3dpbm | Insights

Metal AM

How the latest advancements are shaping the segment

October 2022

3dpbm

About

3dpbm is a leading media company providing insights, market analysis and B2B marketing services to the AM industry. 3dpbm publishes 3D Printing Media Network, a global editorial website that is a trusted and influential resource for professional additive manufacturing.

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Welcome

Metal additive manufacturing has evolved tremendously since the early days of laser powder bed fusion in the 1990s. And we don't even have to look that far back to see game-changing innovations in the segment: this past year alone has signaled that a new era in metal AM is here thanks largely to the emergence of metal binder jetting systems and advances in industrialization.

In this eBook, we want to take a close look at the blossoming metal binder jetting sub-segment, taking stock of acquisitions and mergers that are influencing the shape of the industry as well as the new technologies that are coming out. After an in-depth analysis by 3dpbm founder and industry expert Davide Sher, we zoom in on HP's brand new Metal Jet S100 binder jetting system, which promises large-batch production for the automotive and consumer industries, among others. We have also put together a comprehensive overview of the five leading metal binder systems on the market, looking at each of their capabilities and potential.

We are also very excited to feature a close-up look at Theta Technologies' new non-destructive testing system, the RD1-TT, which promises accurate pass/fail inspections of metal 3D printed parts in just seconds. We also focus on the largest of the large-format metal AM technologies: Relativity Space's Stargate 3D printer (4th generation!), which is now in operation at the company's one-million-square-foot facility in Long Beach, Wormhole. Finally, get an exclusive look at our recent visit to GE Aerospace's Additive Technology Center (ATC) in Cincinnati, Ohio. You don't want to miss this edition!

Tess Boissonneault
Editor in Chief, 3dpbm

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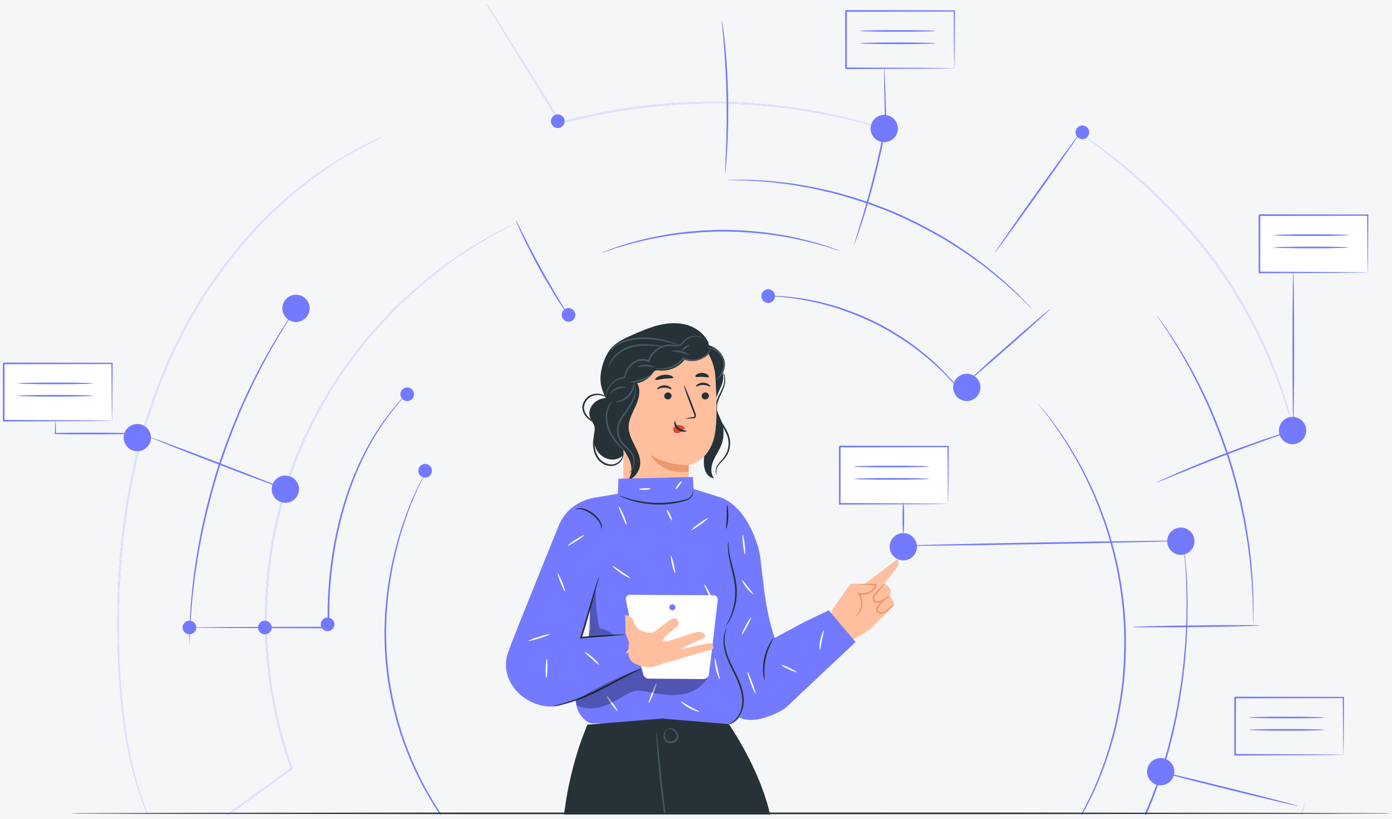

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Image: Schneider Electric via HP

ANALYSIS

The year of the binder

Desktop Metal/Exone, HP 3D Printing, GE Additive, Markforged/Digital Metal, Ricoh (and others) are going all out in the exciting next phase of the metal AM market

Metal binder jetting technology, now also known by the acronym MBJ, is, at the same time, the first and the newest opportunity for binder-based metal AM processes. Invented at MIT in 1993, the technology uses an inkjet printhead to apply binder to a bed of metal powder and form green parts which are similar to parts produced by metal injection molding (MIM). These parts then undergo a series of post-process (which differ for each specific technology), including sintering, to deliver final parts.

Segment pioneer ExOne introduced its first metal binder jetting nearly two decades ago, after licensing the original patent from MIT in 1996. However, only recently has the company introduced new systems tailored for higher productivity. ExOne did so as a response to several other large players announcing plans to enter the market for metal binder jetting. In particular, working with metal binder jetting technology inventor Eli Sachs, Desktop Metal was founded in 2015 by serial entrepreneur Ric Fulop and introduced the concept of a high-productivity metal binder jetting system. Fulop's intuition was that by optimizing and automating the post-processing phase (including eliminating the need for metallic supports during the build phase), metal binder jetting workflows could deliver significantly higher productivity and thus lower per part cost than the more established metal powder bed fusion technologies.

After extensive development, these machines have now entered full-scale commercialization. The relationship between the two companies came full circle when Desktop Metal conducted a successful IPO via a SPAC merger in 2020 and used the funds to acquire ExOne in 2021.

The growing competition in this segment, as the technology evolves to target larger batch production than metal PBF processes, brought these two fierce competitors together, within a scenario that is seeing many things happening at the same time. Desktop Metal and ExOne joined forces to compete against two large industrial groups that have already become leaders in different areas of production 3D printing: GE (GE Additive) and HP (HP 3D Printing).

THE MBJ PROCESS

The metal binder jetting process involves selective deposition of binder droplets and ex- tensive post-processing. First, inkjet-style printheads selectively deposit droplets of binder material onto a bed of metal powder until an entire layer has been created; the printing plate then lowers, a new layer of powder is applied, and another layer of binder is deposited. When every layer of the binder has been deposited, the part (in its brittle green state) is left to cure for several hours. To further increase its strength and reduce its porosity, the part must be put through a process of sintering or infiltration. Sintering involves heating the part for up to 36 hours in a furnace at around 100°C. This burns away the binder material and causes the metal particles to fuse together. Infiltration introduces a molten metal with a low melting temperature, which seeps through the part and fills the voids left by the burnt-out binder material. There are advantages and disadvantages to each method. Infiltration pro- duces slightly less dense parts than sintering, but sintering can cause unwanted and unpredictable part shrinkage.

Metal binder jetting is seen by multiple stakeholders as the most viable solution for introducing high-throughput, cost-effective, large batch and serial additive manufacturing to segments such as mass-market automotive and consumer products, as well as a viable solution for large batch production of parts for industrial machinery.

Because the metals are not melted during the process, binder jetting eliminates some issues related to in-process residual stresses and prints green parts at a very high speed. No supports are required, as

> “Metal binder jetting is seen by multiple stakeholders as the most viable solution for introducing high-throughput, cost-effective, large-batch and serial AM to segments such as mass-market automotive and consumer products”

overhangs are supported by loose powders in the bed, which results in shorter post-processing and more complex geometrical possibilities.

New and established firms are now investing heavily in building up production capabilities, driving metal material companies to develop more powder materials. One expected key benefit of newer binder jetting technologies is the ability to rapidly adapt powders used in MIM processes to the binder jetting process, further lowering material costs. However, several obstacles remain, including the fact that one of the most relevant materials for binder jetting adoption, aluminum, is not well suited for MIM processes.
In addition to process-related challenges, the need to sinter parts in a furnace after fabrication presents some inherent challenges. These include the cost of sintering systems, the long times required for furnace sintering and the need to account for significant part shrinkage through advanced software capabilities, which presents more challenges for AM than other manufacturing processes due to the complexity of certain AM parts.

MBJ BENEFITS

- Higher productivity (up to 10x compared to PBF)
- Several large operators entering the market with significant investments
- Does not require supports
- Potentially lower CapEx (compared to PBF)
- Produces net shape parts
- Very high resolution

MBJ CHALLENGES

- Still unproven for large-scale production
- Requires lengthy sintering in a furnace as a post-process step
- Some MBJ processes require lengthy debinding
- Significant part shrinkage to account for
- Still mostly unproven for fully dense parts without additional infiltration steps
- Still limited selection of available materials (compared to PBF)
- Some processes require finer powders than PBF
- Challenging to produce large parts

Image: Desktop Metal

Desktop Metal finalized its acquisition of binder jetting pioneer ExOne in 2021

In its first Metal AM Market Report, 3dpbm Research forecasted overall metal AM hardware revenues to grow at 33.7% CAGR over the next 10-year period, from just under $1 billion in yearly global sales in 2020 to just over $18 billion in yearly global sales by 2030.

L-PBF technologies are, and will remain, the primary revenue area for metal AM hardware, growing from $640 million in global sales recorded in 2020 to an expected $8.9 billion in 2030, with an expected CAGR of 30%. L-DED technologies will experience a more rapid growth trend with a CAGR of 34.7%, however, among the most relevant high-growth revenue opportunities we will find all binder-based processes—both bound metal (a segment closely related to metal binder jetting) and metal binder jetting itself. Binder jetting is expected to grow at 55% CAGR. This very high rate is down to binder jetting being only marginally commercially explored as of 2020, whilst very significant investments are being poured into these technologies by major stakeholders.

