The additive journey:
THE TIME IS NOW

Industry in 3D
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EXECUTIVE SUMMARY

Additive is changing the world. It is already disrupting industries and accelerating the way products are designed and manufactured. **Its time is now.**

That is not by chance. Decades of research and development by academics and companies have led to this point – a truly amazing global opportunity. However, we don't expect the additive industry to stand still – the journey will and needs to continue.

This report shows a **dynamic, transformative sector on the move**, spurred on by digital transformation. AM is adding value and reducing costs for many industries and multiple applications. We offer our point of view on the current market environment, shifts in workplace and skills requirements, and the evolution of supply chains and business models. A series of case studies from a diverse range of sectors demonstrate how additive is impacting industries - today.

Of course, our customers will experience a few more twists and turns on their own journey. As one of the biggest additive users, **GE brings an unparalleled level of materials science and application expertise** to our customers. Whether they are just beginning to explore the business case for additive or ready to scale to production, GE strives to be the manufacturing partner of choice.

And as for GE's additive journey, we have a target of removing US$3 billion to US$5 billion cost out across GE, and we couldn't do this without additive. Today, we make parts using additive technologies that we never would have dreamed of just a few years ago. So, our own journey continues to be an amazing one. Only now, we're also helping other manufacturers realize their vision, too.

INTRODUCTION

Additive manufacturing (AM), including 3D printing technologies, have been among the most heavily explored manufacturing innovations in the history of modern manufacturing. Though these terms tend to be used interchangeably, additive and 3D printing refer to separate concepts. In the August 2017 issue of Additive Manufacturing magazine, Peter Zelinski wrote: "… 3D printing is the operation at the heart of additive, just as 'turning' or 'molding' might be the operation at the heart of a conventional manufacturing process."[1] Additive manufacturing, on the other hand, refers to a more rigorous process and includes 3D printing.

The use of 3D printing technology dates back to the 1980s for polymer applications, but the ability to print functional parts from metal alloys has spurred significant interest and investment into AM over recent years. GE Additive partner and leading industry analyst firm, SmarTech Publishing, estimates that approximately US$13 billion have been spent on 3D printers, materials, software and services over the past four years – with half of that being spent during 2017 alone. They project more than US$280 billion will be invested in additive manufacturing over the next ten years.[2] Similarly, according to the recent 2018 Wohlers Report, "the additive manufacturing industry grew 21% from 2016 to 2017 globally, reaching $7.3B".[3]

These huge growth rates are represented in business leaders' sentiments toward additive according to the 2018 GE Global Innovation Barometer (a survey of nearly 2,100 business executives worldwide). Global executives are excited about the potential of additive; 63% say it will have a positive impact on businesses, 91% believe it will increase creativity, and 89% believe it will help deliver goods to the market faster.[4] This will help to power the emergence of a global manufacturing movement that will disrupt how the world thinks about product development, design, production, supply chain, and lifecycle management.

A combined 41% of these executives claimed AM has had an impact on their organizations; with 27% reporting "additive has become a reality that is impacting businesses," and a further 14% saying "additive has already had an impact on businesses." At the same time, the study noted that just over half of the business executives believe additive has yet to reach its full potential, requiring more education and reassurance.[5]

AM is now reshaping the product design process, entire supply chains, and the vast landscape of manufacturing. Engineers are embracing new design freedoms to create valuable product performance improvements and cost efficiencies with lighter weight, better thermal management capability, better fluid mixing, customization, and/or the ability to make different structures and textures that yield better part integration. Many companies, like GE, are investing and scaling the technology in order to reap the benefits of AM.

Arcam Q10Plus machine at GE Aviation's Additive Technology Center.

[1]Additive Manufacturing Magazine 'Additive Manufacturing & 3D Printing are Two Different Things' – April 8, 2017
www.additivemanufacturing.media/columns/additive-manufacturing-and-3d-printing-are-two-different-things
[2]SmarTech Publishing; custom analysis
[3]Wohlers Report 2018, "3D Printing and Additive Manufacturing State of the Industry Annual Worldwide Progress Report" pp. 25, 142
[4]2018 GE Global Innovation Barometer survey - www.ge.com/reports/innovation-barometer-2018
[5]2018 GE Global Innovation Barometer survey - www.ge.com/reports/innovation-barometer-2018

Now is the time for companies to define their new paths to production. AM is ripe for investment. The critical mass of industry investment combined with entrepreneurial innovation is creating a momentum of adoption. Recent market analysis proves that the technology has advanced beyond the R&D stages and is now being adopted as a production platform.

