World Economic Forum

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White Paper

Technology and Innovation for the Future of Production: Accelerating Value Creation

In collaboration with A.T. Kearney

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Preface

This World Economic Forum white paper is proposed in the context of the Forum's System Initiative on Shaping the Future of Production, launched in 2016, which seeks to better understand transformations in global and local production systems and to provide a platform for pilots and collaborative efforts that stimulate innovation, sustainability and employment.

The Forum defines the world of production as the full chain of activities to "source-make-deliver-consume-reintegrate" products and services, from origination, product design, manufacturing and distribution to customers and consumers, incorporating principles of the circular economy and reuse.

Production fundamentally impacts economic structure at global, regional, national and local levels, affecting the level and nature of employment, and today is inextricable from environmental and sustainability concerns, considerations and initiatives. Collectively, the sectors of production have been the source of economic growth in developed and developing nations alike, a major source of employment for a rapidly evolving and increasingly skilled workforce, and they continue to be the dominant focus of innovation and development efforts in most countries.

The transformative potential of technology in production systems is widely recognized, even while the precise configuration and extent of the possible transformation remain unknown. Trends towards higher levels of automation promise greater speed and precision of production as well as reduced exposure to dangerous tasks for employees. New production technologies could help overcome the stagnant productivity of recent decades and make way for more value-added activity. The extent of automation is, however, causing significant anxiety about issues of employment and inequality.

The new technologies of the Fourth Industrial Revolution have the potential to transform the global geography of production and will need to be deployed in ways that address and adapt to the impact of climate change.

This white paper, prepared in collaboration with A.T. Kearney, explores the new technology landscape focusing on five technologies that will have the most immediate impact on production-related sectors, individually and in combination. It raises questions for chief executive officers, government leaders, civil society leaders and academics about the implications for individuals, companies, industries, economies and society as a whole, and is intended to bring new perspectives and generate responsive and responsible choices.

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Executive summary

Technologies of the Fourth Industrial Revolution[1] are blurring the lines between the physical, digital and biological spheres of global production systems. The current pace of technological development is exerting profound changes on the way people live and work. It is impacting all disciplines, economies and industries, perhaps none more so than production, including how, what, why and where individuals produce and deliver products and services. However, amid overcharged media headlines and political and social landscapes, business and government leaders find it difficult not only to have an accurate understanding of where these technologies can create real value, but also to successfully focus on the appropriate and timely investments and policies needed to unlock that value.

To address some of these issues and shed light on technology's impact on global production systems, the World Economic Forum introduced the System Initiative on Shaping the Future of Production at the beginning of 2016. This white paper summarizes the key insights and understanding of the five technologies with the greatest impact on the future of production, and the role of government, business and academia in developing technology and innovation. The insights are based on more than 90 interviews with chief operations, technology and information officers of companies developing and implementing in-scope technologies across 12 industries. The findings were validated through discussions with over 300 business leaders, policy-makers and academics conducted in six regional workshops.

Key findings

Business leaders and policy-makers must keep track of more than 60 technologies and philosophies impacting production systems today (see Figure 1). These technologies are obliging companies to rethink and retool everything they do internally, and governments to reassess their national competitive advantages and development strategies. The chief executives and chief operating officers who embrace these technologies and rapidly transform their enterprises will set their companies on course for success. The government leaders able to set the right policies, develop and diffuse these technologies, and ready their workforces, infrastructure and supply chains to leverage them, will position their economies for growth.

Within the broader technology landscape, five technologies are transforming global production systems and unleashing a new wave of competition among producers and countries alike. Exciting advances in the internet of things, artificial intelligence, advanced robotics, wearables and 3D printing are transforming what, where and how products are designed, manufactured, assembled, distributed, consumed, serviced after purchase, discarded and even reused. They affect and alter all end-to-end steps of the production process and, as a result, transform the products that consumers demand, the factory processes and footprints, and the management of global supply chains, in addition to industry pecking orders and countries' access to global value chains.

