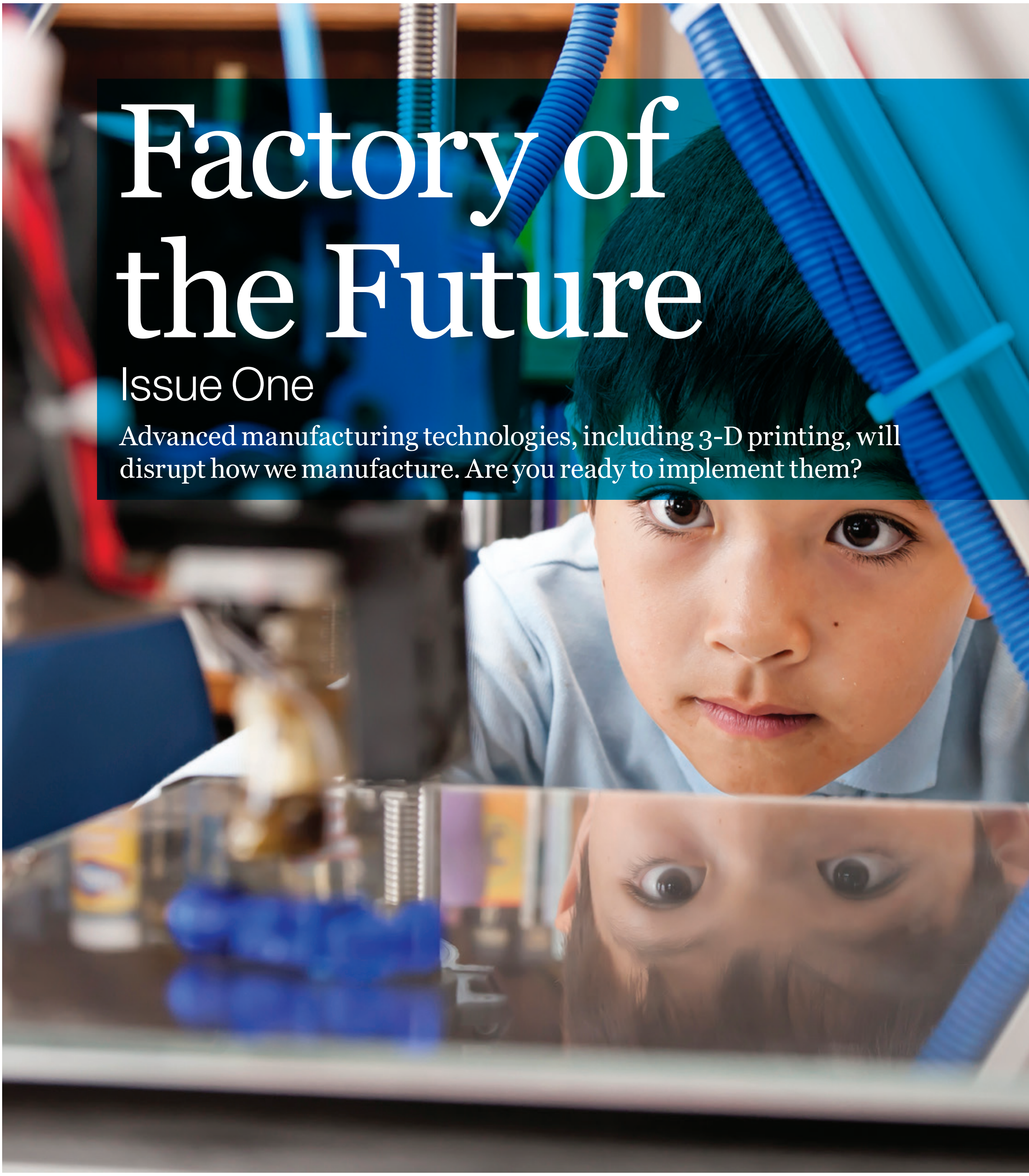
McKinsey&Company

Operations Practice

Factory of the Future

Issue One

Advanced manufacturing technologies, including 3-D printing, will disrupt how we manufacture. Are you ready to implement them?



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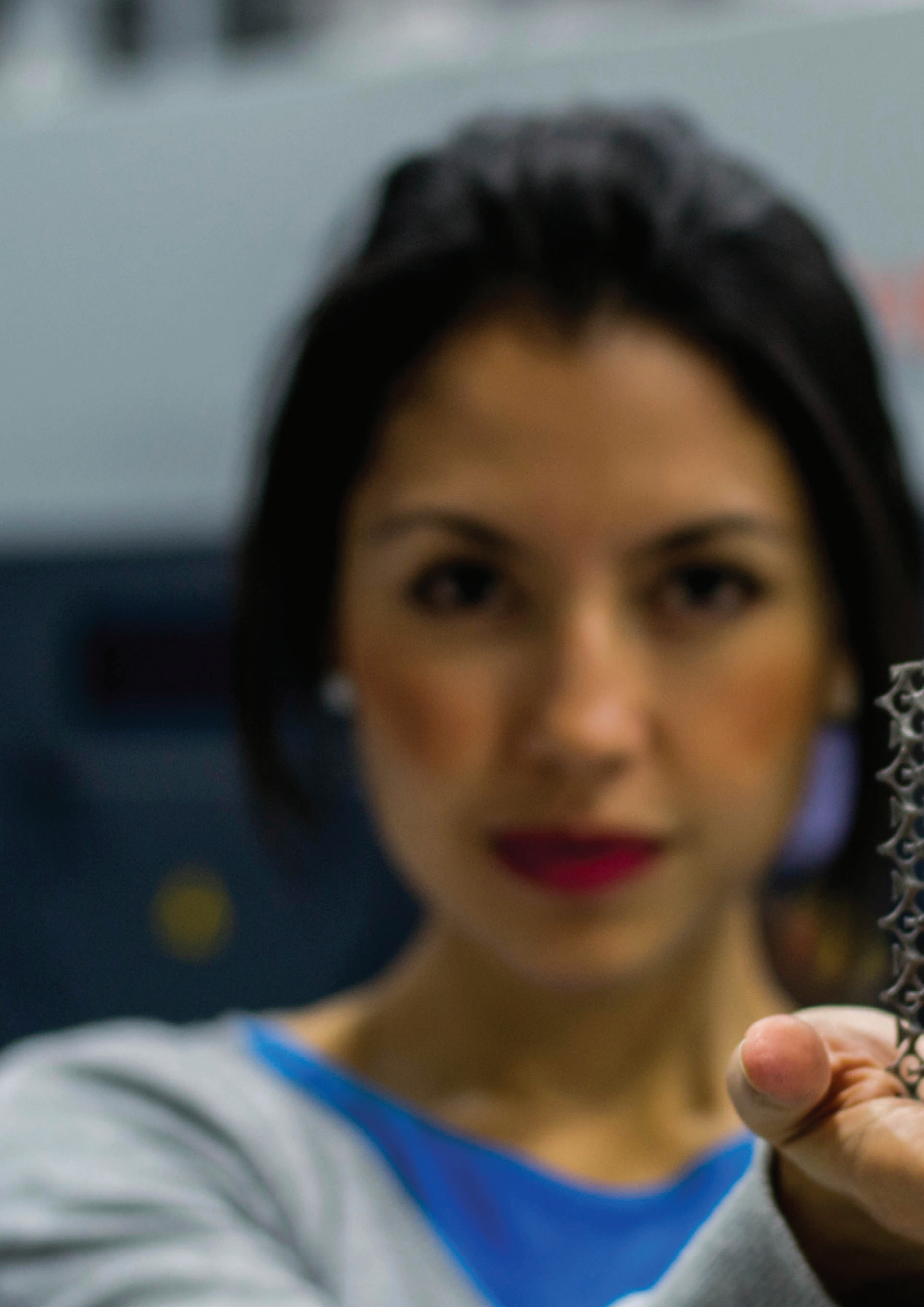
Ben Sheppard
Colin Shaw
Barry Williams
John Persaud
Jörg Bromberger