Medical and dental industries have been aggressive adopters of AM technology. According to SmarTech Publishing, an estimated 68% of total metal AM solution revenues in 2014 were spent in the aerospace and healthcare industries. Healthcare (including dentistry and biomedical), and aerospace will combine to account for some $8.2 billion in revenues for metal AM solutions by 2027.[6] However, looking forward, fast growth is expected as metal AM becomes adopted in other segments, including automotive and energy.

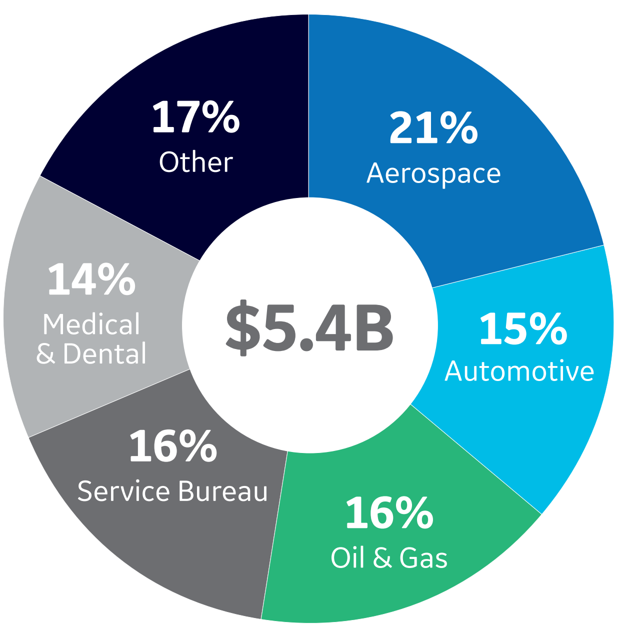
The automotive segment is expected to grow the fastest, rising to $2.3 billion by that same year.[7]

The sales of additive machines are indicative of the industry adoption rates, as well as the significant opportunity for regional growth. As highlighted in Figure 1, by 2027, 52% of the metal machines will be operating in heavy machinery industries, including aerospace, automotive, oil and gas, and energy.

Regional expansion is an equally important growth factor. While North America and Europe have been the leading regions for incubation and use of metal additive technologies, the rest of the world has seen a huge increase in adoption since 2014. According to the Wohlers Report, North America leads the global share of installed industrial AM systems with 38%, with Asia-Pacific and Europe following at 30% and 28% shares,