The five technologies, in different stages of technical readiness and adoption, also come with varied levels of uncertainty about their future direction. Some, such as advanced robotics ($35 billion market) and 3D printing ($5 billion market), have a long industrial history and are on the cusp of mainstream adoption, albeit in certain geographies and industries. Others, such as artificial intelligence and enterprise wearables ($700 million market), are in a more nascent stage, but present promising use cases. For now, North America, Europe and pockets of Asia (China, Japan and South Korea) are leading in technological adoption, with the rest of the world lagging behind (see Figure 3). In 2015, North America and Europe together made up 80% of the wearables market[2] and almost 70% of industrial 3D printing units. With the exception of wearables, today's technologies are heavily concentrated in specific industries, with automotive, electronics and aerospace being early adopters in most cases. Technologies have not disrupted all industries in the same way and at the same time, and even within the same industry the technologies have a dramatically different impact and value proposition for specific functions (see Figure 5).

However, many of these technologies have yet to realize their full potential and contribution to inclusive global productivity. Unlocking their value will largely depend on the ability of businesses and governments to improve the technical readiness of the technologies, educate the necessary skilled workforce, foster inclusive diffusion and adoption, ensure availability of underlying infrastructure and address issues of data governance and cybersecurity.

Inevitably, the demonstrable benefits of new technologies will lead to their greater adoption, and failure to invest in them will be fatal for many firms' long-term prospects. While the technologies are at different levels of development and adoption, the Forum identified five cross-technology tipping points that will indicate widespread adoption (see Figure 6).

Disruptive technologies shaping production assesses the readiness and adoption level of each technology, its most relevant applications in production and the key barriers to further adoption.

Unlocking the value and avoiding the perils

The technologies touch on every step of the end-to- end production process and global value chains; their convergence raises a new set of strategic choices related to value. Those choices deal with how value is created within firms and redistributed among industry players, countries and society.

The section on the promise of converging technologies: new opportunities to create value explores the value of the

Eleven "What if…" questions

For government and business leaders to reflect on the impact of technology and innovation in global production systems:

What if…

1. The factories of the future are small, mobile, invisible and located in urban undergrounds?
2. The best robot on the factory floor is the technology-augmented operator?
3. You can track in real time the performance of every machine, employee and supplier in your network, as well as your products in the hands of the consumer?
4. You can produce at the same cost and quality anywhere in the world?
5. Your customers are willing to pay only for performance and all the value of your flagship products comes from their digital and cognitive features?
6. With hyperpersonalization, brands become irrelevant?
7. You can turn your recycled products into raw materials for a new production batch?
8. Technologies do not diffuse beyond select large producers and technology giants?
9. Over 80% of global production output is produced and delivered through contract manufacturing?
10. Technologies enable labour relations to become self-organized?
11. Technologies fail to deliver on their promised value?

technologies on five levels: factory floor, firm, industry, society and the individual.

While technologies hold valuable opportunities for efficiency and growth, their current development pace shows they may also exacerbate existing inequalities. Not every company and country in current value chains will capture the value unlocked by these technologies to the same degree. Laggard producers (large ones, as well as small- and medium-sized enterprises), bear the highest risk of negative impact from technologies. Many countries will be challenged in assisting their small- and medium-sized producers to reap the value of technologies. Additionally, economies solely dependent on labour arbitrage will see their source of economic growth erode, as technologies increasingly enable competitive production in higher-cost environments. "Reshoring" is unlikely to occur across the board; it will predominantly occur in the capital-intensive sectors with high transportation costs, where proximity to consumers is a key value driver. Technologies will negatively impact white- and blue-collar workers on the factory floor if societies do not ready their workforce for the new skill sets and put in place transition mechanisms to ease negative impacts.

A few companies and countries have already launched significant transformation and policy initiatives, unleashing a whole new wave of industrial and geopolitical competition. Industrial giants are waging a fierce war in industrial platform dominance and extracting higher value from their large-production footprints.

Recognizing the importance of production to their industrial future, countries have launched programmes to support the deployment of these technologies to their domestic manufacturers. Notable examples include the Made in China 2025 programme, with more than $3 billion in advanced manufacturing investments, and the European Union (EU) €7 billion Factories of the Future initiative.