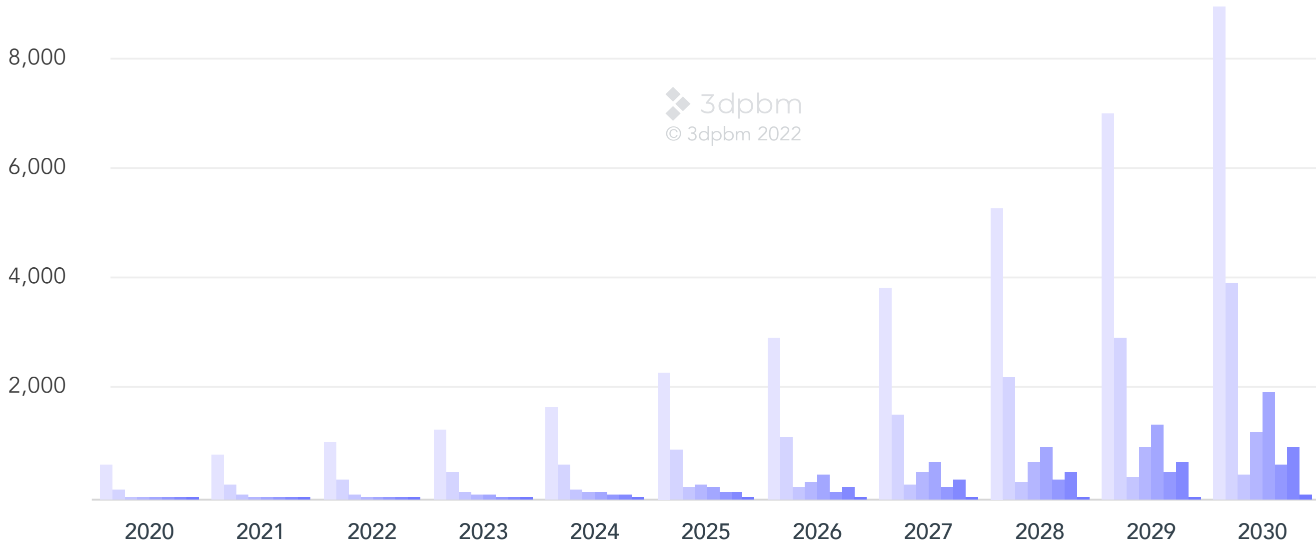
Binder jetting is seen as a key technology to enable large throughput AM production in segments such as automotive and consumer products. Bound metal is currently more established than binder jetting, hence the lower CAGR of 45.8%; however, its overall potential as the most affordable metal AM process is also still largely unexplored.

MBJ IS HERE

Starting in 2017-2018, GE Additive and HP 3D printing revealed they were entering the market for metal binder jetting with the goal of offering high-productivity systems within a few years. The

10-year forecast of metal AM hardware revenues ($US M) by technology 2020-2030

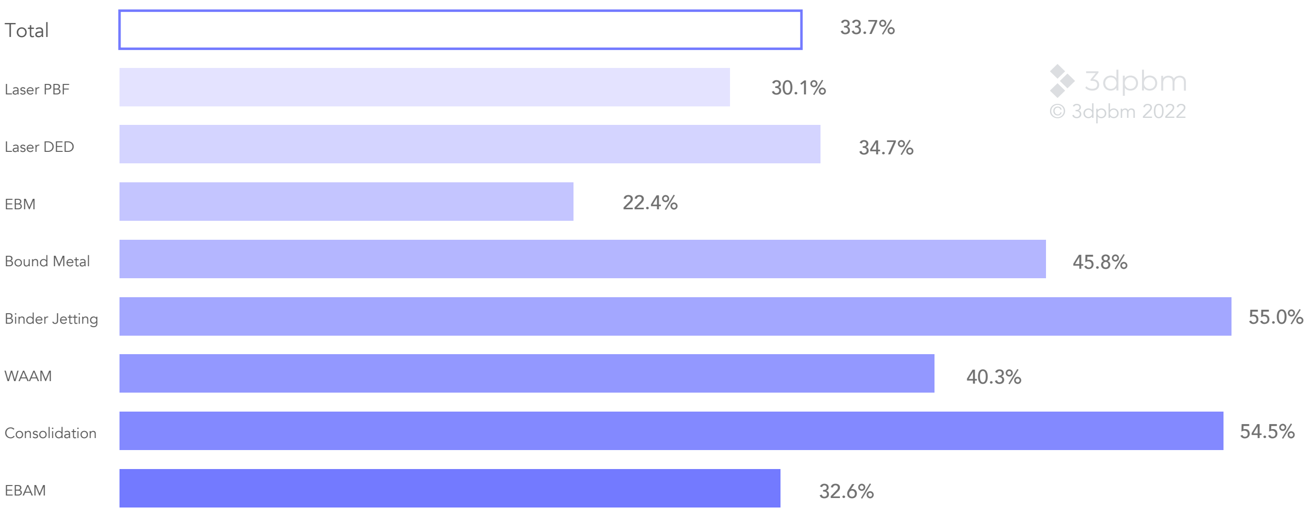
Source: 3dpbm Research



	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Total	996	1,381	1,758	2,234	2,994	4,280	5,585	7,516	10,450	13,911	18,176
L-PBF	640	846	1,036	1,268	1,681	2,315	2,951	3,823	5,264	6,980	8,900
L-DED	199	289	368	488	648	925	1,132	1,559	2,226	2,952	3,914
EBM	64	93	111	139	180	234	258	297	350	403	483
BMP	29	45	78	106	154	262	343	516	700	951	1,245
MBJ	25	42	72	99	143	251	453	676	975	1,356	1,955
WAAM	21	32	44	65	84	133	171	237	352	488	628
Cons.	12	27	41	57	86	138	248	372	521	703	950
EBAM	6	7	9	11	17	22	29	36	61	78	101

10-year forecast of metal AM hardware revenues CAGR by technology

Source: 3dpbm Research



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pandemic slowed down their effort but the time has now arrived for full market commercialization of their first metal binder jetting systems. In the meantime, other companies also entered this market segment offering credible production solutions: these include Markforged (the US company acquired another MBJ pioneer, Digital Metal, in 2022) and Ricoh (by developing its own solution in-house).

HP 3D Printing vs GE Additive

As we will examine more in-depth in the dedicated feature story of this eBook, HP 3D Printing was the first large industrial player to commit to developing a production-capable MBJ technology. What is today known as MetalJet was first announced at the IMTS 2018 exhibit, along with a timeline for the technology's development in collaboration with key alpha and beta partners. The market-ready machine, the Metal Jet S100 was finally presented at IMTS 2022 and is on show for European customers for the first time at Formnext 2022. HP is entering the metal 3D printing production segment leveraging the overall successful experience in the polymer AM segment with MultiJet Fusion technology, which dramatically accelerated and reduced costs for the production of polymer AM parts.

The company is leveraging this experience, together with its leadership in the overall global inkjet printhead

HP's Metal Jet S100 system, based on its MetalJet binder technology, will be presented in Europe for the first time at Formnext 2022

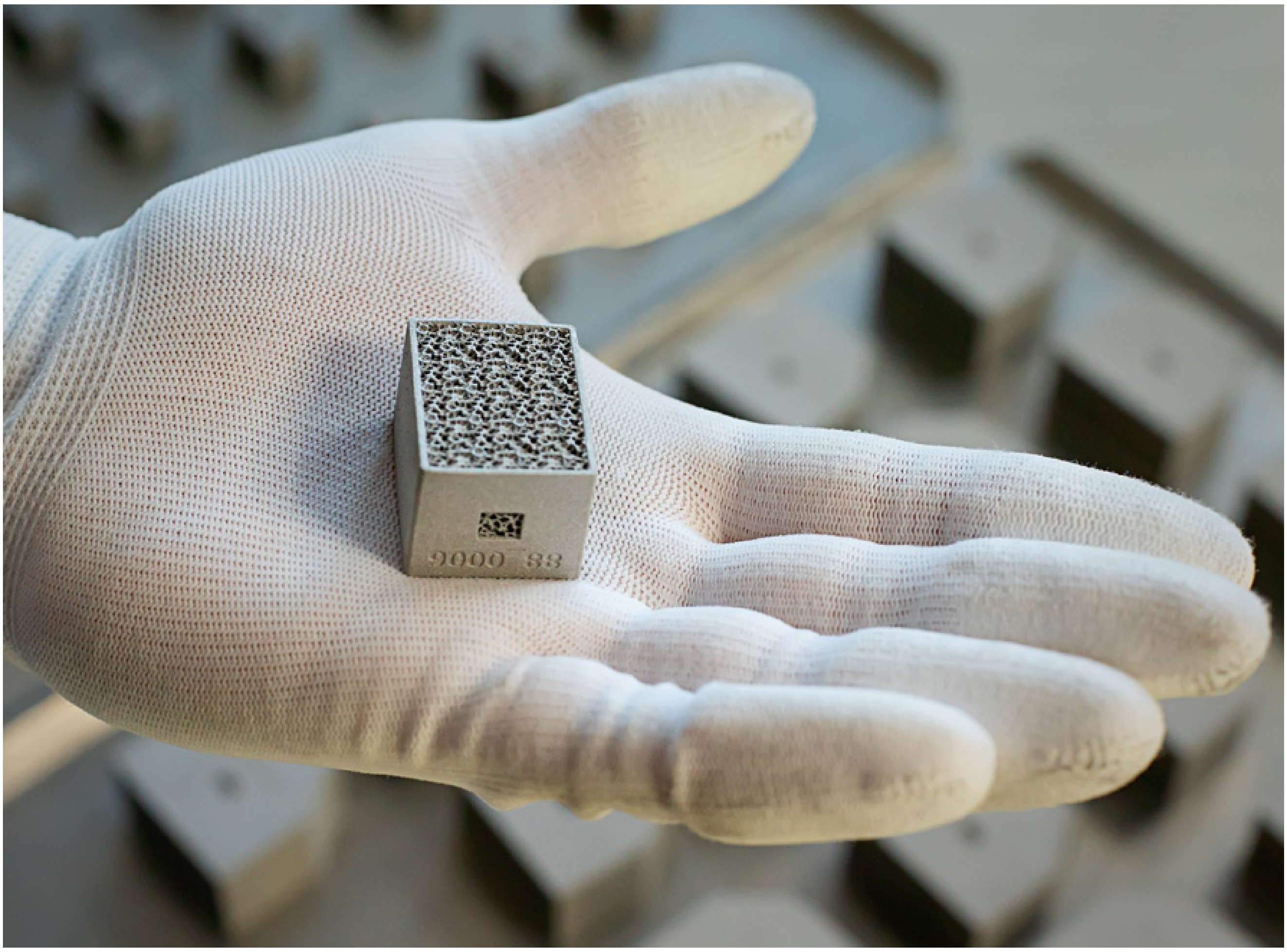

Image: GKN via HP

market, to open the doors for a digital reinvention of the global metals manufacturing sector, with a strong focus on end-to-end supply chain solutions in both software and hardware. HP has identified stainless steel as the primary material for high-throughput applications and will build its offering around these materials similar to the way its polymer additive manufacturing production strategy was centered on nylon 12.

The next largest contender to MBJ market dominance, GE Additive, is entering this segment from the experience that the company built in metal AM production via metal powder bed fusion processes. In 2016, General Electric acquired German laser metal powder bed fusion hardware manufacturer Concept Laser and Swedish electron beam metal PBF hardware manufacturer Arcam (and Arcam-owned metal powder manufacturer AP&C). Both companies formed the foundation of the GE Additive division and their technologies have been progressively developed to accelerate productivity and cater to the needs of serial manufacturers. At the same time, GE Additive began developing its metal binder jetting technology in-house under codename H1 (later H2) in 2018. What started as a purely experimental project rapidly picked up momentum and has led to GE Additive releasing the Binder Jet Line and Series 3 printers, which are on display for the first time at Formnext 2022.

The Binder Jet Line Series 3 has been developed to additively manufacture complex, small, and large parts, up to the weight of 25kg, in stainless steel, with no known limitations on maximum wall thickness. Based on input from customers and partners during the technology development phase, GE Additive is focused on enabling the eventual deployment of 40, 50, and 100+ machine installations that will drive repeatable process quality, while minimizing operator contact with equipment and materials.