FIGURE 1

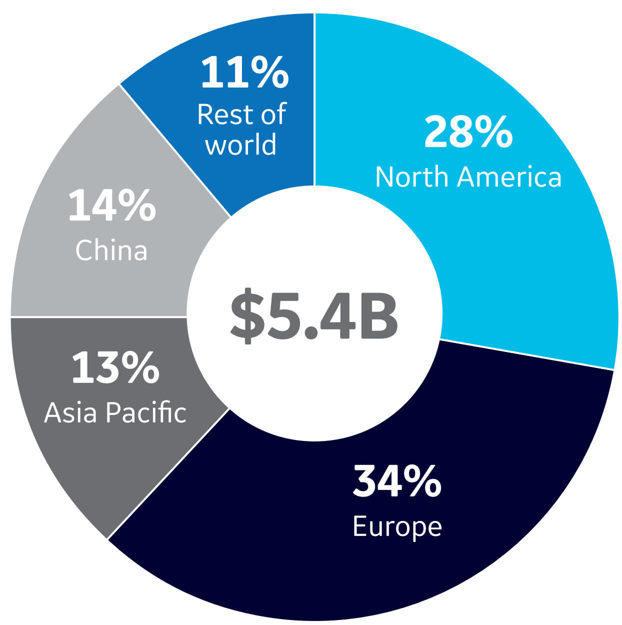
2027 metal system revenue by industry



Source: SmarTech Publishing

FIGURE 2

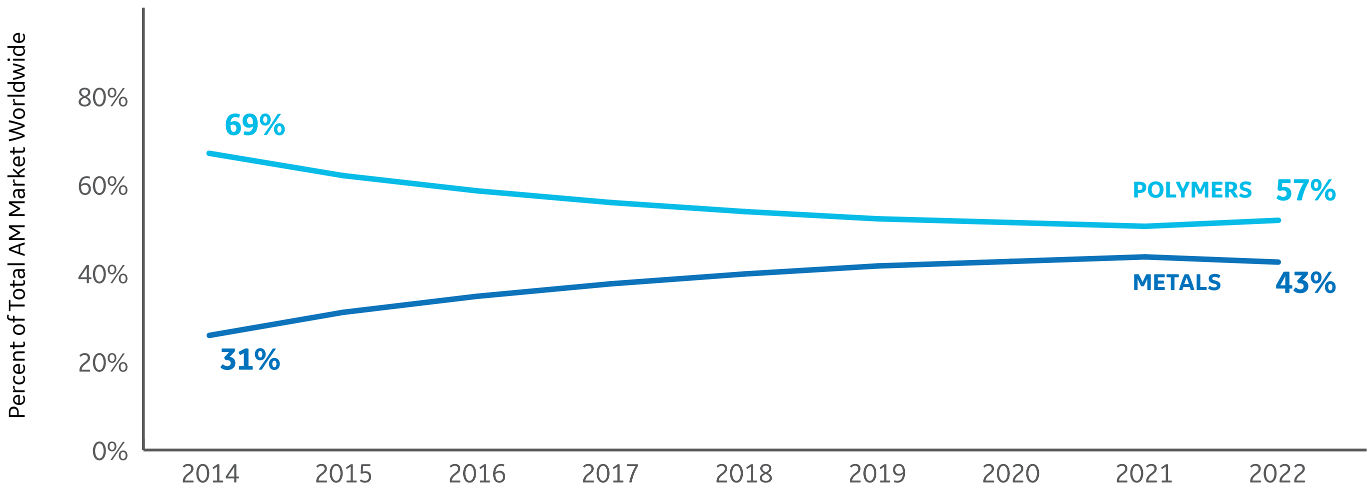
2027 metal system revenue by region



Source: SmarTech Publishing

FIGURE 3

Total projected AM revenues by material class as a percentage of total value, 2014-2027E



respectively.[8] In comparison, SmartTech's estimates of metal additive technologies illustrate that the Asia-Pacific owns just under 25% of the current install base, with the compounded annual growth rate (CAGR) for metal AM installations projected at nearly 29% from 2018 to 2027[9]. Even though the Asia Pacific region – particularly China -- is catching up with adoption of metal additive systems, 62% of the deliveries are expected to be made within North America and Europe by 2027. (Figure 2)

The Wohlers Report reveals, "companies use AM to make functional parts more than anything else."[10] The report also captures the key reason why. The report states, "... a product development manufacturing company may spend 5-10% on design and prototyping for a development program ... however 90-95% is spent on production."[11]

Furthermore, there is a shift from polymer to metal sales, indicating more direct printing of production parts. Historically, polymer printing has controlled the majority of industry investment and utilization for additive technologies. However, the future of AM is in production, and the metals segment is already altering the balance between polymer and metal printing. The Wohlers Report notes: "Metal machine unit sales grew 76.9% from 2016 to 2017 (from 983 to 1,768 systems)".[12]

This shift toward future metal additive investments is also revealed by a custom analysis from SmarTech Publishing. Their projected revenues of hardware and software solutions, will evolve from more than a 2:1 polymer-to-metals ratio in 2014 to just over a 1:1 ratio by 2027[11]. (Figure 3) GE Additive believes as laser printing and electron-beam melting (EBM) methods mature with faster throughput rates, and other modalities gain acceptance, such as directed energy deposition (DED) and metal binder jet, the metals segment may potentially surpass polymer.