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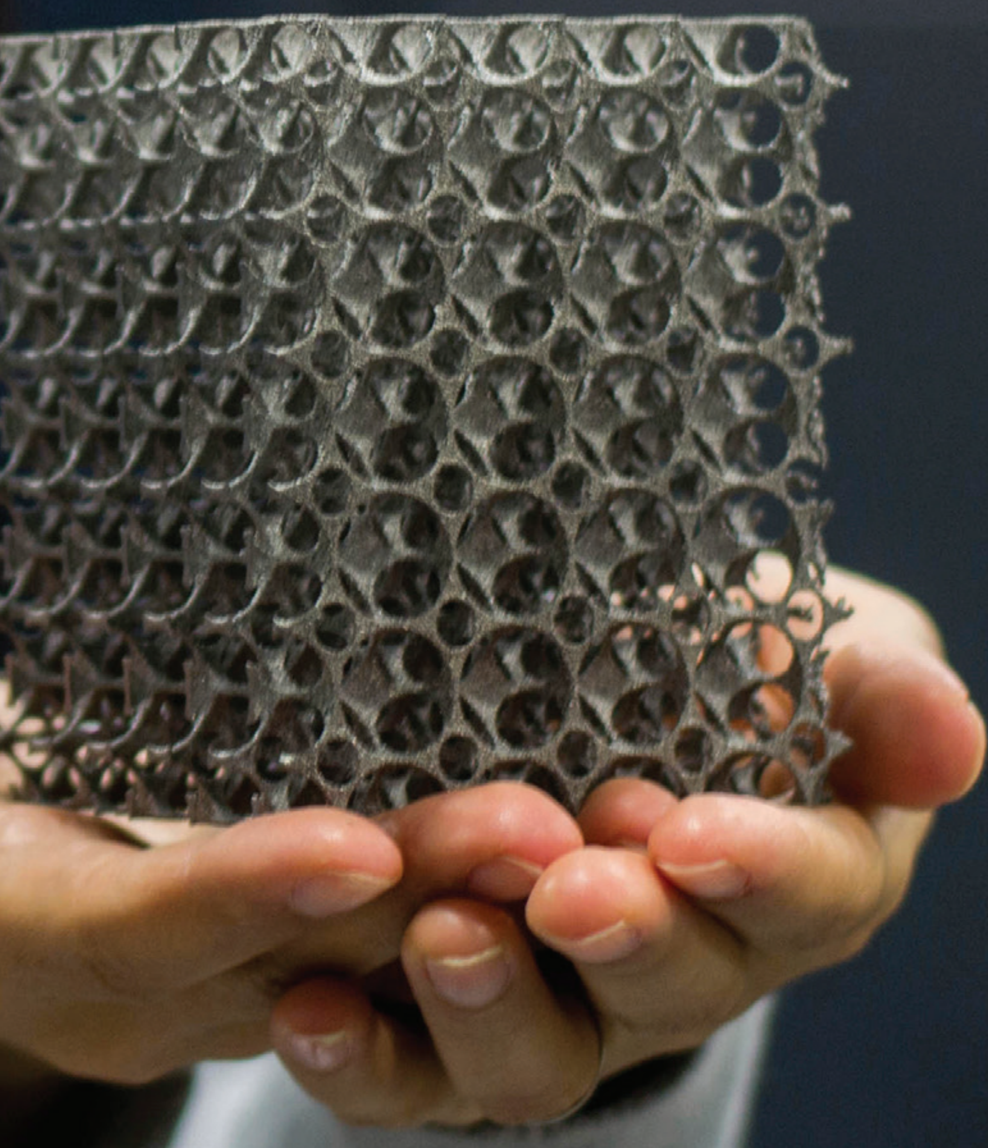


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Introduction

Executive summary

Manufacturing is going through one of its greatest periods of change since the Second World War. The manufacturing technologies used to shape, join, finish, and measure components are changing dramatically after decades of more incremental evolution.

The landscape of these advanced technologies is rapidly shifting and poorly mapped. Through a process of extensive interviews with manufacturing managers and experts, we have compiled a list of the 25 technologies with the most potential for impact this decade. Of these, additive manufacturing (AM, commonly referred to as 3-D printing) and metal injection molding (MiM) have the broadest potential for cross-industry disruption. Metal injection molding is ready for widespread adoption now, while the tipping point for additive manufacturing for the majority of companies is still five to ten years away for full-scale production.

Choosing to implement one of these new technologies is no small undertaking: the cost of a poor transition can wipe out the potential savings and cause production delays. Less than 10% of companies today possess a robust capability for moving rapidly from a manufacturing strategy through technological identification and prioritization to implementation. However, those who succeed have a competitive advantage through increased flexibility, reduced costs, and a shorter time to market.

Introduction: the shape of things to come

If you visited a manufacturing shop floor in the 1960s, you would have seen a small army of technicians working on lathes, milling machines, presses, and casting equipment. Jump forward half a century, and what has changed? Hopefully, the value stream is leaner with less waste, there are visual management processes in place, inventory and order management are slicker, and a degree of automation has been introduced. However, the machines themselves are still recognizable from their 1960s predecessors. They have evolved and improved but, in many cases, are still based on the same twentieth century principles *(Exhibit 1).*

Exhibit 1

Similarity between shop floors in manufacturing value chains in the 1960s and 2000s