Markforged acquired Digital Metal from Höganäs AB in summer 2022.

Image: Digital Metal | Markforged

Markforged/Digital Metal and Ricoh

The remaining contenders include Markforged/Digital Metal and Ricoh. While the investments and efforts behind these projects are not nearly as significant as those made by the previously mentioned companies, they both present unique opportunities. The Markforged/Digital Metal deal is almost identical in nature and strategy to the Desktop Metal/ExOne merger. Markforged is a direct competitor to Desktop Metal in the bound metal 3D printing segment (the two companies also went through a lengthy patent court case), however, Markforged can leverage an already successful composite 3D printing solutions business. Just like Desktop Metal, Markforged went public through a SPAC merger finalized in 2022 and raised significant funds. Some of these were immediately used to acquire metal binder jetting pioneer Digital Metal from Swedish company Hoganas.

While the two companies have not yet begun the integration process, Digital Metal MBJ technology is relevant as the company has been using it to produce large numbers of very small, highly complex parts for well over a decade. As such, Digital Metal developed a production solution, the DMP/PRO which can produce up to 1,000 cm3 of parts per hour at 1600 dpi, with a build volume of 250 × 217 × 70 mm.

> “ 3DEO has produced the largest number of MBJ 3D printed parts out of any company to date.”
>
> METAL AM OPPORTUNITIES AND TRENDS 2020-2030 REPORT

Hoganas understood it would not have the resources needed to emerge in a highly competitive MBJ market and the deal with Markforged - an increasingly solid and strong company both in terms of product offering and marketing capabilities - could prove an ideal match.

Ricoh is much farther behind in the metal MBF segment but the company's world-leading expertise in the inkjet printhead market can be a formidable asset, as it has been in HP's own venture. The Japanese company is currently keeping its additive manufacturing development under relatively tight wraps, with much of it taking place at its Customer Experience Center in Telford, UK. The CEC is looking to develop 3D printers and a total solution for production workflow to manufacture aluminum parts using MBJ 3D. The company chose aluminum as it is one of the most challenging materials to sinter however it would be an ideal material for many MBJ applications due to its low cost, lightweight and high versatility. In fact aluminum is a key element in both Desktop Metal's and ExOne's strategy, however, it has not yet yielded results in terms of commercial applications.
One last company to keep in mind in this segment is US-based 3DEO. The reason why we do not consider them a contender in the MBJ market is that they use a proprietary MBJ technology for internal part production. Focusing primarily on large batches of very small parts (similarly to Digital Metal), 3DEO has produced the largest number of MBJ 3D printed parts out of any company to date, according to data published in 3dpbm's Metal AM Opportunities and Trends 2020-2030 market report. At this time, it does not appear that the company intends to make its technology available to external customers, however, its service capabilities provide a clear indication of the potential that MBJ can have for the AM industry and all metal manufacturing.

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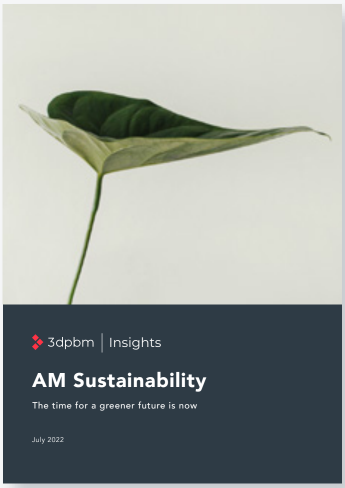

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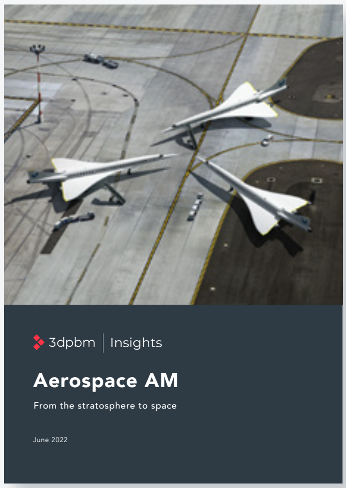

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Image: HP

FEATURE

HP Metal Jet and the future of production

After Multi Jet Fusion changed polymer AM, HP wants to take metal AM to the next level.

In partnership with

Image: HP

After announcing the technology in 2018, HP has officially launched its first metal AM system: the Metal Jet S100.

It has been four years in the making. From IMTS 2018 to IMTS 2022, from the first announcement of Metal Jet technology to this year's official launch of the commercial Metal Jet S100 Solution. HP Metal Jet is here and with it the era of metal AM for large batch production, in mass segments such as automotive and consumer products, can begin.

"Since announcing the breakthrough Metal Jet technology in 2018, we have been working to develop the industry's most advanced commercial solution for 3D metals mass production," said Ramon Pastor, Global Head and General Manager of 3D Metals, HP Inc. "3D printed metal parts are a key driving force behind digital transformation and the new Metal Jet S100 Solution provides a world class metals offering for our customers, from the first designs right through to production, but more importantly helps them to realize the unlimited potential for digital manufacturing."

Ever since HP introduced its polymer AM technology, Multi Jet Fusion, the AM market has not been the same. Competitors in thermoplastic additive manufacturing have not disappeared, in fact, they are generating more or less the same revenues as they did before. However, the overall polymer AM market has grown significantly because many new adopters have embraced the benefits of AM attracted by the high productivity and high-value proposition of HP's offering.

HP 3D Printing now expects to do something very similar with Metal Jet technology, HP's own version of metal binder jetting. Compared to the polymer business, there are similarities and there are differences. MJF was the first high productivity planar, thermal polymer powder bed fusion process to be marketed. However, it is not the first to have been invented. Metal binder jetting, on the other hand, has been around for many years, with several other companies either marketing the technology already or getting ready to do so.

Pushing the build envelope

The first element of HP's strategy replicates the company's approach to the polymer 3D printing segment. It consists in targeting the entire manufacturing industry and competing with other manufacturing technologies for a much larger pie, rather than other metal 3D printing processes. Here, as explained by Ramon Pastor, now Global Head and General Manager for HP Metals, is to leverage Metal Jet as a means to transition from manual assembly to digital manufacturing.

This means reducing the dependency on hard-to-find skilled laborers while addressing challenges related to the supply chain, both of which are very pressing issues in this particular time period. In addition, as a 3D printing process that does not require supports, metal binder jetting, in general, can enable engineers to fully exploit the geometric benefits of AM in terms of both complex geometries and custom subassemblies, with a reduced environmental impact compared to subtractive and formative processes. This approach is not only strategic for HP and AM, it is necessary. A qualified workforce for manual labor-intensive tasks is getting harder to find for many companies and labor costs are too high in the West. In an ideal scenario, this does not mean taking jobs away, it means shifting them away from manual labor. It is an inevitable trend for many reasons. Efficiently redistributing wealth is a different matter, one that belongs to political decision makers.

The second element, the actual Metal Jet 3D printing process, is perhaps where HP believes it has the biggest advantage. The company's unique position as a global leader in digital printing processes is exploited in at least three different ways. The first is by driving superior customer value when compared with traditional metal manufacturing processes, which of course applies to certain specific part geometries. The second is with respect to other metal 3D printing processes, where metal binder jetting in general and Metal Jet in particular aim to offer much higher productivity levels in the build phase alone. In addition, metal binder jetting can, in theory, use many of the same powders used in established MIM (metal injection molding) processing, which can shorten the time requirements for qualifying new materials.

The third advantage that HP expects to be able to exploit is specifically based on its unique decades-long experience in the development of industrial thermal inkjet printing technology. This means that HP counts on having both the most efficient printheads on the market (1200 dpi, 4x nozzle redundancy, advanced error detection, high-speed calibration, easy to replace) and the most effective binders. HP's latex binders feature long polymer chains packed compactly into particles dispersed in the liquid phase. This results in low residual carbon, low-temperature cure along with higher accuracy, finish quality and green part strength.

Close-up inspection of a part 3D printed on the Metal Jet S100.

Image: HP

> “ HP is launching a modular S100 Metal Jet system featuring dedicated, HP-branded machines for powder management, curing and powder removal.”

The final element, the end-to-end Metal Jet workflow, is the most challenging to implement because it goes beyond the printing itself and is of fundamental importance to scaling metal 3D printing into mass production. Leveraging many lessons learned with MJF technology, HP is launching a modular S100 Metal Jet system featuring dedicated, HP-branded machines for powder management, curing and powder removal. Designed to support multiple printers, the Powder Mixing and Sieving unit improve process economics by efficiently mixing and controlling the addition of fresh materials and automating powder loading to the build unit. The Powder Removal unit also improves process and labor economics, while enabling a clean and safe work environment. Multiple units can be added to increase productivity.

The only aspect of the workflow which is not currently managed by HP is the sintering phase, which requires highly specific knowledge. For this reason, HP is working closely with experts such as Elnik systems on sintering. When digital additive mass production will be implemented, the company will also require more complex systems for part handling and sorting, but this will probably have to be explored through machines such as those introduced by companies like AM Flow.

Meet HP Metal Jet

Binder jetting can theoretically boost the productivity of metal 3D printing tenfold, allowing for processing layer by layer versus point process. Isotropic properties also require no post-processing and no support removal, and the use of metal powders is also more cost-effective than laser-based 3D printing powder. In addition, the HP printheads leverage decades of industrial thermal inkjet technology developments, defining geometry and delivering high resolution and system robustness, making mass 3D metal parts a viable option for commercial manufacturing.

HP Metal Jet printers can precisely place up to 630 million nanogram-sized drops per second of a liquid binding agent onto a powder bed to define a part’s cross-section layer by layer. The HP Metal Jet binding agent is a water-based liquid agent precisely delivered by HP Thermal Inkjet printheads. The binding agent is formulated with a polymer that binds the metal particles together wherever HP Metal Jet binding agent is printed.
Capillary forces pull HP Metal Jet binding agent into the smallest interstices between the metal particles to produce a uniform binder distribution. Curing the bed evaporates liquid components and cures the polymer to produce a high-strength green part. The binder

flows to act like a hot-melt adhesive holding the metal particles together in preparation for sintering. Afterwards, the polymer decomposes during sintering.

The printhead for HP Metal Jet printers is based on a design that has been proven in-service in HP's Page-Wide Web Presses, HP Latex printers, and HP Jet Fusion 3D printers. Internal architecture to HP Metal Jet printheads has been further adapted to improve robustness to metal powder particle ingestion. Each printhead produces a 108-mm (4.25-inch) print swath with two independent columns of 5,280 nozzles that are spaced 1200/inch in each column. There are two independent supply ports for HP Binding Agent and two built-in pressure regulators. A key feature of HP printheads is quick and easy replacement by the operator. No tools, handling fluid or electrical connections, or manual alignment are required.

HP's technology uses HP Thermal Inkjet to precisely deliver HP Metal Jet binding agent to a powder metal bed and industry-standard metal injection molding (MIM) metal powders. Multiple parts produced at the same time, or large finished parts, with isotropic properties that meet ASTM and MPIF standards. High material reusability reduces materials cost and waste without compromising part quality. Part density after sintering is > 96%, similar to MIM. However, whereas MIM requires a debinding process to remove the wax, and this can add up to 20 hours to the MIM workflow, this time-consuming wax debinding process is not part of the HP Metal Jet process.

The HP Metal Jet S100 powder management station can support multiple printers.

Image: HP

Image: Schneider Electric via HP

HP's new metal binder jetting technology is now commercially available on a global scale.

