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Metals 3D printing

**Closing the
cost gap and
getting to value**

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EXECUTIVE SUMMARY

Although 3D printing has captured imaginations everywhere and is moving toward the mainstream in making plastic components, it has yet to take off in mass production of metal parts. However, we believe this is changing rapidly. We expect metals 3D printing to disrupt many existing manufacturing processes and to become a fundamental part of how we make metal products in the digital age.

The technology — also known as additive manufacturing (AM) — has formidable potential across the manufacturing landscape. It enables products to be made on demand, at point-of-use, and with very efficient material usage. The metals share of the market is very small now, but it is expected to grow at 20 percent compounded annually, almost twice as fast as more mature plastics AM, and faster than traditional manufacturing.

While AM's primary use to date is in rapid prototyping, tooling, and production of replacement parts, leading practitioners are shifting their ideas about the technique. Increasingly, they see it not only as a substitute for traditional production techniques but also as a way of rethinking the supply chain to unlock substantial value. They also see that AM can scale cost-efficiently to serve high-volume needs.

Today there are three primary metals AM technologies: powder bed; deposition; and binder jet, all at different stages of maturity and capability. PwC sees a distinct metals AM supply chain taking shape: material suppliers developing unique powder alloys; machine manufacturers; software suppliers; services businesses to help industry learn how to gain value from AM; and AM machine operators.

Acknowledging AM's well-known benefits to the supply chain, PwC emphasizes its potential to optimize functional design and leverage materials properties. For example, AM can sharply reduce component weight and cut parts counts — improving the performance of the systems into which AM-made parts are assembled.

To date, these types of value propositions in metals have involved complex, low-volume parts, but PwC's analysis suggests that the same economic arguments can apply to simple metal parts that have relatively low design costs and higher volumes. The economics of AM start to look far more favorable when the technique is viewed as more than an isolated production stage.

To help manufacturing business leaders identify where metals AM offers them the greatest economic value, PwC pinpoints five value propositions, from the high impact of system value and performance (entailing the redesign of an entire production system) to the downstream impacts on the service and aftermarket supply chains.

Recognizing that metals AM is still relatively expensive, PwC breaks down AM costs compared with those of traditional manufacturing for two types of aerospace parts, and flags some of the strategic questions that business leaders must ask themselves if they are to understand how to integrate AM into their supply chains.

A promising future for 3D printing of metals

For more than a decade, additive manufacturing has generated enthusiastic coverage in the media and among manufacturers. AM, otherwise known as 3D printing, has captured imaginations with its promise to manufacture at point-of-use, on demand, and with efficient material usage through product or system design optimization, in ways not possible through traditional “subtractive” manufacturing.

The concept has been widely embraced as an alternative to traditional production techniques, such as forging, casting, injection molding, and machining. Compelling examples of lower-volume and often exquisitely detailed AM parts can be seen in aerospace engines and medical and dental implants.

However, most of AM’s practical use to date is in the rapid prototyping, tooling, and production of replacement parts. Moreover, much of the activity thus far has been with plastics and polymers; the technical and economic challenges of working with metals, glass, ceramics, biomaterials, and composites mean that progress with those materials has been slower.

The truth is that, for most manufacturers, the technique has yet to live up to its potential to fundamentally transform the supply chain — especially when it comes to producing metal parts in high volumes.

Now, leading practitioners are shifting their views on AM. Increasingly, they see it not only as a substitute for traditional production techniques but also as a way of rethinking the supply chain to unlock substantial value. They also see that AM can scale cost-efficiently to serve high-volume market needs.

The authors of this Viewpoint contend that progress on all fronts — across many component types and manufacturing settings, and in metals in particular — can and will accelerate if business leaders have a wider vision of AM’s economics. The manufacturing scenarios highlighted below demonstrate where AM can transform the value chain.