1962

Image courtesy of Eastside Community Heritage

2014

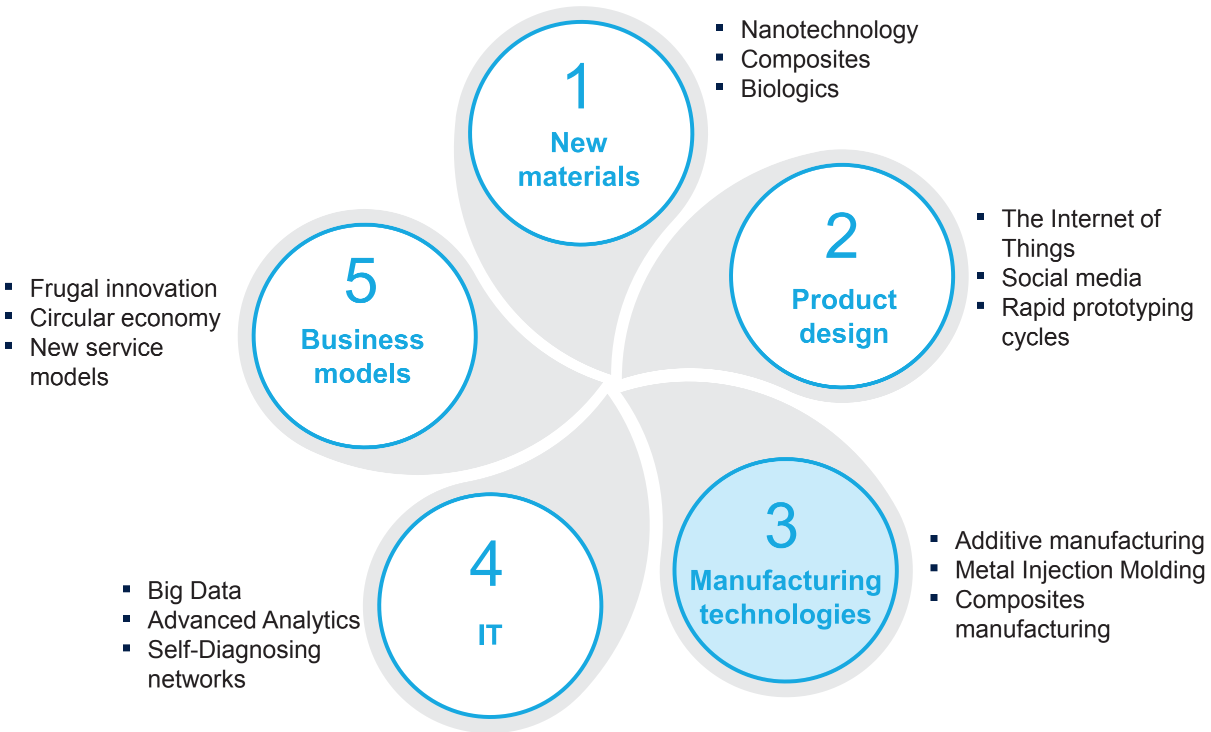
Image courtesy of Turnxon Precision LTD

SOURCE: http://www.hidden-histories.org.uk; http://www.turnxon.com

That may be about to change. McKinsey has identified accelerated development across a broad range of manufacturing areas in the past three to five years: materials, product design, manufacturing technologies, IT, and business models *(Exhibit 2)*.

Exhibit 2

Factory of the Future: Five trends of rapid change in manufacturing



This paper focuses on advanced manufacturing technologies. Additive manufacturing has put this field into the limelight, and over the past 12 months, McKinsey has received more questions from COOs and manufacturing executives about advanced manufacturing than about any other of the five areas mentioned above.

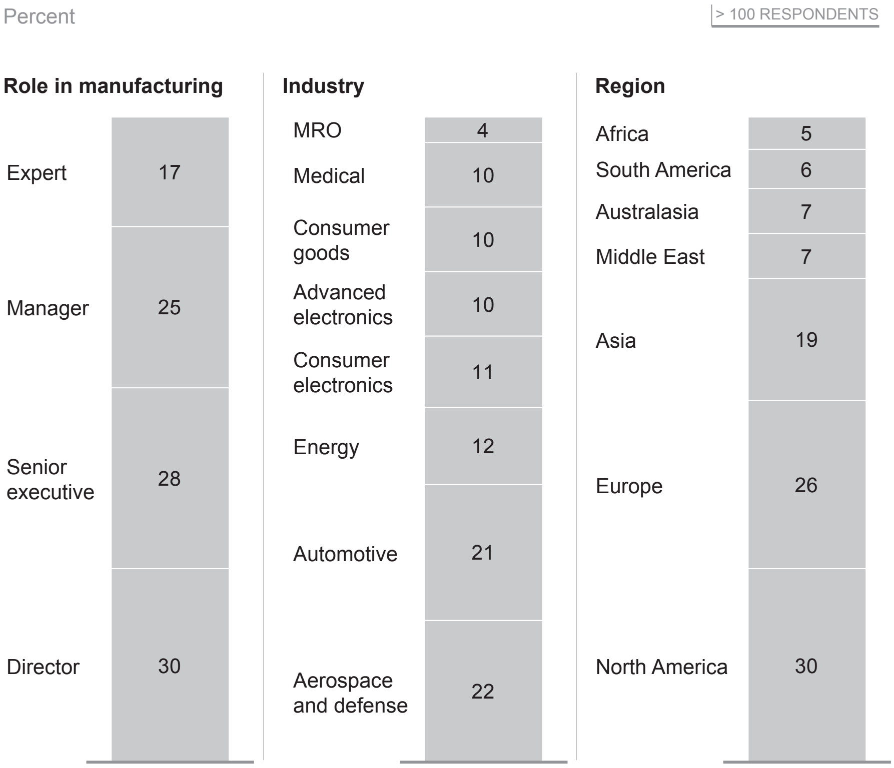
1 The advanced manufacturing technology landscape

Advanced manufacturing technology is a notoriously difficult field to track and manage. Technologies are constantly evolving and emerging. Technical operational data for new equipment is scant and not readily comparable across suppliers. Descriptions of maturity, cost, and readiness for adoption are sometimes skewed by suppliers and media. In order to develop a robust and independent perspective on which technologies matter the most, we have interviewed and surveyed over 100 top manufacturing leaders from broad geographic and industrial backgrounds *(Exhibit 3).*

Exhibit 3

Background of survey and interview respondents

Percent



SOURCE: McKinsey Advanced Manufacturing & Assembly survey

We identified 25 technologies to watch. These are either fundamentally new or have recently gone through a cycle of such improvement that they offer performance in a different league compared to previous-generation equipment. Benefits include reduced tooling cost, improved precision, faster production time, and greater flexibility *(Exhibit 4).*

This broad collection of technologies spans shaping, joining, finishing, and measurement. It ranges from the widely documented field of additive manufacturing to the lesser known F3T sheet stamping process, invented by Ford, which allows sheets to be stamped without the need for tooling.