Inside the HP Metal Jet S100 Solution

HP 3D printing's new Metal Jet S100 Solution was officially launched at the 2022 International Manufacturing Technology Show (IMTS). Now commercially available on a global scale, the new metal binder jetting system was made to digitally print mass quantities of quality parts, transforming industries and helping scale 3D metals to mass production.

"We are witnessing entire industries, from industrial to consumer, and healthcare to automotive, looking to digitally transform their manufacturing processes and supply chains in a world where volatility is the new normal," said Didier Deltort, President of HP's Personalization and 3D Printing business. "As the promise of additive manufacturing takes hold, HP has become a trusted partner to help speed the path to production. The introduction of our new Metal Jet commercial solution, along with innovative collaboration with market leaders like Schneider Electric, is delivering the blueprint for more sustainable, reliable, and efficient manufacturing."

HP's new Metal Jet S100 Solution is opening the doors for a digital reinvention of the global metals manufacturing sector, with a strong focus on end-to-end supply chain solutions in both software and hardware that are customer-centric and design-led. It provides industrial production capabilities, integrated workflow, subscription and service offerings – an unprecedented level of technical and business advantages for customers, helping them achieve their goals for business transformation. The modular solution enables build units to travel between four different stations, meaning users can continually run production at scale for mass metals production.
The HP Metal Jet S100 Solution promises the ability to

realize new geometries, density control and designs to lightweight or consolidate metal parts, pushing the boundaries of what is possible with 3D printing. The system also features improved customer economics: process steps needed to create parts are shortened whilst costs due to manual labor or complexity requirements are reduced, driving efficiencies across the supply chain.

Under the software umbrella of the HP Metal Jet Command Center (Client/server application for system setup, registration, device monitoring, and connectivity management) and the HP Metal Jet API, the HP Metal Jet S100 Solution consists of four main hardware components, which correspond to the four phases of the HP Metal Jet workflow: Load, Print, Cure and Depowder. The first phase is carried out in the HP Metal Jet S100 Powder Management Station, which loads the powder into the HP Metal Jet S100 Printer using the moving HP Metal Jet S100 Build Unit (which is similar to the one use in the MJF systems).

After the Print phase, the printed parts are moved via the Build Unit to HP Metal Jet S100 Curing Station. After curing, the BUild Unit is used to manually load the parts into the HP Metal Jet S100 Powder Removal Station (Depowder), which automates the removal and recovery of loose powder for 100% reusability, while simultaneously performing build unit cleaning. All reclaimed powder is pneumatically recovered into the HP Metal Jet S100 Powder Management Station Portable Tank for storage and reintroduced into the HP Metal Jet S100 Powder Management Station.

HP supports the entire workflow, from initial idea to final part—even going beyond the HP Metal Jet Printing process—to cover the entire ecosystem, including sintering and surface finishing assistance if required. When it comes to sintering, HP can provide additional assistance with sintering operation requirements. After printing and sintering, if additional finishing is required, HP's engineering team can provide services that help customers achieve their final desired part properties using alternative processes (such as machining, polishing, coating, and hot isostatic pressing).

Targeting mass production

While technology is regarded by HP as a strategic advantage to emerge in the metal AM market, the company has also identified other key drivers of Metal Jet technology that will pull the transformation of materials into actual digital parts. As is generally the case, the strategy leading to adoption and industrialization starts from the materials. Using MIM powders can accelerate the deployment and qualification of new materials but this does not mean that introducing a new material is immediate.

HP Metal Jet is entering the market with two materials, both based on stainless steel: 316L and 17-4PH. These are respectively the most common austenitic and precipitation hardened (PH) stainless steels used for powder-based AM processes today and some of the most common metals used in all manufacturing. These steels are expected to have a similar role in Metal Jet as nylon (PA12) did in MJF: cover a wide range of large batch applications in segments not currently addressed by metal AM, such as automotive mass production and broadly accessible consumer products. Steels will be followed by an expansion phase with new metals and alloys, all while working with large clients on the development of custom materials based on application demand.

Applications are, in fact, the next key element of HP Metal Jet's industrialization strategy. After developing successful application production case studies with partners GKN and Parmatech, and customers including Volkswagen during the early customer testing and initial rollout phase of the Metal Jet technology, HP also built strong momentum with additional partners and customers including Cobra Golf, Legor Group, and more. HP is also collaborating on mass metals production opportunities with new partners and customers around the world, including Domin Digital Motion, an innovative industrial company focused on hydraulic systems and valves, John Deere, the global manufacturing leader of of agricultural and construction equipment, Lumenium, a startup developer of advanced rotational engines, and Schneider Electric. Schneider Electric is the global leader in the digital transformation of energy management and automation. Their product portfolio includes products, controls, software and services across residential, commercial, industrial and critical applications.

"We are excited about the new possibilities for our business as a result of this collaboration with HP," said Michael Lotfy, SVP of Power Products & Systems, North America, Schneider Electric. "We are constantly in pursuit of solutions that will enable more sustainable, agile innovations development. Leveraging HP Metal Jet our teams have delivered a proven use case showcasing the benefits of digital manufacturing and 3D printing, and we look forward to uncovering many more applications that meet the evolving demands from our customers addressing the challenges around sustainability and Electricity 4.0."

Together with GKN, a new filter used on Schneider Electric's NSX breaker was produced using HP Metal Jet technology, which could not be achieved with conventional industrial manufacturing capabilities due to the shape & material complexity. HP Metal Jet technology not only facilitated the design of new power filters shapes that reduce gas, pressure, and heat impact in a more limited space, it also resulted in significant productivity gains and environmental benefits.

The company wants to continue strategically working with OEMs who own application IPs to develop and architect customized DfAM and supply chain solutions. HP itself is going to develop and expand the market for immediate applications, mainly in stainless steel, for filtration, hydraulics, medical devices and robotics (as well as some consumer products). Finally, HP will work with contract manufacturers (CMs) to further industrialize the design process, produce parts on demand and offer a local supply chain solution to OEMs.

Customers can also order the HP Metal Jet printed parts you need via the HP Metal Jet Production Service and work with HP through every step of the metal printing journey, receiving technical support when and where needed. Subscription plans are available to fit specific business needs and ensure a predictable, affordable, and convenient payment model with fixed monthly costs and a lower upfront investment.

The application of all these aspects is driving the industrialization of Metal Jet technology. It began with the completion of the alpha program that was first announced in 2018 and it continued through the implementation of actual serial production by OEMs, delivering thousands of parts per month. They are taking it to another level with a modular system, automation and advanced software and data capabilities. Now, HP is go for launch. Next stop: mass production of metals AM on a global scale made possible by HP Metal Jet.

Metal parts can also be ordered via the HP Metal Jet Production Service.

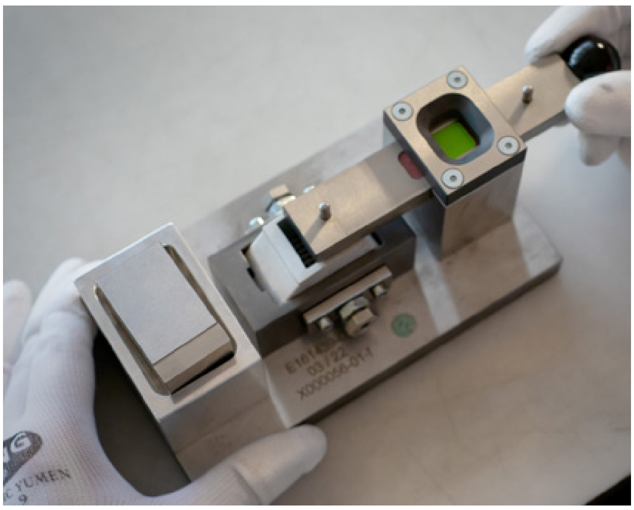
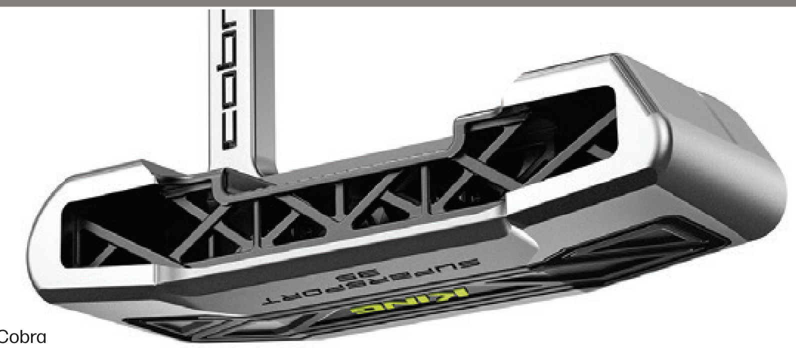


Image: GKN via HP

HP Metal Jet S100 3D Printing Solution

Reinvent business opportunities with digitally driven metal 3D printing for mass production. Accelerate innovative designs and products, and efficiently produce high-quality 3D metal parts at scale.



Data courtesy of Cobra

Data courtesy of Schnider Electric

Data courtesy of Legor

Learn more at hp.com/go/3Dmetals

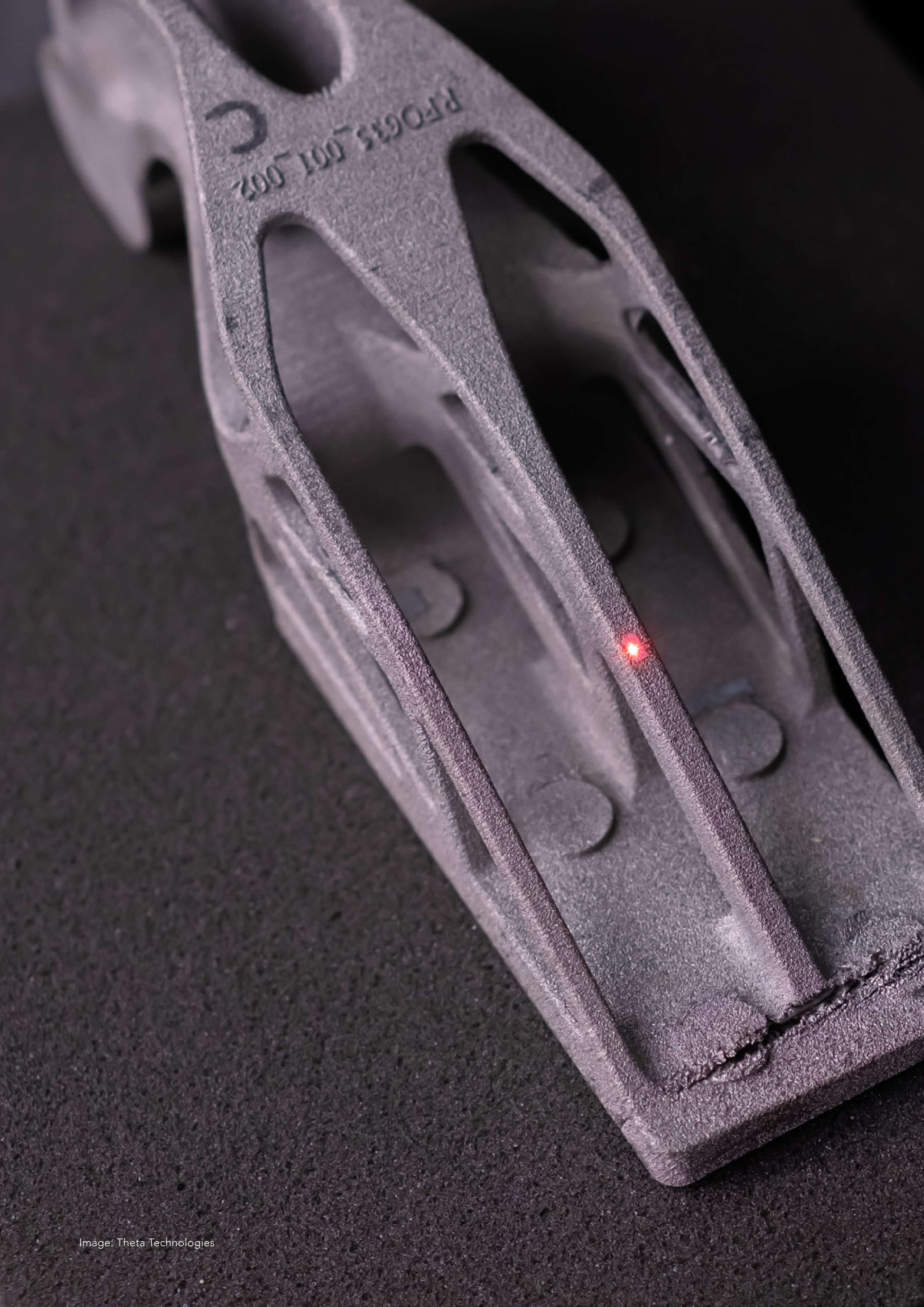


Image: Theta Technologies

SPOTLIGHT

A close-up look at Theta Technologies' RD1-TT NDT testing solution

Based on the company's nonlinear acoustics technology, the RD1-TT offers rapid, geometry-agnostic testing for metal AM parts

In partnership with

Image: Theta Technologies

RD1-TT leverages ThetaTechnologies' patented nonlinear acoustics (NLA) technology to detect flaws in metal AM parts.