Sizing the AM market

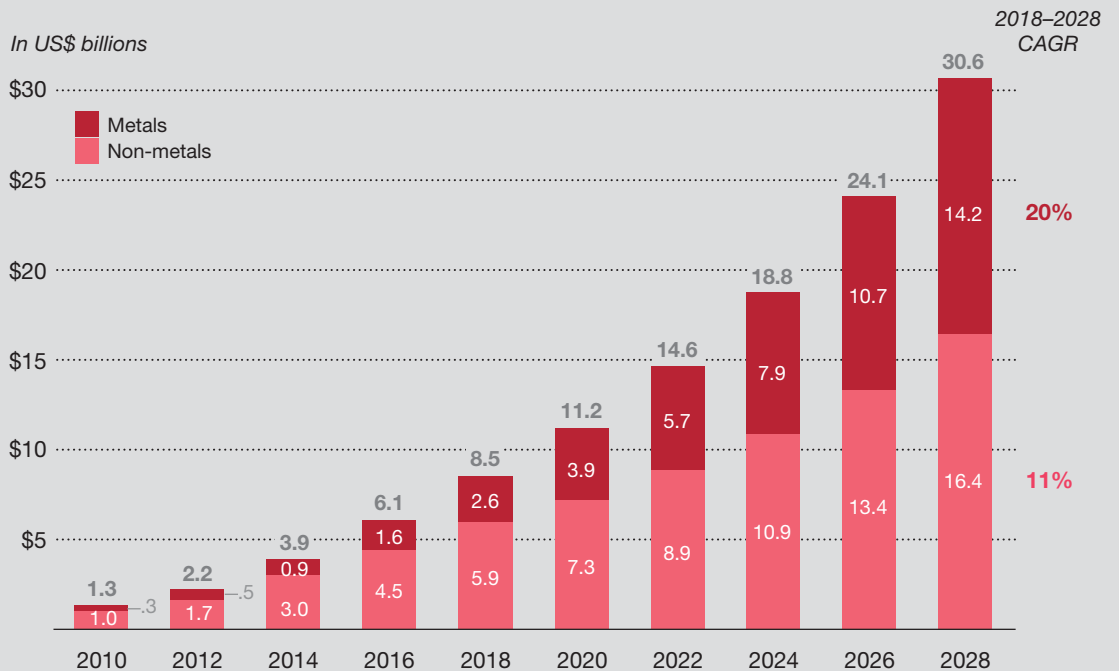
In 2018, the market for all AM activity in plastics and metals — including machines, powders, and services — was worth US\$8.5 billion (see *Exhibit 1*). The metals share of that — valued at around \$2.6 billion — is expected to grow at 20 percent compounded annually, almost twice the pace as that of plastics, and faster than that of traditional manufacturing. The AM metals market is still in its infancy; broader adoption is just starting.

But the potential to add value is absolutely enormous: Across the aerospace and defense, medical/dental, industrials, and automotive sectors, the total value of parts that could be additively manufactured using currently available tools and techniques is close to \$0.5 trillion — about a quarter of the value of everything produced in those industries today.

EXHIBIT 1

The metals AM market is set to grow twice as fast as that for plastics

Estimated additive manufacturing market size



Note: "Metals" Includes metal additive machines, powder metal inputs, design and manufacturing services for metal parts and products
 Source: Wohlers Report 2017; Strategy& analysis

Three key AM technologies

Three types of metals AM technologies are at various stages of maturity in today's market:

Powder bed technologies are the most widely used; they yield a high-quality surface finish as layers of metal powder are melted to become a finished part. Powder bed capability is expanding, for example with the introduction of faster equipment, such as multi-laser machines that can print larger parts.

Deposition processes are advancing quickly and attracting significant interest and investment. The technology's potential benefits are dramatic: It can produce parts of all sizes, lay down material at higher speeds, use lower-cost material such as readily available wire, and add features to existing parts. Automotive vehicle frames and large internal structures for aircraft lend themselves to this method.

Least developed is **binder jet** technology, which is analogous to inkjet printing and 3D printing of plastic. It deposits metal powder with a binding agent. Binder jet has the potential to increase production speed tenfold (compared to traditional manufacturing methods and to the two AM technologies just mentioned) across many sizes of components that are larger and more complex than what is being produced in powder bed today.