Exhibit 4

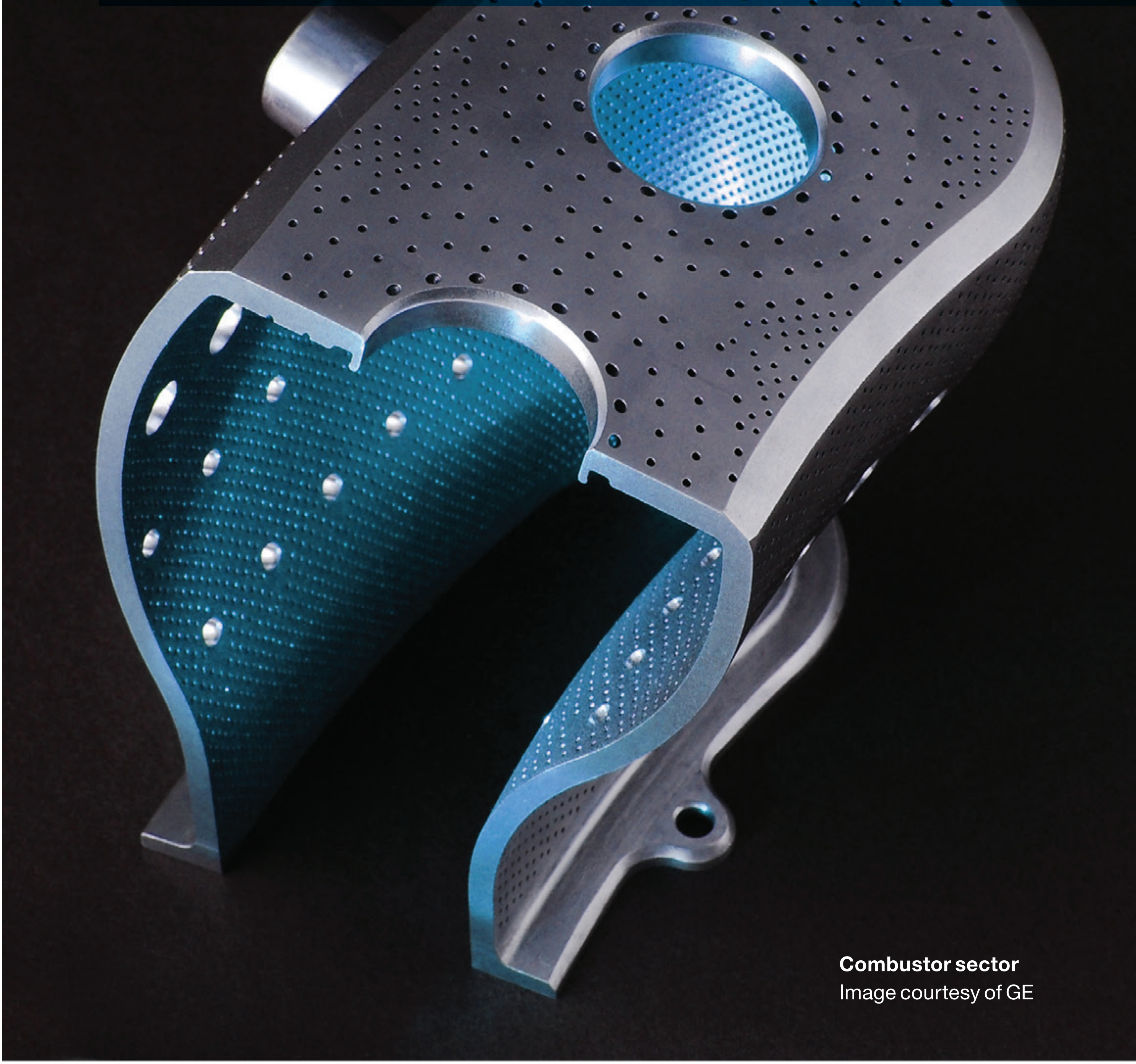
25 advanced manufacturing technologies rated by impact by survey respondents

Category		Technology	Reason for inclusion
Shaping	**Mass reducing**	Electric discharge milling	Has improved greatly in recent years. Used to create holes where cutting tools can't
		Combination mill/ turn machining	Application is growing dramatically in some sectors as single use machines are replaced
	Mass conserving	Metal injection molding	New application for plastic injection molding processes. Reduces needed for further finishing steps
		KIS (injection molding tool consolidation)	Unique injection molding process from Daimler, with potential for expansion to other companies and industries
		Hydroforming	Relatively mature in aerospace and automotive, but underused in other industries
		Electromagnetic forming	Several advantages over conventional mechanical forming (for conductive material only)
		F3T sheet stamping	Tool-less sheet stamping. Currently unique to Ford, with potential for future expansion
		Carbon composites production	Lay-up equipment improving and potential for expansion outside of aerospace and automotive
		Metal foaming	New equipment with potential to create lightweight, strong structures
	Mass adding	Additive manufacturing	Widely believed to be the most impactful technology available today
Finishing	**Heat treatment**	Dual microstructure heat treatment	Can create 2 grain sizes in a single part with a single heat treatment process (NASA, Rolls-Royce)
	Surface finishing	Cold spraying	New technology for depositing a thin metal surface onto a part
	Other	Spray-on circuit production	Sprays copper traces directly onto a circuit board: potential to replace "print-and-etch" in the long term
		Waterless dyeing	New technology for dyeing textiles without water. Currently limited to polyester, but expected to grow

Category		Technology	Reason for inclusion
Assembly	**Welding**	Ultrasonic welding	Faster than conventional adhesives or solvents and can easily be automated
		Autonomous electron beam welding	The backscatter electron checking process is new
		Laser hybrid welding	Technology has existed since the 1970s but has only recently been used in industrial applications
		3-D lock seam welding	Developed by Honda; eliminates need for spot welding to join 2 panels
	Adhesive	Composite adhesive bonding	Improvements in automation, strength and allowable geometries are expanding the scope of this joing technique
		Composite co-curing	Eliminates 1 process step. Will grow as the application of carbon fiber grows
	Soldering and brazing	Ultrasonic soldering and brazing	Removes the need for a flux around the solder by vibrating off oxides
		Lead-free soldering	Environmental legislation leading to rapid growth. Combination of new material and better manufacturing techology
Measure-ment	**Hybrid**	Portable laser/CMM measurement	New scanning technology is getting faster and more reliable, e.g., FARO ScanArm
		Industrial boroscopy	The technology is not new, but a reduction in equipment size is leading to new uses
	Noncontact	Capacitive measurement	Increasingly able to sense the shape/quality of objects within packaging

SOURCE: McKinsey Operations Practice, expert interviews; McKinsey Advanced Manufacturing & Assembly survey

2 Top technologies: additive manufacturing (AM) and metal injection molding (MiM)



Combustor sector
Image courtesy of GE

If you only remember two technologies from this paper, they should be additive manufacturing and metal injection molding.