As metal additive manufacturing continues to advance—both in terms of the quality and complexity of parts and the technology's scalability—the remaining hurdles to industrialization have become clearer. Among them is quality testing and part validation. Today, many existing non-destructive testing (NDT) approaches are not viable for complex 3D printed components or cannot be scaled efficiently to meet increased production rates. That's where UK-based NDT specialist Theta Technologies and its new RD1-TT come in.

RD1-TT is a new NDT solution that leverages Theta Technologies' patented nonlinear acoustics (NLA) technology to detect flaws in even the most complex metal AM parts. According to the company, its new NDT system was designed to be easily integrated into existing metal AM production workflows. But how does the RD1-TT system work? To really understand the new testing product, we first have to dive into Theta Technologies' nonlinear acoustics testing technique.

What is Nonlinear Acoustics testing?

Nonlinear acoustics, or NLA, is a patented process that detects flaws inside metal components using audible and ultrasound frequencies. As Theta Technologies explains it, every metal part has a characteristic acoustic signature. This signature is influenced by a number of factors, including the part's dimensions and geometry.

The NLA process takes advantage of these acoustic signatures, using sound waves to excite the metal component, which in turn emits an acoustic response, and detectors to read the response. If the printed part has no internal flaws, the acoustic response will be characterized by a consistent pattern between low and high amplitude excitations; if there are any flaws inside the part, the acoustic response will be nonlinear and irregular. The degree of accuracy of the NLA process is also worth mentioning: it is able to detect flaws narrower than a millimeter, including cracks, creep or delamination, no matter how complex the part geometry is or what the surface finish is.

Interestingly, Theta's NDT technique can be used to different ends. It can rapidly detect flaws in a metal 3D printed component, providing a pass/fail indication in less than a minute. Or it can provide more detailed results, generating a picture of the component's structure and highlighting inconsistencies. The former, which is offered in the RD1-TT, is ideal for manufacturers that want to quickly assess and validate parts to increase the efficiency of production chains.

How does NLA compare to existing NDT?

Theta's NLA technique not only goes far beyond conventional dimensional NDT tests, it also stands out compared to other internal NDT processes, including low-cost techniques like dye penetrant testing, and more advanced methods like x-ray CT scanning. Among its advantages are the fact that it can detect minuscule flaws in highly complex geometries and that its efficacy is not influenced by different surface finishes.

NDT processes such as dye penetrant testing and

NLA can rapidly detect flaws in metal 3D printed components, providing a pass/fail indication in under a minute.

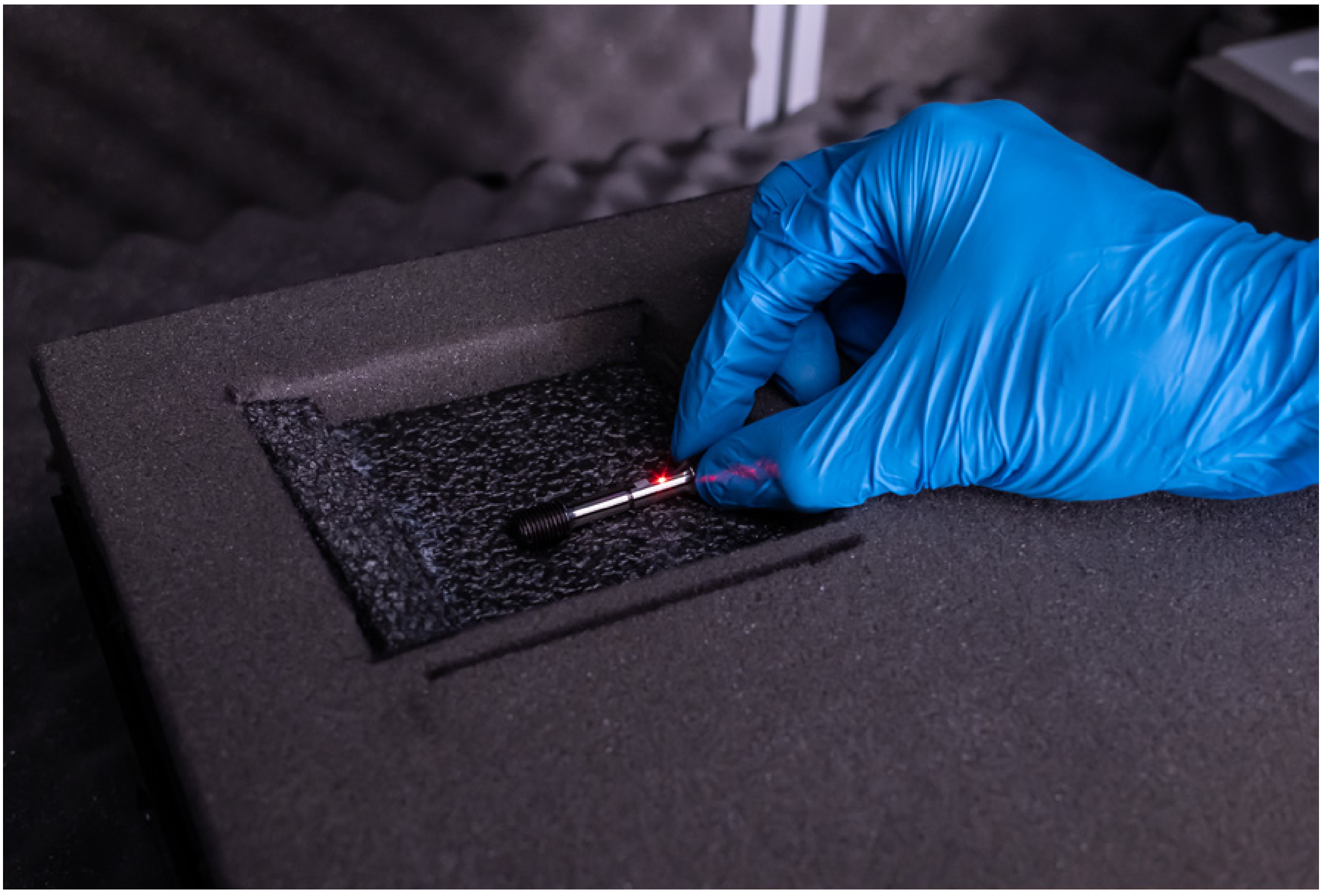


Image: Theta Technologies

even ultrasound testing struggle to keep up with the increasing complexity of 3D printed components, like heat exchangers that integrate internal channels. This is no challenge at all for NLA. And while x-ray CT scanning is effective for larger flaws, it is a costly process that requires skilled operators. Naturally, this inhibits scalability and accessibility. NLA, on the other hand, is rapid, scalable and does not require highly skilled technicians to implement.

Another notable benefit of NLA is that the testing process does not require a reference part. That is to say, it can find and identify flaws within a part without comparing it to an original unflawed component. Manufacturers can therefore test and validate any component—whether it's the first part to come off the printer or a unit from the 15th batch.

"The freedom that AM design offers manufacturers has meant that until now, there have been limited options available to thoroughly inspect these components," Theta Technologies explains. "The increasing complexity of geometric designs and a plethora of surface finish options now available to manufacturers has made it notoriously challenging for other methods such as ultrasound and dye penetrant to accurately inspect anything other than simple designs.

"As the industry matures and critical applications increasingly utilize AM produced parts, there is a real need for an efficient and scalable NDT solution. Theta Technologies are primed and ready to supply the AM industry with that very solution with the release of the RD1-TT."

RD1-TT can accurately test parts with any surface finish.

Image: Theta Technologies

RD1-TT, the solution for scalable NDT

RD1-TT is the first NLA-based product to be launched on the market by Theta Technologies. The industrial NDT solution is designed for in-house use and for easy integration into existing production workflows. With it, AM manufacturers can seamlessly and rapidly assess the success of printed components and ensure that printed parts are meeting necessary specifications, whether they are for aerospace, energy, defense, automotive, or maritime applications.

The new system promises accurate pass/fail results in under a minute and provides flaw detection earlier in the production chain than other NDT processes thanks to its compatibility with any surface finish. This gives manufacturers a distinct advantage: they can analyze and validate 3D printed components immediately after printing and before any post-processing, meaning they won't waste time or resources finishing flawed components. The results of the NDT tests also provide valuable insights into the AM production process, indicating when tweaks or improvements could be needed.

As the company puts it: "Without the RD1-TT at this stage of the workflow, flaws within the parts would not be discovered until much later; something that could prove costly to your entire production. This

Image: Theta Technologies

Theta Technologies will be presenting its NDT technology at Formnext 2022 in Frankfurt, Germany.

early detection of flaws will allow AM manufacturers, particularly for safety-critical applications, to re-evaluate their production practices prior to scaling up."

Moreover, the RD1-TT can be used after post-processing for additional quality assurance. Because post-processing can influence the structure or specifications of a part, further testing is typically required. Theta Technologies suggests adding the RD1-TT to existing quality testing at this stage for added confidence.

See the technology yourself at Formnext 2022

The NDT technology has been put to the test: last spring, Theta Technologies launched a still-active campaign where they invited metal AM manufacturers to send their most complex components for complimentary testing. And thermal engineering company HiETA Technologies Ltd participated in a case study through which it tested two 3D printed Inconel heat exchanger samples. The company knew beforehand that one of the samples was flawed and one wasn't. Theta's RD1-TT results were in line with this: it reported a nonlinear signature that indicated that there could be trapped powder inside the part. While the second heat exchanger passed the inspection with a linear acoustic response.

Theta Technologies' new NDT product was recently launched and gives AM manufacturers an unprecedented ability to rapidly evaluate parts, which in turn will allow for greater and more efficient scalability. To see the technology in person, visit Theta Technologies' booth at Formnext 2022 in Frankfurt, Germany. The company can be found from November 15 to 18 in Hall 12.0, Stand E67.