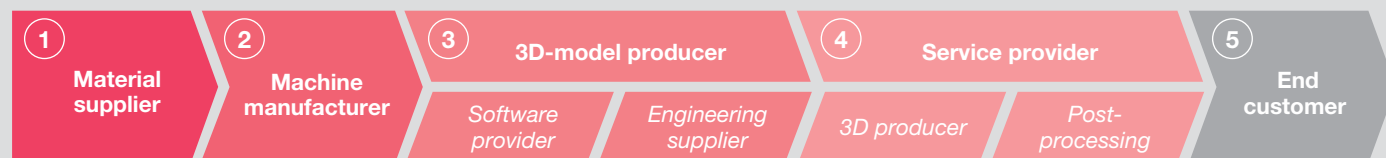
Each segment of the metals AM value chain is evolving rapidly (*see Exhibit 2, next page*). For instance, raw material suppliers are developing unique powder alloys and improved powder manufacturing processes, expanding the range of raw material types and costs. Machine manufacturers are innovating to make larger, faster, more efficient, and more accurate machines. Software suppliers are developing more advanced and automated conversion software.

Meanwhile, engineering and production services businesses are emerging to facilitate and support AM demand — and could become one of the largest segments of the market. Because metals AM is still in its nascent stages, most of today's AM machine operators are traditional OEMs and product integrators. However, specialty AM competitors are starting to evaluate how to build an AM business, and research and potential investment are going into the buildout of AM contract manufacturing capabilities.

But AM still has a long way to go if it is to be cost-competitive for higher volumes. Players in every segment of the value chain must do more to optimize their business processes.

EXHIBIT 2

If AM is to be cost-competitive for higher volumes, players all along the value chain must optimize business processes



VALUE DRIVERS (SELECTION)

<ul style="list-style-type: none"> Innovative materials Material norms Recycling Material scalability 	<ul style="list-style-type: none"> Speed Dimension Spatial resolution Material processing Material-linked process parameters Loading/unloading printer 	<ul style="list-style-type: none"> Topology optimization Product lifetime simulation Manufacturing cost calculation Security of infringement 	<ul style="list-style-type: none"> Design thinking TCO calculation Security of infringement Structure-material optimization 	<ul style="list-style-type: none"> Design/model platforms Global footprint Quality standards/certifications Complementing traditional manufacturing skills 	<ul style="list-style-type: none"> Surface finishing Adjustment to 3D-P material Cost of processing Speed 	<ul style="list-style-type: none"> Performance improvement New design option Flexibility, speed, and agility Customization Simplification Availability of spare parts
<ul style="list-style-type: none"> Material — machine interactions Material — machine alignment Flexibility 	<ul style="list-style-type: none"> 3D-P design Digital file translation Model auto-correction Output prediction 	<ul style="list-style-type: none"> Process integration Operational efficiency (speed, cost, and flexibility) Enhancement of product properties Third-party services, e.g., with printing farms 				

Source: PwC's Strategy&

Additive manufacturing's value proposition: Five compelling cases

AM's well-known benefits to the supply chain include shorter time-to-market for new products, improved supply-chain efficiency, on-demand production, lower inventories, less material waste, and the ability to rapidly prototype and redesign. What is far less familiar is the technique's significant potential to optimize functional design and leverage materials properties. For example, AM can reduce component weight (by as much as 70 percent in some cases) and reduce the number of components — consequently improving the performance of the systems into which AM-made components are assembled.

To date, these types of value propositions in metals have involved complex, low-volume parts, but PwC analysis suggests that the same economic arguments can apply to simple metal parts that have relatively low design costs and higher volumes. In the aerospace and medical equipment sectors, for example, even “cheap” components tend to cost more than equivalent parts in, say, the high-volume automotive industry.

As with any emerging technology, there are barriers to wider adoption: the cost of initial investment, technological maturity, organizational resistance, and unbounded risks such as data security. In many cases, the cost of metals AM has not yet achieved parity as a substitute for traditional manufacturing techniques, even in the case of highly complex, small-batch components.