The importance of technologies varies by industry: spray-on circuit production holds great potential for the electronics industry, and composite adhesive bonding remains a focus for aerospace and defense. However, additive manufacturing and metal injection molding were consistently voted as the technologies with the most potential to further improve manufacturing across a broad span of industries and geographic areas *(Exhibit 5).*

Exhibit 5

Top 10 advanced manufacturing technologies

Low readiness
High readiness

Rank	Technology	Description	Overall impact[1]	Maturity[2]
1	Additive manufacturing	Build up parts from a powder or resin layer by layer	44	
2	Metal injection molding	Inject a metal powder and a binding agent into a mold	21	
3	Composite adhesive bonding	Adhesive bonding of 2 or more precured composite parts to avoid bulky joints	10	
4	Carbon composites production	Solid 3-D structures of lightweight carbon fibers bound in layers at high heat, pressure, and vacuum	10	
5	Spray-on circuit production	Spray a thin film of metal onto a circuit board instead of the traditional print-and-etch technique	9	
6	Lead-free soldering	Using a solder containing no lead to meet new environmental regulations	9	
7	Combination mill/turn machines	Cutting machines that drill holes in stationary parts, then create profiles by spinning the parts	8	
8	Cold spraying	Powder particles accelerated by a compressed-gas jet to thin metal film on an object	8	
9	Ultrasonic welding	High-frequency ultrasonic acoustic vibrations applied to work pieces to create a solid-state weld	7	
10	Capacitive measurement	Use capacitance sensors to sense the shape/quality of metal objects, even within packaging	7	

1 Percent of experts rating the technology as having high or very high impact on manufacturing over the next 0 - 5 years
2 Derived from the Manufacturing Readiness Level assessment

SOURCE: McKinsey Advanced Manufacturing & Assembly survey

Additive manufacturing

Additive manufacturing is a collective term for a range of technologies that build a component “from the ground up” by binding together powders, resins, or fluids into a single object. The main benefits are:

- There is little material waste in contrast to “subtractive” processes like milling.
- There is no custom tooling, which saves time and money, as well as allowing for the customization of each component printed.
- It is capable of making complex geometries, which are not possible using subtractive techniques.

Selective Laser Sintering (SLS) and Direct Metal Laser Sintering (DMLS) are the most widely used additive technologies for industrial applications, accounting for over 70% of the market. Fused Deposition Modelling (FDM) has become popular for consumer and smaller prototyping machines, due to the simplified workflow of not needing to empty or fill a powder bed. *(Exhibit 6).*

Exhibit 6

Overview of additive manufacturing technologies

Technology	Description	Primary material
Stereolithography (SLA)	A liquid resin is cured by exposing it to UV light	Polymer
Selective laser sintering (SLS)	Polymer powder (free of binder or fluxing agent) is completely melted with a high-power laser	Polymer
Fused deposition modeling (FDM)	A plastic filament is extruded through a heated nozzle	Polymer
Direct metal laser sintering (DMLS)	Metal powder is fused with a high-power laser	Metal
Jetted photopolymer (JP)	Inkjet print heads are used to deposit tiny drops of material, which are then cured by a UV lamp	Polymer
Laminated object manufacturing (LOM)	A heated roller adheres successive sheets of material together. A laser cutter then cuts an outline in each sheet	Paper
3-D printing (3D)	An inkjet print head deposits a liquid adhesive onto a powder bed to bind materials together	Polymer, metal
Inkjet printing (IP)	An inkjet print head deposits molten material. As each layer is completed, a grinding wheel flattens the top surface	Polymer
Laser metal deposition (LMD)	Nozzle sprays metallic powder into a laser beam, melting the powder in layers	Metal

SOURCE: McKinsey Manufacturing Practice

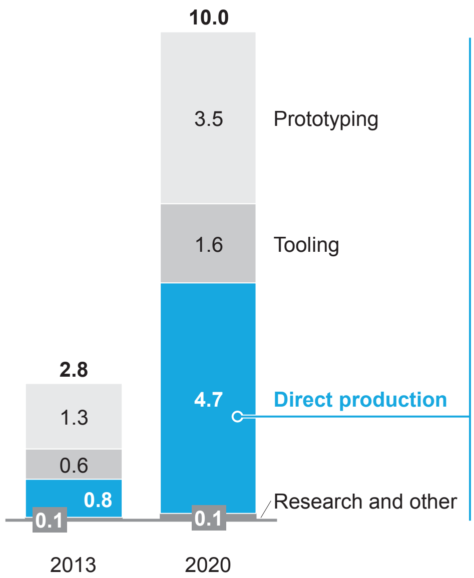
Despite its promise, additive manufacturing has taken 30 years to achieve widespread interest. However, we believe the technologies are finally reaching the tipping point, and the market for equipment and materials will grow from USD 3 billion in 2013 to USD 10 billion by 2020. The market for production parts is forecasted to grow at twice the rate of the market for prototype parts, which is an encouraging sign for the technology's maturity *(Exhibit 7).*

Exhibit 7

Additive manufacturing – global market size for equipment, materials, and services

USD billions

While the direct market is estimated to reach USD 10 billion by 2020, the full economic impact is predicted to be closer to USD 100 billion



- 2x higher growth rate in direct production compared to other categories
- Ratio of prototypes to production parts is typically 1:1,000; so, as strength in prototyping moves to direct production, growth will explode

Direct production parts from GE aviation

Image courtesy of GE

SOURCE: McKinsey

The industries leading the use of 3D printing are aerospace, defence, medical devices, high end automotive and luxury jewellery/fashion. This is mainly due to the freedom that additive manufacturing gives them to make low volume runs of complex parts quickly and cost effectively. Case examples of the impact include:

- **Better performance.** GE aviation is 3-D printing fuel nozzles that are 25% lighter and five-times more durable.
- **Faster time to market.** Ducati's development process for high-performance engines rapidly decreased from 28 weeks to eight weeks.
- **Customization at a lower cost.** Medical device companies like Anatomics have cut the cost of bespoke medical implants by 30 to 50% through reduced tooling costs and material waste.

Today, however, direct 3-D manufacturing is still limited to low-volume and high-cost/complex parts. There are three common limitations on the adoption of additive manufacturing:

Firstly, the **skill sets and processes** within many organizations are designed for reductive processes, and there is currently a limited talent pool with the necessary design skills for support structure design, powder release, and axis-specific precision.

Secondly, **material costs** are high. The powders used in additive manufacturing typically cost USD 50 to 200 per kilogram for steel and USD 400 to 800 per kilogram for titanium. Suppliers will often not guarantee part quality unless their own powders are used, effectively locking manufacturers into a single proprietary source. However, the recent entrance of lower-cost material suppliers from China (30% in some cases) will hopefully accelerate the fall in prices, increasing the affordability of additive manufacturing for medium-volume applications.