[6] SmarTech Publishing
[7] SmarTech Publishing
[8] SmarTech Publishing
[9] Wohlers Report 2018, "3D Printing and Additive Manufacturing State of the Industry Annual Worldwide Progress Report", pp. 149
[10] Wohlers Report 2018, "3D Printing and Additive Manufacturing State of the Industry Annual Worldwide Progress Report" pp 25,
[11] Wohlers Report 2018, "3D Printing and Additive Manufacturing State of the Industry Annual Worldwide Progress Report" pp 142
[12] Wohlers Report 2018, "3D Printing and Additive Manufacturing State of the Industry Annual Worldwide Progress Report", pp. 149

It is no secret that AM has attracted a tremendous amount of talent and capital over the past few years. Entrepreneurs are innovating across the value chain, from materials and machines to software and services. Ceramics, composites, novel alloys and bio-materials can now be printed, and innovators are developing new modalities that enable faster printing and larger build volumes. Software developers are creating "generative design" tools--organic geometries that once would have been impractical to produce by conventional methods, as well as software that manages workflow from design through large-scale production. Creative entrepreneurs are even leveraging AM to re-imagine products ranging from shoes and jewelry to dental implants, automobiles and rocket engines.

Because of these developments, additive companies have attracted the attention of venture capital funding over the past three years – printers make up 50% of the investments; software and service companies make up another 30%[13]. We expect to see more deals and dollars move beyond the box, to cloud-based AM software and services with "as a service" subscription business.

Below are some product examples illustrating the industry investment in AM:

Jung & Co. Gerätebau GmbH, a German company specializing in stainless steel components, is using AM to keep spare parts more readily available for their customers. Additionally, the firm noted that the assembly of a filler valve in a can-filling plant consists of seven components and requires the addition of the necessary seals. Manufacturing the part by conventional means takes roughly 8-10 weeks, including the procurement of the required precision cast part.

With AM, the whole process takes roughly one week, reducing the component's overall weight by 35%, according to Jung & Co. CEO Thomas Lehmann. "Additive enables short machine downtimes for the beverage fillers that previously seemed impossible," he says. "A new 3D design and rapid availability saves the customer time and money."

Optisys LLC, based in West Jordan, Utah, makes sophisticated, 3D-printed, metal micro-antenna products for high-performance aerospace and defense applications. The company says the next generation of radio-frequency (RF) antennas can be made via AM – and deliver better performance. AM enabled Optisys to reduce the number of parts in one of its antennas from 100 to just one, while reducing the product's weight by 95%. The firm also decreased the production lead time to two months from 11 months, and realized a 75% reduction in non-recurring costs.

Optisys CEO Clinton Cathey states: "By combining RF design simulation, mechanical engineering, and system optimization focused on AM, we provide metal 3D-printed antenna products at greatly reduced size, weight, lead times, part count and cost—with as-good or better RF performance than conventionally manufactured systems. We're creating structures that were simply not possible to produce in the past."

LZN Laser Zentrum Nord GmbH, GE's own Concept Laser partnered on a project in which Airbus re-designed a metal cabin bracket for the Airbus A350 XWB airplane. A 3D-printed part made of titanium replaced a previously milled bracket made of aluminum. This resulted in a 30% weight reduction, enabling Airbus to lower the plane's fuel consumption or increase its load capacity.

Moreover, Peter Sander, head of Emerging Technologies & Concepts for Airbus in Hamburg, notes: "The omission of tools reduces the costs and shortens the time until the component is available for use by up to 75%. Since tools are not required in the process, it's now possible at an early stage to produce functional samples of components that are similar to series-produced components. This is done without upfront costs for tools. This means that sources of error can be identified in the early stages of the design process, which allows for optimization of processes within the project as a whole. Previously we budgeted around six months to develop a component – now, it's down to one month."

Sutrue Ltd., a UK-based medical device manufacturer, developed an automated suturing device to streamline and create a safer suturing process. The needle rotates softly and with pinpoint precision during suturing, owing to a complex miniature gear mechanism that drives the needle assembled by AM. Thanks to the suture device, up to three rotations of a needle per second with highest precision are now possible, instead of one stitch per 25 seconds produced by hand. The use of the suture device reduces the risk associated with the operation for both patients and surgeons.

Alex Berry, Sutrue director and shareholder, says: "AM makes it possible to produce geometries that cannot be achieved using traditional manufacturing methods. In addition, the parts have greater performance capacity or functional precision, or else they are extremely delicate or small."