PwC believes that AM can and will unlock tremendous market value. The economics of AM start to look much better when the technique is viewed as more than an isolated production stage, as illustrated in the following transformative value propositions, ranked from high to low impact:

- **System value and performance:** redesigning an entire system (e.g., GE's Advanced Turboprop Engine) to drive immense, compounding improvements to part count, weight savings, and system performance. Full system redesign is the hardest to adopt, given product lifecycle timing, industry regulation, and the huge upfront investment.
- **Part value and performance:** focusing on individual and individualized parts, such as medical implants or aerospace brackets. AM allows for more optimized part design (lower weight, improved performance), rapid adoption and lower delivered cost for certain applications.
- **Product customization:** tailoring emerging applications for smaller-batch, short turn-time applications, such as customized, patient-specific medical implants. AM goes beyond assembly-to-order and configure-to-order, delivering part-level customization.
- **Supply chain and operations:** restructuring a supply chain and satisfying demand at the point of consumption (e.g., production line), reducing overall logistics, reducing lead times, serving unplanned demand, and enabling real running changes. AM enables a new era of responsiveness.

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- **Service and aftermarket:** printing of spare parts close to the point of demand to address obsolescence concerns or diminishing supply base. AM is a practical solution to efficiently manage the long tail of support needs.

Not every value proposition will have equal value to every industry or product. For example, product customization is particularly well suited for medical/life sciences and niche industrial applications, while system value is more likely to apply to the higher-value, lower-volume products typical of the aerospace and defense (A&D) business and of some high-end segments of the automotive industry. (See *Exhibit 3, next page.*)



The economics of AM start to look much better when the technique is viewed as more than an isolated production stage.”

EXHIBIT 3

Different industries are likely to experience different values from AM

Industry	Example transformative value proposition	TRANSFORMATIONAL VALUE PROPOSITION				
		System value	Part value	Customization	Supply chain	Aftermarket
Auto	Redesign powertrain to improve efficiency					
	Redesign systems for performance improvement	●	●		●	●
	Redesign vehicle components for reduced weight					
	Produce specialized aftermarket parts					
Medical	Optimize design for new, innovative products					
	Rapid manufacture of in-house, unique parts		●	●	●	
	Consolidate operations footprint					
Industrial	Increase uptime and reduce operations footprint by printing aftermarket unique spares in the field	●		●	●	●
	Produce unique and custom parts in-house					
	Optimize design of complex systems					
A&D	Optimize total system design to reduce part count, assembly time and complexity while increasing performance (weight, time on wing, etc.)	●	●		●	●
	Manufacture unique spares and simple parts in-house, on-site, and on-demand to drive more efficient supply chain					

● Dominant value proposition
● Secondary value proposition

Source: PwC's Strategy&

Where is the economic value — today and in the future?

Currently, metals AM is a costly solution compared to traditional manufacturing, especially when factoring in the cost of redesigning or converting parts for AM. However, as AM adoption increases, material costs are decreasing and printing technology is improving, closing the gap with traditional manufacturing methods for many components. PwC looked at how AM costs compare with those of traditional manufacturing for two types of aerospace parts (see *Exhibit 4* and *Exhibit 5*, next page).