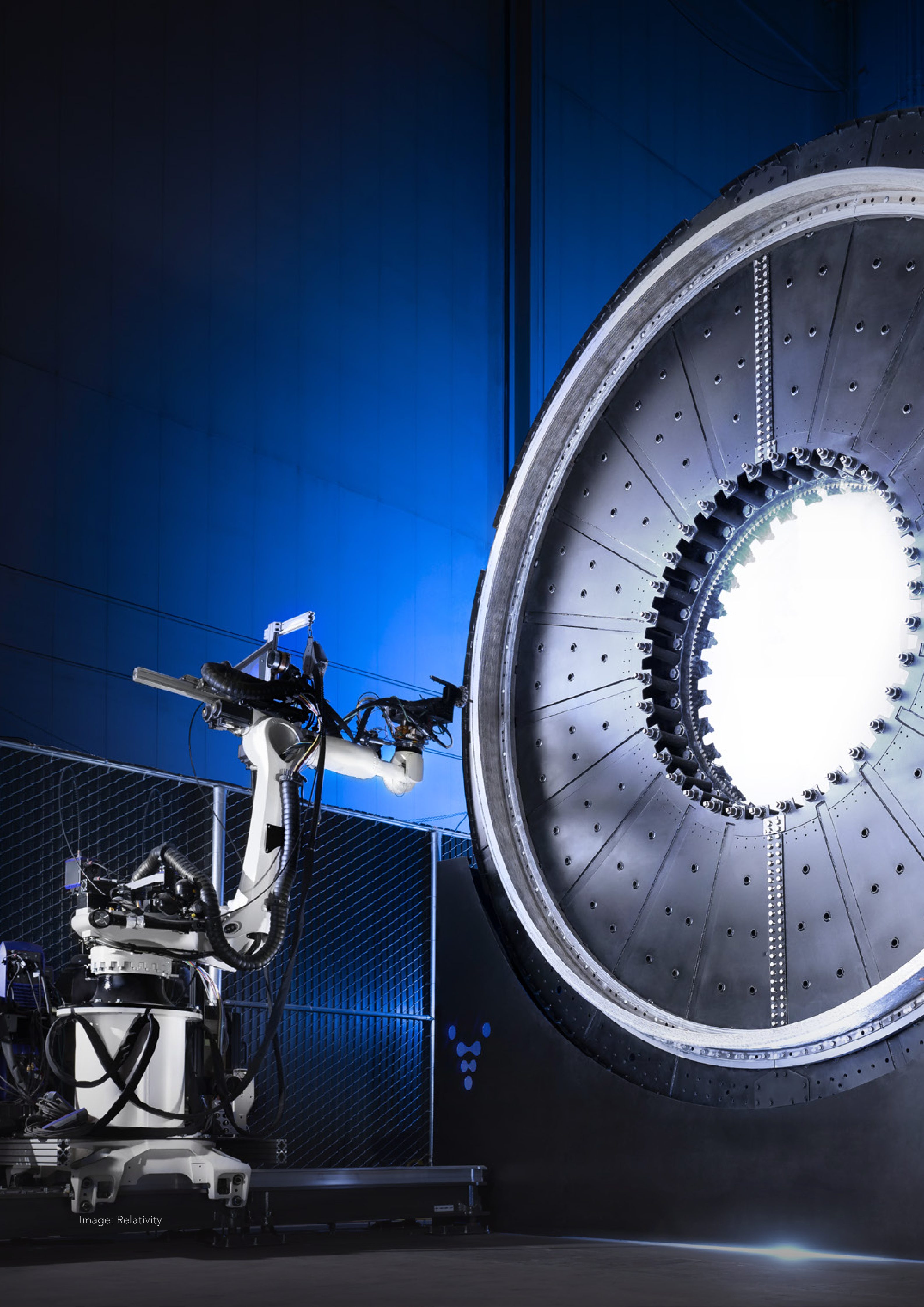


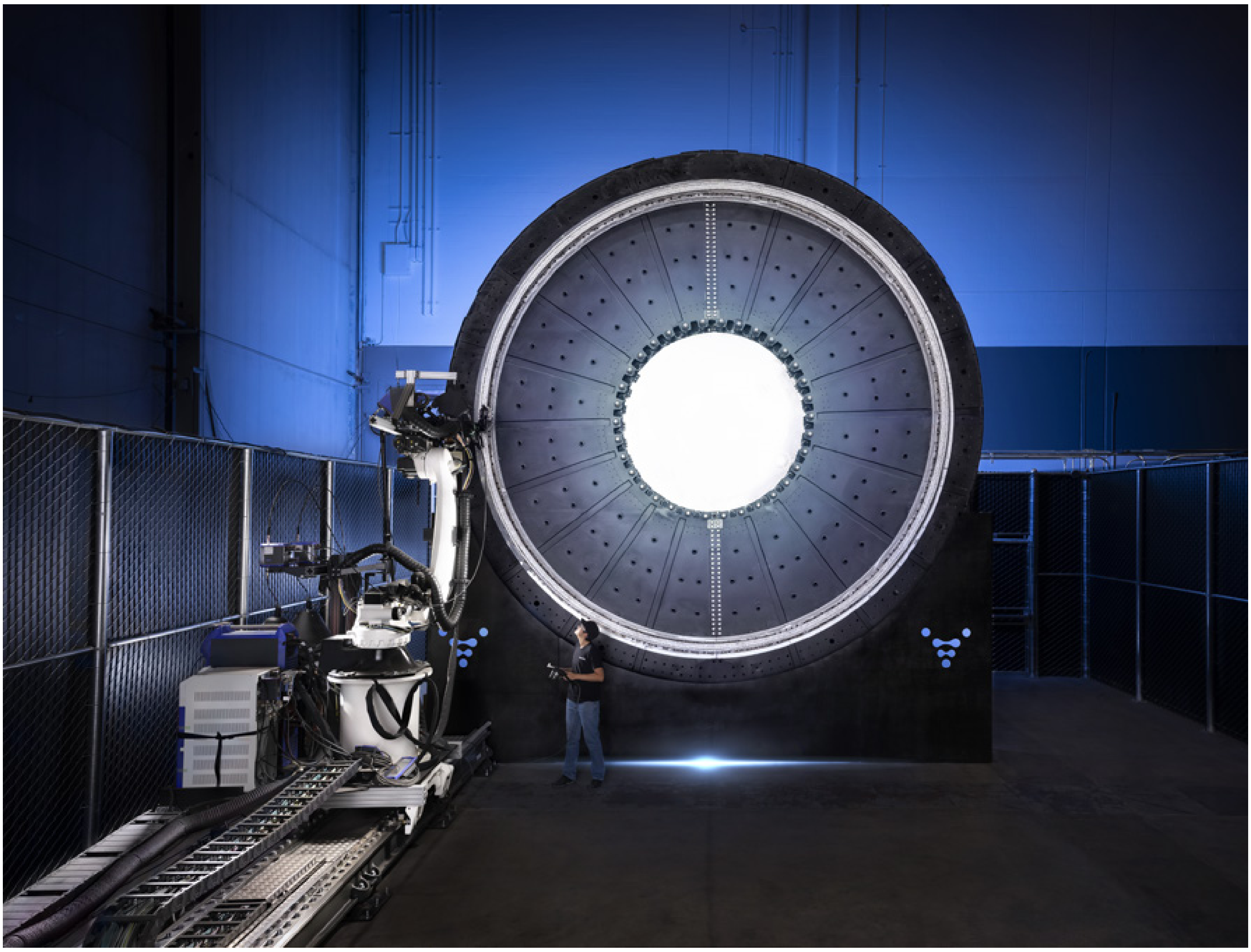
Image: Relativity

FUTURE

Relativity *enters* Stargate 4th Generation

The largest active metal 3D printing system in the world is now operating at the company's Wormhole Long Beach facility

Image: Relativity



Relativity Space's latest Stargate printer generation prints horizontally, feeding multiple wires into a single printhead.

Relativity Space, the first company to 3D print rockets and build the largest metal 3D printers in the world, unveiled the latest iteration of its first-of-its-kind proprietary manufacturing platform, Stargate 4th Generation metal 3D printers. These printers will underpin both the development and rate production of Terran R, Relativity's fully reusable, 3D printed rocket that will be capable of launching 20,000 kg to low Earth orbit (LEO).

The newest Stargate printer technology defies traditional printing constraints by moving horizontally as it feeds multiple wires into a single printhead to print orbital rockets. Relativity is developing customized software and machine learning techniques to allow these printers to print more complex and significantly larger metal products, with improved print speed and reliability. Stargate 4th Generation printers also radically simplify manufacturing supply chains, as they are capable of printing a rocket with 100x fewer parts in a matter of months.

"Large-scale products that are designed to fly will inevitably be 3D printed," said Tim Ellis, co-founder and CEO of Relativity Space. "The lighter a product is, the better it performs, and when 3D printing that product, it's also faster and more cost-effective to produce with each successive improvement. The compounding rate of progress is high, and we are still in the early days of what printing can achieve. We see 3D printing as an automation technology that has the power to change the pace of innovation in manufacturing, which is why we've invested in building our own proprietary tech stack from day one. Stargate printers are designed to unlock rapid iteration, which opens up opportunities for innovation in large-scale manufacturing products. What would take traditional aerospace and space manufacturers years to develop and build, will be reduced down to months due to a highly adaptable, scalable, and automated process, made possible through software-driven manufacturing."

With faster iteration cycles, Stargate printers are capable of accelerating progress and innovation within the aerospace industry. Most immediately, Stargate 4th Generation printers will serve as the primary manufacturing infrastructure for Terran R production. Longer-term, Stargate 4th Generation printers offer tremendous value-generating potential for other end-product use cases within the $1T+ aerospace, aviation, energy, and defense industries as the core of a new tech stack for aerospace products. To date, Relativity has secured five customers across $1.2B+ in customer contracts for Terran R, including a multi-launch agreement with OneWeb and a commercial mission to Mars with Impulse Space.

The Stargate 4th Generation printer technology promises significant improvements in print speed: 1st, 2nd, and 3rd Generation Stargate printers already operate at print speeds well beyond industry standards. Stargate 4th Generation printers offer 7x faster than earlier generation Stargate printers and achieve up to 12x faster printing over Relativity's already industry-leading performance.

In addition, the use of a horizontal print orientation increases print size capacity. Stargate 4th generation printers remove ceiling height constraints that impact vertical 3D printers. Through horizontal printing, these printers are capable of producing objects up to 120 feet long and 24 feet wide, resulting in an increased volume capacity of 55x its 3rd generation predecessor.

Reduced print start time and cost are supported by an integrated approach to build setup and print plate preparation. Reduced entropy, for more consistent, reliable manufacturing can be realized through a configuration that centralizes work centers around Stargate's robotic automation platform. Improved print quality and work center efficiency is achieved through powerful perception technology for in-process monitoring, which fuses together computer vision, advanced sensors and real-time telemetry.

Relativity Space shows off (horizontal) Stargate 4th Generation, the largest active metal 3D printing system at its Long Beach facility
This results in radical part count reduction, as well as rapid design iterations, as Stargate printers are not beholden to long-lead, high capital expenditure fixed tooling. Lighter, more cost-effective aerospace product production through rapid iteration is generated by leveraging Stargate printers and material science advancements developed in Relativity's in-house metallurgical laboratory.

Relativity also has proprietary, high-performance next-generation materials which will be used for products printed with Stargate 4th Generation printers. Most immediately, Terran R will be the first product in a series of products to benefit from the use of lighter materials and a faster production time, creating significant cost reductions for customers downstream.