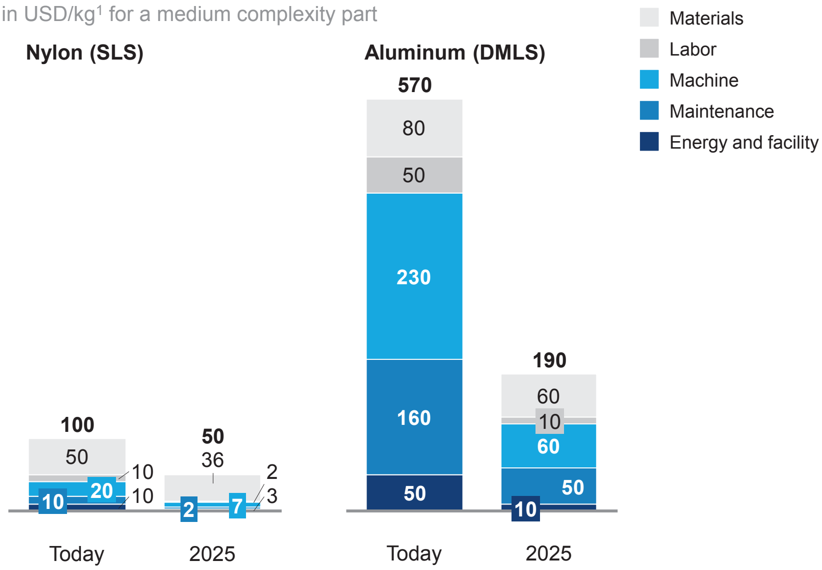
Thirdly, **build speed** remains slow. Few machines are capable of building faster than 200 grams per hour, resulting in low volumes and high associated labor and overhead costs. Increasing laser power and multiple lasers or print heads will increase speed in the coming years, but not to a level where additive manufacturing can compete with high-volume processes like injection molding or stamping.

In practice, these obstacles combined lead to total costs for in-house 3D printing of USD 500 to 1,500 per kilogram for steel and aluminum, and USD 100 to 300 per kilogram for plastics. The exact cost is heavily influenced by annual volumes, printer specifications, part geometry and the decision on whether to use OEM or third party materials *(Exhibit 8).* This typically limits

Exhibit 8

Example in-house printing costs for aluminum and nylon

Figures in USD/kg[1] for a medium complexity part



1 Assuming 5% scrap rate and 60% equipment utilisation. Assumes printing at scale, using materials from the OEM
Output today is assumed to be 450 grams per hour for nylon SLS and 70 grams per hour for aluminium DMLS
Note that an object's geometry can impact the cost of the print by as much as 50% for a given volume

SOURCE: McKinsey Manufacturing Practice

companies to using additive manufacturing for complex parts with volumes of less than 50 units per year, or to produce tooling rather than direct manufacture.

None of these obstacles is insurmountable. In the coming decade costs will fall by over 60% and usage will become more mainstream. As this happens, the impact of additive manufacturing will grow beyond manufacturing to cover the whole value chain, including distribution. The CEO of a major logistics company recently asked whether the arrival of additive manufacturing will put his whole company out of business, as localized production would eliminate the need for third-party logistics. The answer might be yes, but not for at least 20 years. The impact is likely to be gradual at first, then accelerate as printing equipment begins producing more-complex parts like printed circuit boards, and the costs start to converge with traditional manufacturing methods.

Other elements of the value chain will also be affected. Low-cost-country manufacturing will become less relevant as manual machining and finishing processes become unnecessary. IP protection will increasingly focus on the digital printing files, not the product itself. Sales and marketing will have to deal with the complexity of unique tailoring for each customer. We may eventually move to an era when manufacturing is completely commoditized and carried out either in global megafactories or at very localized print stations *(Exhibit 9).*

Exhibit 9

Additive manufacturing impact along the value chain

Fast forward 20 years from today

R&D/product design	Purchasing	Manufacturing	Sales and marketing	Distribution	Customer support/ service	Reuse/ recycle/ discard
3-D design becomes core asset Greater emphasis on design concept rather than manufacturing ability New specialty materials tailored to 3-D printing	Low-cost-country sourcing disappears Shift from tier-1 parts to purchasing of raw materials Purchased-product diversity is diminished	Less hard tooling and reduced assembly Enhanced manufacturing capabilities, i.e., complex geometry, composites) Manufacturing capabilities are no longer a competitive advantage Increasing trend of manufacturing outsourcing	Infinite potential for highly customized products New design possibilities Collaborative product design with customers Fast response from manufacturers to demand surges	Significant increase in manufacturing at point of use/mass on-shore production centers produce a large variety of products Reduced COGS due to less shipping Lighter or nested parts make transportation more cost efficient	Spare parts manufacturing at point of use Customer has more control/ ownership of the product, e.g., allows later differentiation	Up to 70% less energy consumed Less waste and easier integration into a circular economy

SOURCE: McKinsey Manufacturing Practice

Metal injection molding

Metal injection molding is the process of injecting metal powder at high pressure into a die. The component is then removed and placed in a furnace so that the powders fuse to form a solid part. It is particularly well suited to small, complex components in medium-to-high volumes. The main benefits are:

- Reduced material waste
- Better cycle times
- Reduced finishing requirements
- Making use of existing plastic extrusion equipment

Metal injection molding technology has been around for over 20 years, but has experienced significant growth in the last ten years: increasing from a USD 400 million market for equipment and materials in 2004 to USD 1.4 billion in 2014. The growth is forecasted to continue, reaching USD 2.9 billion by 2018. The prevalence of metal injection molding in specific industries varies greatly by continent, driven by leading, innovative companies in each region. These companies are enjoying the ability to form parts with highly complex geometries, at a high volume. This is often achievable often without the need for lengthy post processing to achieve the required dimensional tolerance or surface finish.

The impact of moving from traditional milling and die casting processes can be significant, for example:

- Bosch India saved **80% on the cost** of a fuel control gear through reduced material waste and processing time. It makes three million units a year, which now require no secondary processing.
- One engine manufacturer recently achieved **40 to 60% cost savings** on over a dozen major components for a jet engine
- Motorola makes the hinge barrel for its mobile phones using metal injection molding. Achieving the same thin walls and overhanging geometry would have **cost five-times more** using traditional processes.

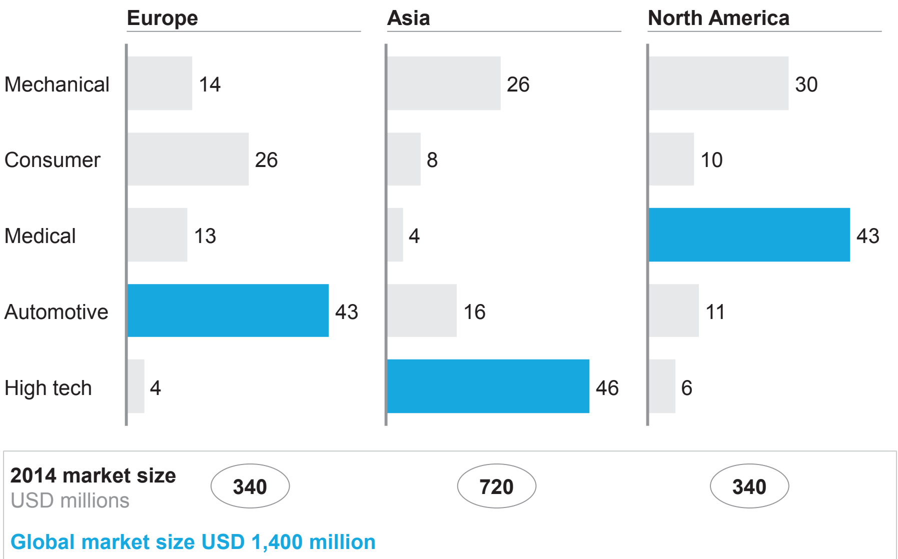
In general, metal injection molding is an increasingly acceptable choice for manufacturers when annual volumes are over 5,000, unit weights are under 200 grams, and the geometry is complex. Metal injection molding also gives designers the opportunity to consolidate mechanical components and reduce the overall part count. This results in a simpler supply chain and better performing products. Metal injection molding will not directly compete with additive manufacturing for 10-20 years due to its focus on higher volumes. Indeed the development of both technologies is likely to be complementary, with additive manufactured tool molds and cores allowing companies to fully exploit the advantages of metal injection molding production.