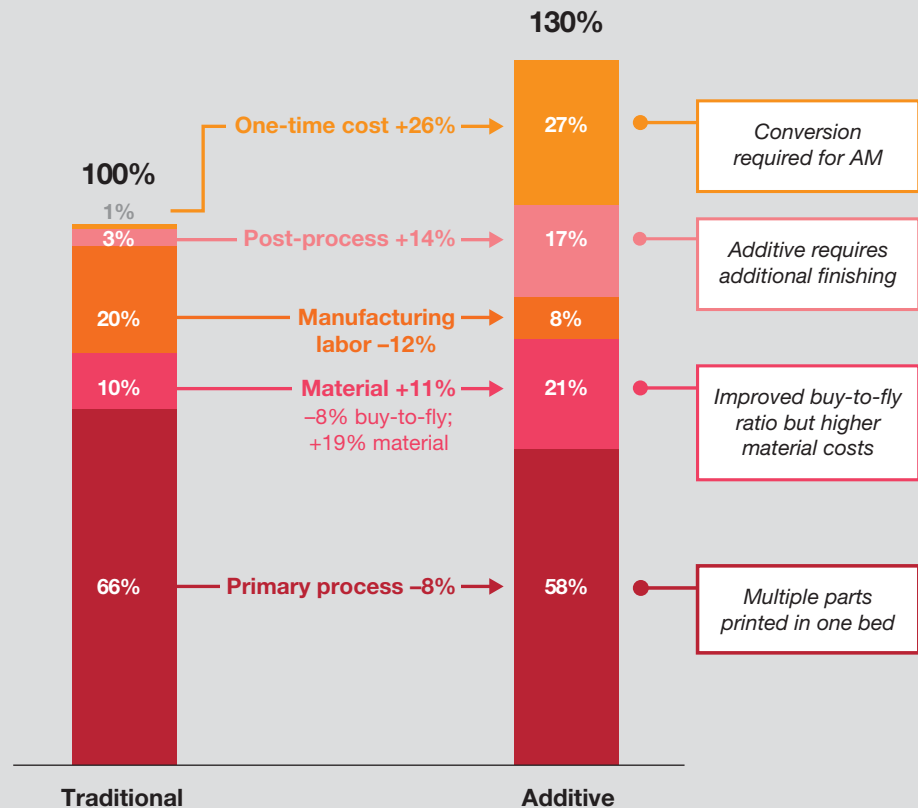
Exhibit 4 shows the cost comparison of a moderately complex, machined bracket with a production run of 1,000 units. This is a simple part conversion; there are one-time costs to

EXHIBIT 4

Cost of AM is less favorable when design is not optimized

Costs for aerospace titanium machined bracket

(Example of a part conversion for a production run of 1,000 units)



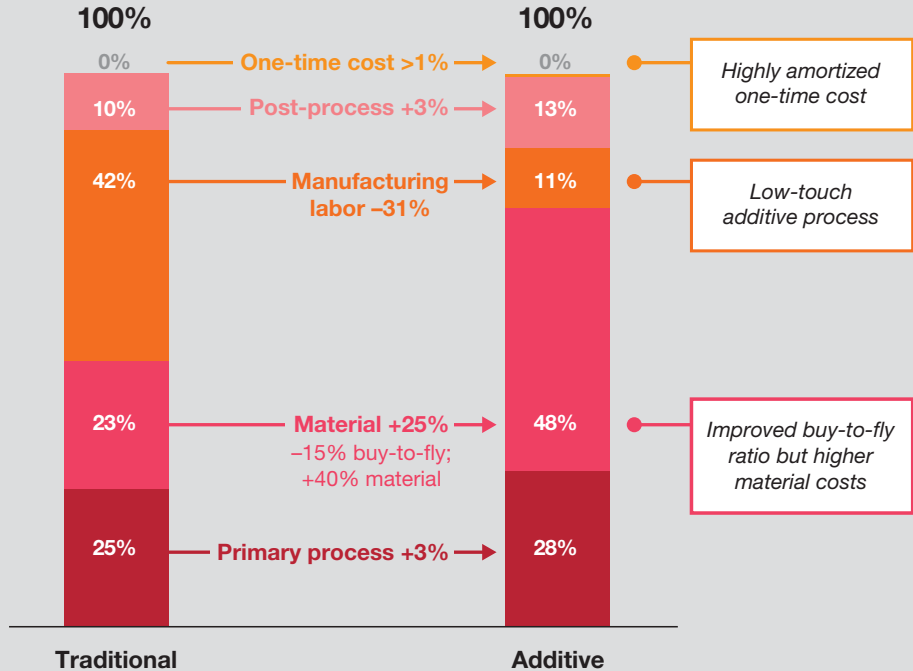
Source: PwC's Strategy&

convert the part for AM, but design is not optimized for AM capabilities (e.g., minimizing material volume to decrease weight). In this example, AM and traditional machining have similar cost profiles. However, if volumes are low, the one-time design conversion cost makes AM about 30 percent more expensive.

