next Billion-Dollar Startups list, and listed as the #2 fastest-growing hardware company in the US in the 2019 Deloitte Fast 500.

To learn more about Markforged, please visit markforged.com.

Explore the Applications Library

markforged.com/additive-manufacturing-movement