An agenda for action

For companies, speed is the defining factor of this transformation, and the key to being successful. If companies cannot develop at a pace that allows them to win, they will fall behind very quickly. Effective, long-lasting transformation in the new context requires an immediate, intense focus on understanding the technologies and how they can create value within the business, while developing the culture and skills to execute the change.

Narrowly prescribed strategies of the Fourth Industrial Revolution will not work for governments, whose role shifts to being orchestrators of comprehensive production ecosystems. Success in the future of production requires a bigger framework, encompassing research, technology, innovation, education, labour and industrial and trade strategies that need to track and move with the external environment. Governments, together with businesses and members of civil society, have four cross-industry and cross-technology areas of action to drive inclusive adoption of technologies and foster a growing production system. These are: focusing in a coordinated manner on research and innovation and improving technological readiness; democratizing production knowledge; creating pathways to production careers, including education and skills; and supporting public–private partnership for business formation, innovation and growth.

The future of production raises important questions for governments, companies and society, and requires global dialogue to shape a vision of production that promotes economic growth and innovation in an inclusive and sustainable manner. Leaders will be forced to examine a series of "what if" questions about sources of global economic growth, innovation through and beyond technologies, national competitiveness, skills and jobs for the workforce, and sustainability.

Introduction to Shaping the Future of Production: Technology Foresight Series

The technologies of the Fourth Industrial Revolution[3] are blurring the lines between the physical, digital and biological spheres of global production systems.

The current pace of technological development is exerting profound changes on the way people live and work. It is impacting all disciplines, economies and industries, perhaps none more than production, and how, what, why and where individuals produce and deliver products and services. Production activities, defined as the full chain to "source-make-deliver-consume-reintegrate" products and services, will be altered and extended in ways that are difficult to fully envisage – from origination of inputs, product design and manufacturing, to distribution, customer/ consumer use and elements of the circular economy/return/ reuse. Breakthroughs in key areas are revolutionizing the future of production, including artificial intelligence, robotics, the internet of things, autonomous vehicles, 3D printing, nanotechnology, biotechnology, materials science, energy storage and quantum computing.

However, accurate knowledge of the value and perils that technologies can create for companies and countries is not widely diffused. Business executives, government leaders and the public would benefit from clearly understanding the current state of technology readiness and adoption, and their converging impact and value on the factory floor, as well as on firms, industries, society and the individual. This will help policy-makers and businesses to distinguish between extravagant claims or publicity and reality, and to make sound business investments and policy decisions.

At the beginning of 2016, the World Economic Forum introduced the System Initiative on Shaping the Future of Production, to understand how the technologies concerned are disrupting production systems and to explore how best to stimulate sustainability, employment and the innovative capacity of nations. The Forum has gathered a unique group of experts, business leaders, worker representatives, civil society leaders, and government ministers and officials, the latter representing nations that deliver 85% of current global manufacturing output. One of the key projects of the initiative is the Technology for Production Foresight Series, which aims to increase understanding among stakeholders worldwide of the value that new technologies could add to global production systems. It also seeks to build knowledge of the keys to unlocking that value, and the potential perils posed by these technologies if their adoption and diffusion are exclusive and not centred on people.

This white paper summarizes the key insights and understanding of the five technologies with the greatest impact on the future of production, and the role of governments, companies and academia in developing technology and innovation. In 2016, the five key technologies of focus were the internet of things, artificial intelligence, 3D printing, advanced robotics and wearable technologies (including augmented and virtual reality). The process of developing insights from the 2016 Technology for Production Foresight Series followed a rigorous three-step approach:

1. Mapping a comprehensive technology radar impacting one or more aspects of global production systems. Exercises followed to prioritize and focus the analysis on five technologies deemed to have the broadest applicability across value chain elements, industries and geographies, and with the strongest impact over the next three to five years, as shown in Figure 1.

2. Delineating the current state of each technology to distinguish between excessive promotion and reality, and to determine their potential development in the near future. A Foresight Series was created for each technology, capturing current technical readiness and adoption levels (across processes, industries and geographies), while extrapolating these findings to determine future impact.