In terms of limitations, our interviews with experts show that metal injection molding is not competitive when parts are large. This is due to the high material costs for powder metal (accounting for over 80% of total cost), and the high capital costs for large furnaces. This means that for the foreseeable future, metal injection molding will continue to grow in the high tech, automotive and medical sector, where the 'at scale' production of complex small components is required *(Exhibit 10).*

Exhibit 10

Metal injection molding market size

Percent



SOURCE: Powder Metallurgy: A Global Market Review; BCC Research, Metal and Ceramic Injection Molding; McKinsey

3 Managing and implementing new technologies

Taking technologies like additive manufacturing and metal injection molding from concept to full implementation on the shop floor is a daunting task for many companies. The cost of prolonged line stoppage from a poor transition can outweigh the potential cost savings, and building the required talent and processes are not trivial tasks.

However, as the cycle of technological change accelerates, having the organizational capability to rapidly identify, prioritize, and implement new manufacturing technologies is quickly becoming a fundamental requirement. Companies that can implement new technology quickly and effectively will have a competitive advantage through increased flexibility, reduced cost, and a shorter time to market.

In our experience, companies that are succeeding on this front have talented people and formal processes in place along all four key steps to execution:

1. **Strategy** – *a clear manufacturing strategy tied to business strategy*. Leading companies quantify the relative importance of lead times, quality, flexibility, and cost for various customer segments and translate them into a prioritized set of strategic manufacturing goals. This allows strategic Capex decisions to be made on investments into new technologies, and where in the manufacturing footprint they should be deployed. The best manufacturing strategies also make it clear when investments are not going to be made. This prevents projects idling in the shadows and consuming valuable resources, allowing the business to re-focus its efforts on other improvement levers such as process optimization.

   We often see companies struggling to quickly and effectively make these strategic decisions. Typically there are two root causes of the problem. Firstly, that the senior leadership does not have access to the right level of quantified insight into what the business needs and what different options will cost to deliver it. This requires both an investment in the organization's analytical capability as well as in data acquisition and management. Secondly, and more commonly, there is disconnect between the strategies and incentives of different departments, such as manufacturing, R&D, and supply chain. It is important for senior management to take the lead in aligning the departments' incentives and metrics: this cannot be left solely to finance and HR. It also requires active risk management and regular feedback loops between the departments. This ensures that corrections are made to their respective strategies, and that they stay aligned.

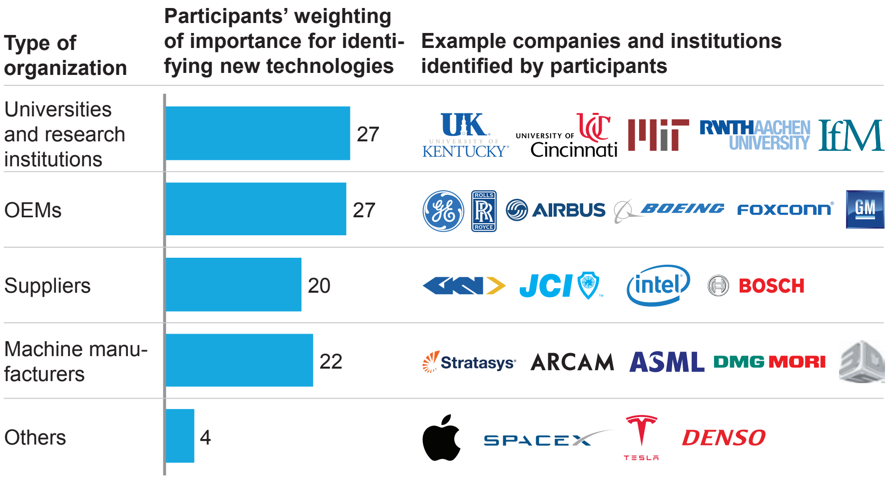
2. **Technology identification** – *strong internal and external networks for identifying relevant new technologies*. We asked executives at over 80 leading companies who they work with to stay abreast of technological advances in manufacturing. Household names like MIT, GE, and Intel came up frequently. However, the companies with the best track record for technological implementation had a wider network of advisors and included "wild-card" organizations like the Disney Institute to join their meetings and think through the operator experience of new machinery.

   Too often, networks look excellent on paper, but the full potential of the industry, government bodies, and academic institutions working together is not exploited. Getting your network to work for you requires a clear framework as well as setting out the responsibilities of each partner and the benefits they will each receive. The performance of the network should be managed compared to a set of quantified input and output metrics. The breadth of the network is also important: bringing in parties with expertise in technological adoption on the front line may be as important as learning about the next best thing in composite adhesive joining. The network's search should be tied back to the manufacturing strategy to avoid "boiling the ocean" *(Exhibit 11).*

Exhibit 11

Leading institutions highlighted by survey results

Percent



SOURCE: McKinsey Advanced Manufacturing & Assembly survey, n = 100

3. **Technology prioritization** – *a robust set of processes to quantify the total cost and relative merits of each technology compared to the business strategy*. A common pitfall is to have a multi-stage-gated process where the answer is always "yes" at each stage. The process needs strong executives with the courage to pilot risky new technologies and even more courage to kill projects with high sunk costs before they do more damage. The executives need to be supported by analysts with the specialist skill set required to forecast the impact over time of transitioning to a technology. Many companies today still do this on an informal basis, even in the aerospace and defense sector.

4. **Implementation** – *a rapid approach to piloting and rolling out new technologies*. The fear of disruption caused by a change in manufacturing technology can often paralyze the implementation process. Several of the companies we interviewed had maintained their existing manufacturing technologies despite having known for two to three years that a better alternative exists.