Lima Corporate was the first company to implant a 3D printed acetabular cup back in 2007 and has been in full production ever since. Lima produces their orthopedic implants on an Arcam EBM 3D printer using Ti6AI4V material. Lima has patented their innovative design for these implants as Trabecular Titanium (TT). Lima states the use of this technology has offered them the ability to manufacture innovative products and at the same time reduce production costs and lead times. Lima has since expanded their Tribecular Titainum capabilities to make other implants including shoulder replacements and partial knee replacements.

[13] CB Insights, Research Brief: 3D Printer Makers Drive Record Deals for Industrial 3D Printing, Jan 7, 2018

AM is rapidly transforming a vast array of industrial sectors, and each industry and company is on its own journey. There are many considerations for an organization when investing in additive and committing to adopt these methodologies as a part of their core manufacturing footprint. In the next section, we will address three considerations that are top of mind for production with additive technologies: business model and supply chains, qualification and policy, and workforce and culture.

Business model and supply chain transformation

AM enables smaller, faster production runs – as well as rapid iterations for new product development. Cost-effective, small volume production opens the opportunity for mass customization, such as patient-specific implants or zero-inventory, on-demand spares. Service bureau organizations, such as Proto Labs Inc., have created business models based on a "digital thread." This end-to-end software and shared data is focused on fast iterations, quick price quotes, digital design, and print-on-demand services that provide economies of scale to make prototypes and low-rate production profitable.

Like most things digital, AM can employ cloud-based solutions and digital technologies, enabling the use of additive printers as a manufacturing resource. Shapeways, Fast Radius and other startups have developed AM infrastructure as a service (MLaaS) clouds in which they own and operate 3D printing resources that can be scheduled on the Internet. New start-up companies have sprung up to manage and monetize cloud manufacturing resources – from scheduling, validation of printability, and securing print files, to full-blown MLaaS and manufacturing platforms as a service (MLaaS) business models.

In contrast, companies such as Xometry are coordinating manufacturing resources owned by others as a network orchestrator, much like an Uber, Lyft, or Airbnb that offers transportation or lodgings without owning any vehicles or real estate. These companies are helping migrate manufacturing from a centralized factory approach to a distributed, hub-and-spoke model.

These new business models change the when and where products are manufactured and delivered to the customer. More importantly, they are changing the how it will happen. This has led to a flurry of new companies focused on managing the digital manufacturing workflow. Companies such as Authentise and Link3D offer a cloud-based manufacturing execution system (MES) for digital manufacturing. They provide software suites for file management, rights management, print management, material tracking, pricing, product by simulation, post production and tracking. Other companies, such as Aras, offer cloud-ready product life-cycle management (PLM) tools for tracking unique product versions, which is all-important as we move toward "economies of one" in manufacturing.

Digital manufacturing and an end-to-end digital thread allow original equipment manufacturers to rethink their supply chain for spare parts as well as new build. Rather than maintain their own warehouses of spare parts or stocking parts in advance at a logistics provider, OEMs are experimenting with printing them on demand. UPS, for example, has partnered with Fast Radius to print slow-moving spare parts at its distribution centers.[14] Xometry is enabling on-demand spare parts so the printing of these parts is geographically closer to where the parts are needed. In some cases, AM can also offer a means to produce parts where the original tooling or supplier is no longer available.

AM's tremendous impact on industry supply chains centers on how industry OEMs decide to "make or buy." Some companies are leveraging AM to consolidate their supply chains by reducing part counts, and others are moving from sourcing conventionally made parts to producing them additively in-house. Still others are going to encourage their suppliers to adopt AM to serve their needs. These make or buy decisions will ultimately depend on the type of customer, industry, and the specific part that is being manufactured.

Whatever the approach of the company—with or without the cloud, local or distributed, make or buy—one thing is critically important: these supply chain enablers need to be connected to the machine OEM and the users of the technology, in order to understand the part requirements, the material and process parameters, and the ability to qualify their production processes.

GE Additive's Customer Experience Center in Pittsburgh Pennsylvania

[14] www.fastradius.com/news/ups-announces-the-fast-radius-on-demand-manufacturing-facility-in-singapore

Qualification and policy

Qualification and quality assurance are necessary for the market adoption of additive technologies. GE has extensive experience operating multiple AM processes and scaling production across a variety of industries. This experience allows us to provide unique AM insights. Included in this experience is the manufacture of additive parts for highly regulated industries, such as aviation and healthcare, where regulatory approval of additive parts is often required.