Exhibit 5 shows a simple aerospace aluminum sheet metal bracket that has been completely redesigned for AM. There are thousands of these types of brackets on an aircraft. Often costing US\$50+ per unit, they have a high annual production value in aggregate. Modest redesign costs are amortized over millions of units, bringing AM of this simple part to parity with traditional manufacturing. Improved “buy to fly” costs and lower-touch labor (highly automated process, little machine setup time, limited operator handling, etc.) are among the benefits, although those are offset somewhat by material costs that are higher today but declining rapidly.

EXHIBIT 5
AM closes the cost gap when part is fully redesigned

Costs for aerospace aluminum sheet metal bracket
 (Example of a part redesign for a production run of 2 million units)

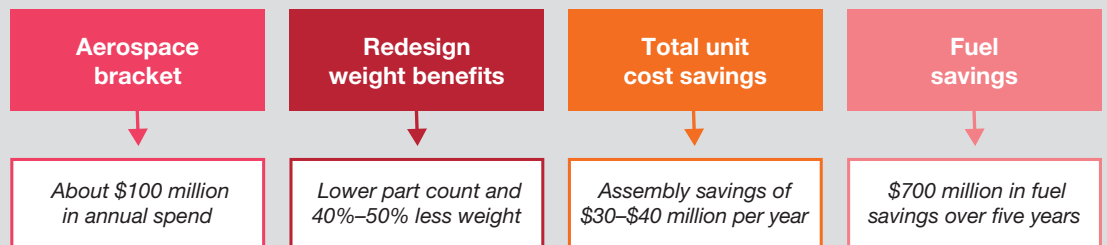


Source: PwC's Strategy&

In general, simpler parts are easier to redesign and can make AM cost-effective even now, while giving manufacturers opportunities to learn how to optimize the use of AM. Yet, this is still not how most manufacturers are exploring the benefits of AM. As the technology matures, costs will decrease and make AM increasingly competitive for more complex and lower production-rate parts.

To be sure, there are already many examples of high-value, complex, low-rate parts that have been successfully additively manufactured. These successes came with consideration of the total lifecycle economics involved — that is, AM’s contribution to the improved performance of the system of which the component became a part. In the example of the aluminum sheet metal bracket, a 40 to 50 percent weight savings through component redesign and optimization could yield \$700 million in fuel savings over five years for one single-aisle aircraft produced in high volumes (see *Exhibit 6*). Extending that idea: Streamlined assembly with fewer AM-made parts could result in total savings of \$10 billion to \$20 billion over the life of a large-scale airplane program.

EXHIBIT 6
Example of aerospace bracket redesign to suit AM



Source: PwC's Strategy&

Toward a new economic model for metals manufacturing

Most manufacturers are still at the experimentation stage with AM. It's not yet clear how they should, or can, integrate the technique into their established production setups. The transition is not simple. It begs a *strategic* company-wide decision that calls for alignment of the entire enterprise. That extends to the company's investment choices, the extent to which it has (or can rapidly develop) an innovation mindset, and its ability to plan for risk contingencies.

Some of the most pressing questions that manufacturing business leaders must consider include:

- What types of parts can be additively manufactured? What are the economic benefits?
- What is AM's impact on our business strategy and operating model?
- Should the AM strategy be centralized or distributed across our business?
- Who should produce the components/systems (OEMs, Tier 1s, service bureaus)?
- What is the impact of AM on the structure of our supply chain?
- What are the regulatory considerations and barriers to overcome?
- What is the best way to get started?

Before moving to AM, companies must first understand where they can expect the greatest economic advantage. They need a kind of "additive in a box" economic model — an easy-to-use diagnostic tool that quickly enables manufacturing executives to shortlist the types of components that might best lend themselves to AM. At the same time, manufacturers need to pull back to think strategically about how to design the optimal AM operating model. Part of that exercise calls for identifying the business capabilities needed to infuse a new technology into traditional business models.

As metals AM continues to evolve, manufacturing industries will embrace the technology as a fundamental and critical part of the value chain. That point is getting closer by the day — unlocking more and more value as it does so, en route to fundamentally changing the way we manufacture.

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