   There are very few manufacturing managers who can truly balance the day-to-day pressure of meeting operational targets with the creativity and openness needed for the implementation of new technology. Creating a small implementation SWAT team can be a way to address this issue. A high-performing team with tight timelines, concrete goals, a small but liquid budget and freedom from red tape can achieve rapid results and break the paralysis. Some companies have created mock manufacturing environments to test changes in a nondisruptive way and found the cost of the sites was outweighed by the overall acceleration and improved quality of the rollout.

It is important to make sure that the implementation project team's incentives are aligned with the operational manager's incentives. The team's metrics need to encourage long-term benefits over short term disruption. The quality and cross-functional nature of the implementation team are also critical: it must contain people with skills in communication, training, technical transition, and change management.

We interviewed manufacturing leaders from over 80 companies to understand how they performed at each of the four stages. Overall, managing manufacturing technology was acknowledged as an area that has not received sufficient corporate attention. However, as lean and Six Sigma programs increasingly struggle to find more waste to remove from the process, the equipment itself is rapidly becoming the next frontier for major improvement.

Only 20% of companies surveyed felt that their manufacturing strategies were fully effective and aligned with their business strategies. Less than 10% believed that they had fully effective networks and processes for identifying new technologies. Furthermore, less than 10% felt that technologies identified were analyzed as thoroughly as they should be. And finally, less than 10% felt the implementation processes were quick and effective. Obviously, this is an area ripe for improvement *(Exhibit 12).*

Those companies that are building the capabilities to "refresh their shop floor" quickly and seamlessly have a competitive advantage through reduced cost, improved quality, increased flexibility, and faster time to market. Therefore, now is the ideal time for manufacturing executives to ask themselves challenging questions about their own manufacturing technology *(Exhibit 13).*

The answers to these questions vary by company, industry, and region. However, as the pace of technological change continues to accelerate, not having answers to these questions is no longer an option. We do not know what the manufacturing shop floor of 2020 will look like, but we do know that companies cannot afford for it to look the same as it does today.

Exhibit 12

Survey results on moving from strategy to implementation

Percent

> 100 RESPONDENTS

	Question	Not done	Informally done	Formal system in place, partially effective	Formal system in place, fully effective
Strategy	Is your manufacturing technology strategy closely aligned with your business strategy?	7	36	38	19
	Are there strong, formal links between your business strategy department and your manufacturing strategy department?	9	31	34	25
	Is your manufacturing/production strategy department outward facing and focused on the end customer?	10	34	30	26
Identifi-cation	Do you have a broad industrial and academic network that keeps you up-to-date on manufacturing/assembly technologies?	12	49	30	10
	Does that network work efficiently and effectively together, with clearly defined roles?	20	49	24	7
	Do you have sufficient internal resources to make the best use of this network?	23	47	23	7
	Do you have the right internal processes and capabilities to make the best use of this network?	13	50	31	6
	Do you use the network to maintain a list of emerging, potentially relevant technologies?	21	46	29	4
Prioriti-zation	Do you have a robust method for prioritizing competing manufacturing technologies?	11	47	33	10
	Does that process quantify the relative financial impact and competitive advantage of switching technologies?	14	30	42	14
	Does that process quantitatively forecast the capability/cost evolution of the technologies over time?	23	32	36	9
Implemen-tation	Do you have project management organization driving technological implementation?	5	29	51	15
	Do you have a quick, cost-effective ability to pilot new manufacturing/assembly technologies?	17	33	39	11
	Do you have a proven process to transition from existing to new manufacturing/assembly technologies with minimum disruption?	17	36	35	12
	Do you have a closed-loop process with defined metrics to evaluate a successful transition?	20	35	31	15
	Do you take an end-to-end view of potential organizational impact?	18	32	41	8

SOURCE: McKinsey Advanced Manufacturing & Assembly survey

Exhibit 13

Top ten questions for executives on advanced manufacturing technologies

Strategy	▪ Is the manufacturing strategy directly tied back to customer needs and the overall business strategy? ▪ Does it take into account the new products, services, and business models that are enabled through new technologies? ▪ Does it quantify the cost, time, flexibility, and quality improvements to achieve through new manufacturing technologies?
Identification	▪ Do I know which new manufacturing technologies matter most for both my current and planned products? ▪ Do I have a well-managed knowledge network that keeps me up-to-date as these technologies evolve and new ones arrive?
Prioritization	▪ Do I have the organizational capability to holistically assess whether the new technologies have reached the tipping point for implementation? ▪ Are the company's processes for assessing capital expenditures against planned operational savings robust?
Implementation	▪ Does the company's planning for the implementation of new technologies consider the impact to the full value chain, including R&D, supply chain and commercial? ▪ Do I have a team with the capabilities and empowerment needed to pilot and roll out new technologies? ▪ Are my organizational metrics and processes supporting or hindering implementation from being successful?

Authors

Ben Sheppard is the leader of McKinsey & Company's UK Product Development Practice

Ben is a chartered engineer, with a passion for helping clients sustainably improve their performance. He has worked with over 30 of the world's preeminent manufacturing companies, leading major design improvement programs on everything from jet engines to cans of baked beans. He founded McKinsey's Design-to-Value laboratory in London. Before joining McKinsey, Ben designed and built the world's cheapest deep-sea camera.

Benedict_Sheppard@mckinsey.com

Colin Shaw is the leader of McKinsey & Company's UK Operations Practice

Colin is an Expert Principal, based in the London office. He works purely on projects that transform the operational performance and cost of his clients. He covers topics such as lean manufacturing, maintenance and reliability, supply chain management, procurement and back-office optimization. Prior to McKinsey, Colin worked at British Airways on a variety of aircraft performance improvement projects before being involved in resolving technical problems associated with the Concorde aircraft, enabling the aircraft to enter back into service.

Colin_Shaw-PRI@mckinsey.com

Barry Williams is an Expert in McKinsey & Company's Manufacturing Practice

Barry is a former Senior Vice President of Manufacturing at Rolls-Royce and has also held senior leadership positions at BAE Systems and Airbus. As a consultant, he has led diagnostic and transformation activities on everything from latex manufacturing to the production of luxury cars. He was first coached in process improvement by the Japan Institute of Plant Maintenance and later directed his MBA studies to specialize in world-class manufacturing techniques.

Barry_Williams@mckinsey.com

John Persaud is a Specialist in McKinsey & Company's Manufacturing Practice

John is a lean manufacturing specialist who delivers sustainable change through individual and organizational capability building. He has worked across multiple high-technology and high-volume industries, including aerospace, defense, pharmaceuticals, and consumer goods. Before McKinsey, John was an operation leader in pulp and paper manufacturing.

John_Persaud@mckinsey.com

Jörg Bromberger is a Senior Practice Manager in McKinsey & Company's EMEA Manufacturing Practice

Jörg is coleading McKinsey's initiatives in advanced manufacturing technologies with particular focus on 3-D printing and digital manufacturing technologies. He has been serving several clients – both large OEMs and government institutions – in shaping their manufacturing strategies, developing new business models, and setting up competence centers for new technologies.

Joerg_Bromberger@mckinsey.com

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