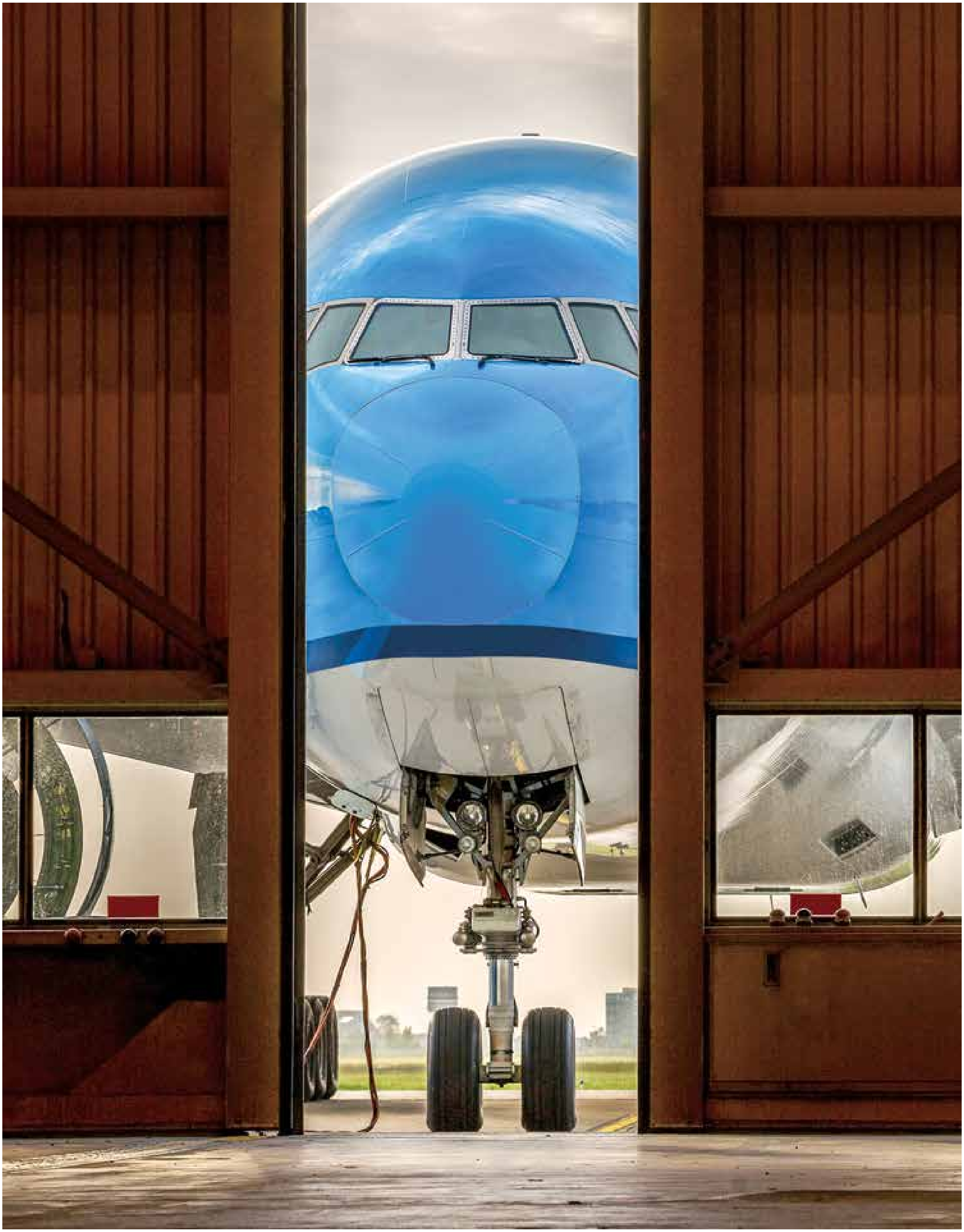
GE Aviation achieved Federal Aviation Administration (FAA) certification of its first additive manufactured part in April 2015. There are now two more FAA-certified additive parts, and at least 20 additional parts are included in active certification projects. GE Aviation has already produced over 23,000 flight-quality additive parts. FAA regulations, policy, and guidance for additive continue to evolve, which in turn, impacts the adoption of industry specifications. We understand that the FAA plans to release several advisory circulars offering guidance on how to comply with FAA regulations for those who make or use additive parts and products. GE is working closely with many of the industry groups that are developing AM standards and specifications. With substantial experience certifying AM components, GE Aviation has developed rigorous internal procedures and valuable knowledge of the additive regulatory process.