"Iteration empowers innovation not only in our rocket design but also in our own Stargate printers," said Scott Van Vliet, SVP of Software Engineering. "In its short history, Relativity has made great strides in evolving its core 3D printing technology, but Stargate 4th Generation printers are our most innovative leap yet. We're fundamentally changing the way our factories are designed and operating, and by flipping the script and going horizontal, we're radically increasing our capacity for scale. Being a software-driven manufacturing company allows us to achieve unique product features, such as integrated pad-ups and domes, with radical flexibility."

The majority of Terran R components will be printed inside Relativity's new 1 million+ square foot headquarters in Long Beach, named The Wormhole. Aeon R engines, for Terran R, will continue to be produced at the company's other Long Beach factory, The Portal. The Wormhole, a former Boeing C-17 manufacturing plant, was secured by Relativity to be its new headquarters in 2021. Currently 33% operational, the factory has several Stargate 4th Generation printers online with more than a dozen printers planned to be producing Terran R components in the coming months. At the full capacity forecasted run rate, each Stargate 4th Generation printer is capable of producing 4 Terran R rockets per year. The remainder of The Wormhole will continue to be built out in phases, bringing more printers online and moving more teams into the company's headquarters as production for Terran R scales.

Much of the company's printing will be based at its new Long Beach facility, which spans over 1 million square feet.

Image: Relativity

Image: 3dpbm - Edward Wakefield

INTERVIEW

Why GE Additive's new Series 3 matters

The company is leading additive manufacturing through to the logical next step in the technology's evolutionary cycle.

3dpbm was invited to Cincinnati, Ohio, to visit GE Aerospace's Additive Technology Center (ATC) and GE Additive. After we had been given the rundown on the operations at these facilities and had the opportunity to interview the team members, from the executives to the engineers on the ground, this writer asked himself "is this really as incredible as it all seems?" The answer, as you will see, is an overwhelming "yes".

An overview of GE

General Electric Company, headquartered in Boston, is one of the largest and most diversified corporations in the world. The company was incorporated in 1892, after acquiring all the assets of the Edison General Electric Company (originally the Edison Electric Light Company, a company founded by Thomas Edison, in 1878, to market his incandescent lamp and other later products), and two other electrical companies.

Today, GE is best known for its work in the Power, Renewable Energy, Aviation and Healthcare industries. GE's purpose statement is "we rise to the challenge of building a world that works." All of GE's businesses have invested in Additive Manufacturing capability over the years and are poised to be one of the leaders in the manufacturing transformation.

GE Aerospace & GE Additive

GE Aerospace recently celebrated its 100th birthday in 2019 and is a world-leading provider of jet and turboprop engines, as well as integrated systems for commercial, military, business and general aviation aircraft.
General Electric formed GE Additive in 2016, under the leadership of David Joyce, after bringing Concept Laser GmbH and GE's production operations together. This was later followed by the acquisition of Arcam EBM and AP&C in 2017 - further strengthening the company's position within the AM market.

Additive Technology Center (ATC)

GE Additive and the ATC are both structured within the GE Aerospace business but are distinct and separate organizational entities.

GE Additive builds and develops metal 3D printing machines, which are sold externally, to a wide range of customers across multiple sectors, as well as manufactures the metal powders which are used by the machines, and offers software and additive consultancy. The ATC uses, tests, and occasionally also co-develops these machines through the group's design and development of aerospace parts. The two groups work closely together and drive each other - one as the 'producer' and the other as the 'customer'.

GE Aerospace's engineering division is responsible for the design, while the supply chain division consists of all the manufacturing sites around the world. The ATC is part of the GE Aerospace supply chain division and contains more than 60 3D printing machines that are working on the development of more than 50 different parts across numerous commercial and military platforms. GE Aerospace's Auburn, Alabama, facility also contains approximately 50 machines and is dedicated to printing production parts.

One of the combined team's most notable achievements, so far, is that of the fuel nozzle tips for the LEAP engine, designed by Josh Mook, the Innovation Leader for GE Additive, and a key mind behind the company's latest Series 3 binder jet 3D printer, which we will get to in a moment. The LEAP fuel tip has been in production for six years, at the Auburn facility - which currently ships approximately 1,000 components per week to support engine assembly.

> “The ATC contains more than 60 3D printers that are working on the development of more than 50 different parts across numerous commercial and military platforms”

Over the next eight years, the team expects a 5x increase in demand for additively produced hardware, including “a lot of military work” (in addition to the current parts the group develops for the US Army and Airforce, which, as non-US citizens, we were unfortunately not allowed to see during our tour of the facilities).

During our visit to the ATC, we were guided by Chris Philp, a former GKN Aerospace manager who joined GE in 2014 and is now the site leader. “We are a development center - we have to learn things,” he said, with reference to the group’s video imaging technology the engineers use to test thermal properties and perform stress analyses.

As an example of how the ATC develops the AM technology - the center was working on creating an engine for the US Army that consisted of 14 different 3D printed parts, using five different alloys. Of these 14 parts, one was too big to be printed with the available technology. “There was not a machine on the market that could build this part,” said Chris Philip. So, the team decided to modify one of its 400mm x 400mm printers and turn it into a 500mm x 500mm printer. The printer also needed to have multiple lasers that would ‘weave’ and ‘stitch’, harmoniously, to avoid seam lines (necessary for parts to be airworthy) - additional requirements that the team provided to GE Additive, which ultimately influenced the evolution of its Concept Laser M Line system.

When we noticed that the factory floor was unexpectedly quiet, we asked Chris “where are all the employees?” He responded by saying, “The machines are running themselves.”

Chris Philp’s approximately eight years at GE is eclipsed by Benito Trevino’s 24-year tenure at the company. After graduating as an electrical engineer from Cornell University, he immediately went on to work for GE and has been there ever since. He is now the general manager of the Additive Part Family within GE Aerospace and leads a team of approximately 400 employees.
According to Benito Trevino, his position at GE is the role of a lifetime. “It’s just fascinating how you can grow parts,” he said. “Nothing is as exciting as going out onto the floor and seeing parts being printed day in and day out. We are literally inventing the future of flight here,” added Benito Trevino.

Past and future of the assembly line

When Ransom Olds created and patented the first assembly line in 1901, towards the end of the Industrial Revolution, it allowed his car manufacturing company to increase output by 500% (to a never-before-seen rate of 20 cars per day) in one year. The Oldsmobile car was the first to be produced in large quantities.

Olds' assembly line method, which was the first to be used in the automotive industry, served as the model for which Henry Ford created his own - with the added feature of the moving platforms of a conveyor system. This method of production is known as 'Fordism' - "involving the mass production of standardized goods on a moving assembly line using dedicated machinery and semiskilled labor," according to Britannica.

GE has now developed, what this writer believes can be accurately referred to as 'General Electricism', except for the fact that the parts are anything but standardized, given the nature of 3D printing, and the semiskilled labor involved in the actual production, compared to 100 years ago, is significantly less, given the nature of 3D printing.

Essentially, the GE Additive Series 3 is a binder jet 3D printer with a conveyor belt running through it, which enables the printing of green parts, non-stop, 24/7. The build boxes, which are loaded onto the conveyor belt, are scanned and tracked inside the machine. Once these build boxes have been filled with 3D printed green parts - using the powder which is loaded, barrel by barrel, into the machine through a centralized material handling station - the boxes are then loaded into the depowdering station.

Interestingly, the engineers use software to alter the design of the green parts, to account for the effects of the heat, when sintering, such as shrinkage and the 'drooping' of parts, due to gravity (I still maintain that the exploration of sintering in zero gravity is a worthwhile endeavor).

The almost fully automated system also allows for minimal operator contact with the system and metal powders - which can often have negative effects on operator health when uncontained.

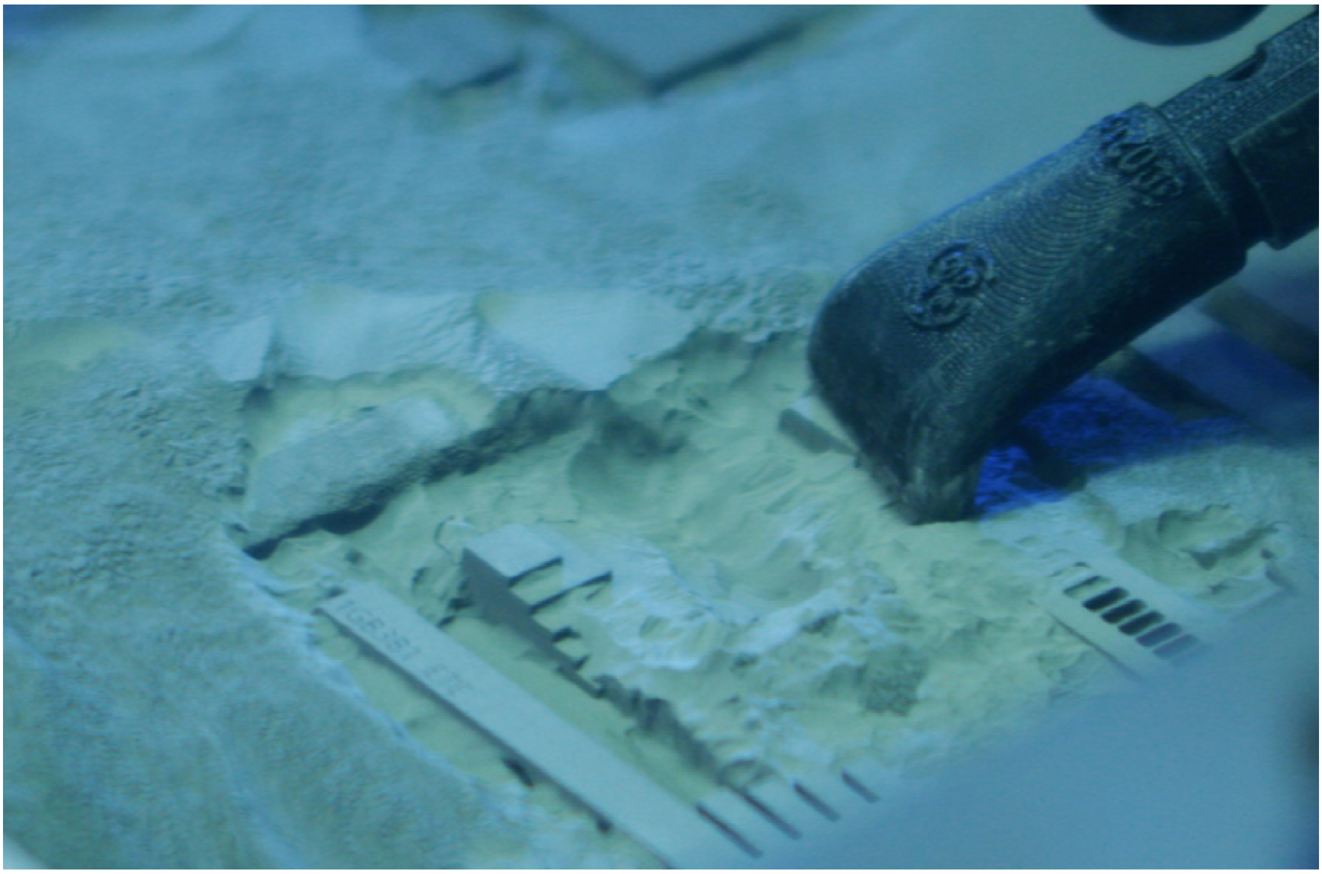
GE Additive's Series 3 binder jet 3D printer is the modern-day version of Ford's assembly line, and the logical next step in the technology's evolutionary cycle. Although the Series 3 has its limits, such as the lack of automation in the post-processing stage, where parts still need to be depowdered by hand (often thousands of parts per box), the progressiveness of the system is exciting, and the future of streamlined 3D printing is looking promising.