> "GE Aviation has already produced over 23,000 flight-quality additive parts."

Healthcare is another heavily regulated industry that requires certification of additive parts, particularly by the U.S. Food and Drug Administration (FDA). Current FDA guidance on AM focuses on design, production, and process-related recommendations regarding the use of AM components in a wide variety of medical devices, from sophisticated imaging machines to implants.

For metals today, the implants themselves are medical devices and require qualification. Today, only Arcam, a GE Additive subsidiary, has customers that have received 4 CFDA (China FDA) certifications on standard metal AM implants. This type of certification and qualification is growing in importance for additive customers. A robust quality management system for additive healthcare customers will monitor the entire workflow from image acquisition on modality consoles through post processing on advanced visualization workstations ensuring that printed medical models follow FDA policies so the printed part may be used for diagnostic purposes. Materialise recently became the first company to receive FDA clearance for the post processing portion of this workflow for 3D printing software used to create diagnostic anatomical models.[15]

Emissions regulations impact GE Transportation and GE Power also. Similarly, the automotive industry has been driven to gain more efficiency to meet Corporate Average Fuel Economy (CAFE) regulations. While these regulations currently are in a state of flux in the United States, clean air and emissions regulations continue to be a focus in other parts of the world. The ability to re-design and reduce weight translates to the ability to redesign at the system level. This enables organizations to gain new fuel and/or air efficiencies than previously imagined.



[15] www.materialise.com/en/press-releases/materialise-first-company-to-receive-fda-clearance-for-diagnostic-3d-printed

Workforce and culture

Any company that chooses to bring AM in-house will have to invest not only in the plant and equipment, but also in the workforce. Team members need to be trained to design and produce parts with these new technologies. Some of this learning happens on the job, but educators are increasingly incorporating AM into engineering and design curricula and technical training programs to serve these needs.

One thing is clear: the global manufacturing sector is changing rapidly, making education and workforce training even more important. Tomorrow's workers will need the knowledge and skills to use these evolving tools effectively. Additive is a culture change and managers need to take steps to bridge the workforce's growing knowledge gap.

Nearly three in four business executives surveyed for the GE Global Innovation Barometer said a lack of adequate skill sets is an issue their industry is facing. It is the responsibility of the private sector working with governments and educators to help close this gap. Advanced training and education is critical to ensure current and future workers have the knowledge and skill sets needed to use these new technologies effectively.[16] GE is acutely aware of this and is taking steps to help. We are investing $10 million over five years in educational programs to deliver polymer 3D printers to primary and secondary schools as well as metal 3D printers to colleges and universities around the world. It is estimated that 180,000 students worldwide now have access to 3D printers because of this education program.

Students participating in the GE Additive Education Program now have access to AM equipment and curriculum. BLT Senior Elementary School

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But that is not by chance. Decades of research and development by academics and companies have led to this point – a truly amazing global opportunity. We do not expect the additive industry to stand still – the journey will and needs to continue.

GE is committed to leading the industry through world-class additive machines, materials and services—accelerating innovations across industries and helping the world work smarter, faster and more efficiently. We have worked tirelessly to build a network of people who are advancing AM every day.

At GE Additive, we're passionate about the transformative value of advanced manufacturing. As the world's biggest user of additive technologies, we have seen first-hand how powerful the technology can be to both the top line and bottom line of an organization. Our goal is to help our customers and industry partners unleash the real benefits of the technology by assisting in every step of their journey – from the initial exploration steps of establishing a business case evaluation and design through production, part qualification, and supply chain disruption. Today, we make parts using additive technologies that we never would have dreamed of just a few years ago. Our own journey continues to be an amazing one. Only now, we're also helping other manufacturers realize their vision, too.

[16] 2018 GE Global Innovation Barometer survey - https://www.ge.com/reports/innovation-barometer-2018/

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