The Binder Jet line

During our visit to the GE Additive facility, in Cincinnati, Ohio, we were also privy to the company's most recent announcement which includes the details of its Binder Jet Line and Series 3 printer. With production deliveries expected to begin in the second half of 2023, the release of the system follows four years of customer discovery, collaboration, and testing to ensure the system is ready and relevant for modern, high-volume, serial production environments.
"In addition to a tangible business model, customers in fast-paced, high-volume manufacturing environments who are considering industrial-scale additive deployments also need to demonstrate positive financial and productivity impact, as quickly as possible. Customers shouldn't have to reconfigure and tweak machines once they have been installed on their shop floor," said Josh Mook, chief engineer and innovation leader at GE Additive.

"We remain focused on only bringing technology solutions to market when they are ready, and can

Image: GE Additive



3dpbm recently visited the GE Additive facility in Cincinnati, Ohio, where we learned about its Binder Jet Line.

help our customers demonstrate return on investment and total cost of ownership. That is certainly the case with our new Binder Jet Line and the Series 3, which is reliable, safe, and meets their needs today and tomorrow," added Josh Mook.

Over the past four years, a select group of strategic customer partners has contributed to the development of the GE Additive Binder Jet technology platform. The Binder Jet Line Series 3 can additively manufacture complex, small, and large parts – repeatedly and reliably, with outstanding material properties that exceed casting equivalents with achievable through-hole diameters and wall thicknesses less than 500µm. GE's Binder Jet technology has regularly proven the ability to successfully print and sinter large parts which meet dimensional and feature resolution tolerances for production, with demonstrated capability in (but not limited to) parts up to the weight of 25kg in stainless steel and no known limitations on maximum wall thickness.

The Binder Jet Line also enables the user to de-powder intricate parts without destroying fine features, enabled by GE's proprietary binder systems, sinter parts within the desired tolerances, enabled in part by GE Additive's Amp TM software's distortion prediction and compensation capability, develop casting equivalent, or better, high-quality parts much faster than traditional methods, and print and sinter parts with low surface roughness.

As GE Additive strives to make industrial metal additive manufacturing an economical process – $/cc is a critical driver of the Binder Jet Line. The further the cost of a final part can be driven down, the more application space is available for the technology.

Part of those calculations includes cost comparisons to conventional manufacturing technologies, in terms of tolerances and cost, from incoming raw material to the final part in hand (total cost of ownership – not just the machine).

Other cost benefits include less spent on raw materials by recycling unused powder and leveraging less expensive material (compared to other powder bed technologies), open space for new applications and innovation, utilization of the entire build box, top to bottom, edge to edge, with no need for supports, and the ability to introduce innovative parts otherwise too costly or difficult to manufacture with conventional or other existing additive technologies.

GE's Binder Jet Line offers high overall equipment effectiveness (OEE), automation readiness, predictive distortion and compensation, and material properties that meet and exceed industry standards. The goal is for all of these aspects to come together to enable the lowest total cost of ownership for metal additive production.

Based on input from customers and partners during the technology development phase, GE Additive is focused on enabling the eventual deployment of 40, 50, and 100+ machine installations that will drive repeatable process quality, while minimizing operator contact with equipment and materials.

Other scale benefits include the ability to print up to 100X faster than other additive manufacturing modalities, automation-ready technology that drives high productivity, process and hardware designed to optimize Takt times, and seamless industrialization and integration into factory cells.

The Binder Jet Line can be installed and operated without hazard zoning required and has been designed for minimal operator contact with the system and metal powders.

The system will be UL-listed and CE-certified, has a 100% inert and sealed environment, fully closed loop powder-free exposure, and is designed for compatibility with reactive and flammable powder and binders.

Other safety benefits include zero operator powder exposure for powder load and operation, a fully independent and real-time safety system onboard, constant monitoring of machine conditions, and real-time OPC UA data streaming for integration into factory MES and safety systems.

"Fast-tracking solutions and bringing them to market too soon is not a sound strategy and is often the reason machines end up gathering dust in R&D labs. During the Series 3 and Binder Jet Line's development phase, we sought out customers who could give us honest, real-world insights from their high-volume manufacturing environments. We have taken their insights to complement our hands-on knowledge and experience of scaling additive production," said Brian Birkmeyer, product line leader for Binder Jet at GE Additive. "The result is a modern, modular industrialized additive system – developed by additive users for additive users – that delivers quality parts, at cost, at scale, and safely."

GE's Binder Jet Line can print up to 100x faster than other AM modalities.

Image: GE Additive


Image: ExOne | Desktop Metal

MAPPING

MBJ 3D printers go head to head on production

The five systems that are about to revolutionize the metal additive manufacturing industry

As the production-ready metal binder jetting technology enters the market, the biggest industry stakeholders are taking different approaches to maximize opportunities and tailor their offering to the specific requirements of their target customers. As is always the case, each system can build on a set of strengths and weaknesses. Here we compared some of their key features to help adopters get a quick view of the landscape and understand which is the ideal system for them.

The most automated
HP Metal Jet S100 Solution

The HP Metal Jet S100 Solution includes a complete integrated workflow unlike anything ever seen in the additive manufacturing industry. The HP Metal Jet S100 3D printer is the second of four items in an end-to-end process that includes the HP Metal Jet S100 Powder Management Station for loading the metal powders before printing, followed by the HP Metal Jet S100 Curing Station and the HP Metal Jet S100 Powder Removal Station, These phase stations are interconnected by the movable build units and the Powder Management Station Portable Tank that brings the unused powder back to the starting point at Powder Management.

As it is one part of many, the S100 printer is also by far the lightest system, weighing less than half as much as the next lightest system, the DMP/PRO, at less than 1 metric ton. The build volume of the S100 is comparable to Desktop Metal's P-50 and its maximum print speed, while generally slower than both the X160 and the P-50, which is defined by HP's focus on workflow optimization. In an effort to make the most industry-ready, viable system, HP is also focusing on a small range of highly used, affordable stainless steel materials. Resolution is a relatively standard 1200 dpi, comparable to the P-50.

The biggest
Desktop Metal X160 PRO

Desktop Metal's X160 (formerly the ExOne X1 160) is a behemoth built for large batch production although it acts as a stand-alone system, letting users build their own production workflows. Because of its extra large, 160-liter build volume, the largest known among binder jetting systems (the size of the build volume of GE Additive's Series 3 has not yet been disclosed) and its wide Triple Advanced Compaction Technology (Triple ACT) printhead, it also has a fast deposition rate, the fastest known after the P-50. This also makes it the heaviest system after the P-50, coming in at 3.7 metric tons. In addition, it can leverage almost two decades of expertise by ExOne in terms of both binders and supported materials, which currently include 316L, 17-4PH, 304L, Inconel 718, M2 and H13 tool steels, copper, ceramics and more. However, the chamber is not inerted.

The fastest
Desktop Metal Production System P-50

More than a machine, the Production System P-50 has represented a vision and specifically Desktop Metal's founder Ric Fulop's vision to establish the concept of additive manufacturing 2.0 and automated, rapid, tool-less production of metallic parts. Based on this vision, Fulop was able to gather the funds necessary to build the company that started the metal binder jetting revolution. Now the P-50 is also a real machine, the fastest on the market, although speed alone is not sufficient without an adequate ecosystem.

According to official data, the P-50's bi-directional Single-Pass Jetting (SPJ) technology enables it to deposit up to 12,000 cc of metal powders, which would make it six times faster than the HP S100 and almost four times faster than the X160. It is also the

> “ GE Additive’s Binder Jet Line is large — 500 x 500 x 500 mm build volume — the next largest after the X160 ”

largest and heaviest machine, measuring 5 meters in length and weighing in at 5.4 metric tons. In an effort to rapidly expand the range of supported materials, the P-50 features an open material system for standard MIM powders and an inerted printing environment.

The most scalable
GE Additive Series 3 Binder Jet line

GE Additive’s Binder Jet line project has evolved rapidly however at this time many of the final system’s features have not yet been revealed. What we do know is that GE is building the system specifically for integration into factories of up to 100 machines and the company’s expertise in scaling production with both L-PBF and EB-PBF metal 3D printing technologies indicates this will be the main objective.

GE has identified different setups that range from 1-2 smaller size Series 2 units to 4-8 Series 3 (Pilot Line), to 12+ Series 3 (Factory Line). We also know that the machine is large (it has a 500 x 500 x 500 mm build volume, the next largest after the X160), modular, highly automated and that it can produce parts as large as 23 kg, with a speed that is claimed to be comparable to Desktop Metal’s P-50 (100x metal PBF). The system should support open MIM powder materials and it operates in an inert environment to include flammable powders and binder.

The most precise
Markforged/Digital Metal DMP/PRO

The DMP/PRO was the last system to be introduced by Digital Metal before the acquisition by Markforged so we expect that it will become the flagship of Markforged’s MBJ offer. Leveraging nearly a decade of expertise in production metal binder jetting of small intricate parts, the DMP/PRO introduced a new printhead with 70,400 print nozzles that eject 2 pL droplets at 15.5 kHz. This means that while it has the smallest build volume and the slowest build rate (1000 cc/hr) among production binder jetting systems, it is also the most precise, with a resolution of 1600 dpi, static accuracy better than 1μm, and 35μm layers in the Z direction. Wall thickness is also at the top of its class, with ≥300 μm as the standard thickness and the ability to push it down to a minimum thickness of ≥150 μm.

	ExOne	Desktop Metal
	X160PRO	**Production System P-50**
Technology name	Triple Advanced Compaction Technology	Single Pass Jetting
Build volume	800 x 500 x 400 mm (160 L)	490 x 380 x 260 mm
Build speed	Up to 3,120 cc/hr	Up to 12,000 cc/hr
Binders	AquaFuse, CleanFuse, Fluid-Fuse, PhenolFuse	Proprietary Desktop Metal binders
Printer resolution	>30 µm voxels, 30 to 200 µm layers	Native 1200 dpi
Printer size	3,500 x 2,000 x 2,200 mm	1,900 x 5,000 x 1,900 mm
Printer weight	3,700 kg	5,443 kg
Supported materials	316L, 17-4PH, 304L, Inconel 718, M2 and H13 Tool Steels, Copper	Open to third party MIM powders
Supported file formats	STL, STEP	STL, STEP
Power consumption	400 V, 50/60 Hz, 3-phase	380 - 480 V, 50/60 Hz, 3-phase, 4 wire 60 Amp
Environmental statement	–	–
Compatible workflow hardware	Third party	Third party
Expected cost	$$$$	$$$$$

HP Metal Jet S100 Solution	Series 3	DMP/PRO
Metal Jet	Binder Jet	Metal Binder Jetting
430 x 309 x 200 mm	500 x 500 x 500 mm (23 kg parts)	250 × 217 × 186 mm
1,990 cc/hr	Up to 100x as metal PBF	1,000 cc/hr
HP Metal Jet binding agent	Supports reactive and flammable binders	–
1200 dpi	Wall thickness down to 400 μm	1600 dpi, static accuracy better than 1μm, 35μm in Z
3,000 x 1,350 x 2,400 mm	–	2,700 x 1,000 x 1,700 mm
851 kg	–	2,000 kg
316L	Supports reactive and flammable powders	Open with customizable parameters
STL, 3MF	STL, STEP	STL, STEP
8 kW	–	3.5 kW (average)
REACH	–	–
Powder Management, Curing, Powder Removal, and Powder Management Stations, Build Unit, Portable Tank	Material Handling Systems for binder and powders.	–
$$$	$$$$	$$$

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