3. Focusing on the converging impact of the technologies: first, by understanding the connections between technologies and how they converge or compete in solving firm and societal problems; and second, by gauging their converging impact on the factory floor and on firms, industries, societies and individuals as summarized in Figure 2.

A series of qualitative and quantitative inputs served as the focus to develop these insights.

– *Qualitative inputs:*
  Consisting of more than 90 interviews, one global survey and over 100 open source reports, these inputs built on World Economic Forum reports and input from the Forum's Global Future Councils. The process included conducting interviews with chief operations, technology and information officers of companies developing and implementing in-scope technologies across 12 industries with global production and supply chain footprints. The findings were validated through discussions with over 300 business leaders and policy-makers conducted in six regional workshops.

Figure 1: Production technology radar

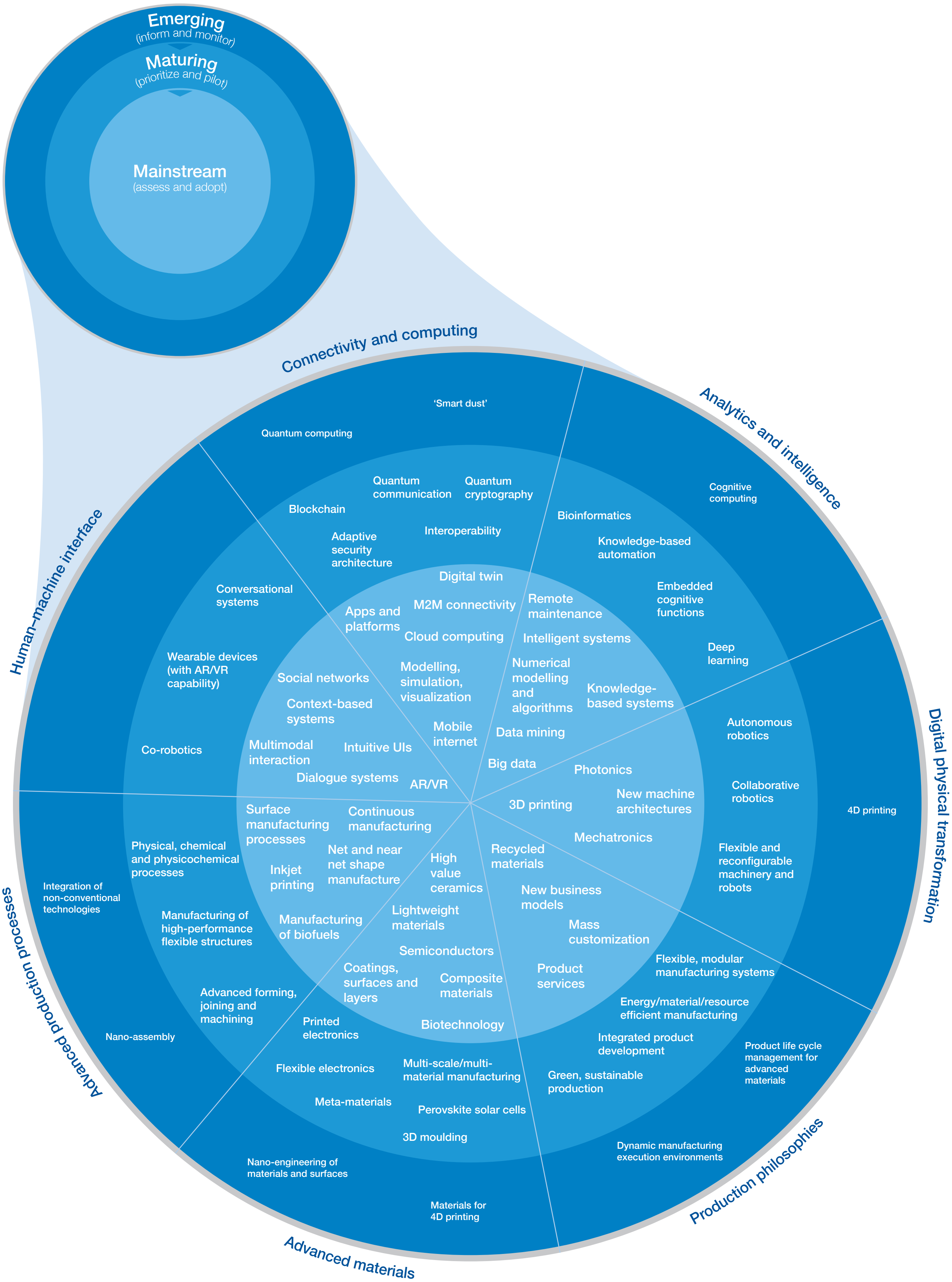
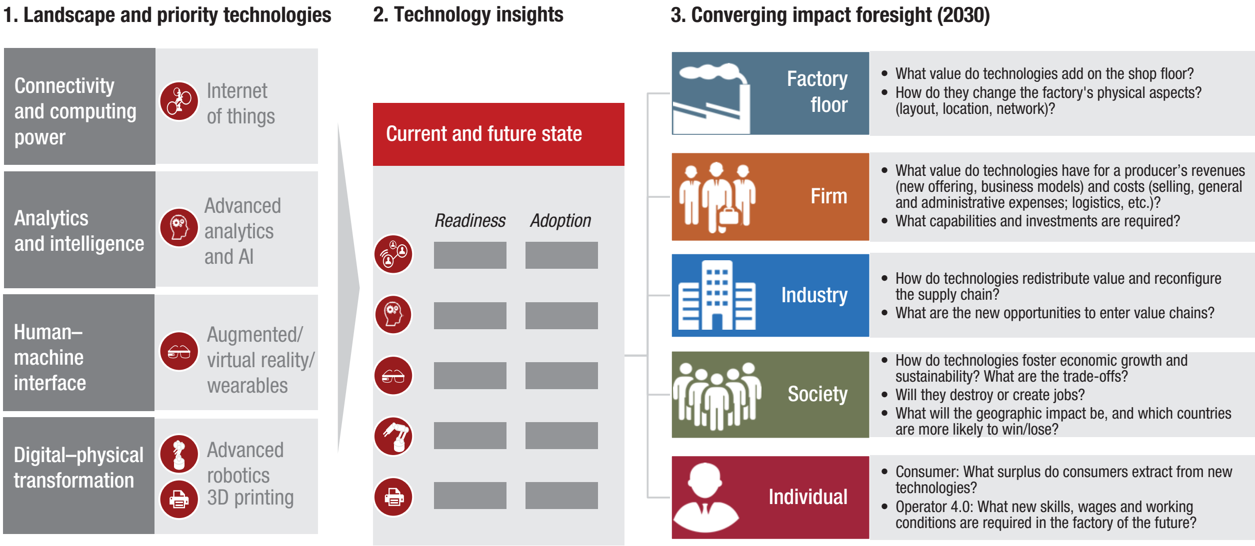


Figure 2: Three-step approach to developing insights



Source: A.T. Kearney

– *Off-the-shelf and custom-built quantitative insights:* These insights supplemented qualitative information on individual and converging technological impact, including global databases on production and labour from the World Bank, the Organisation for Economic Co-operation and Development (OECD), and industry and market reports as well as A.T. Kearney's proprietary Factory of the Year data set. This centralizes performance data for over 2,000 factories in more than 30 countries and 20 industries, with over 200 best practice cases identifying how technologies impact factory floor and operational processes.

– A value chain economics model: The purpose of this is to provide quantitative input on how converging technologies will create new value and (re)distribute it within supply chains. In 2017, the Forum will work with input from stakeholders to select representative products and their associated value chains, so as to map how value was created and distributed in developed and developing economies in 2015, along with how technologies would change that by 2030 in incremental and disruptive scenarios.

Disruptive technologies shaping production

Cross-technology insights

Business leaders and policy-makers must keep track of a vast range of technologies and philosophies impacting production systems today. The Forum has developed a production technology radar as a guide to action for business leaders and policy-makers (Figure 1). The high-level categories selected for this graphical representation take in those largely information and communication technology (ICT)-enabled technologies that are the primary focus of this white paper: connectivity and computing, analytics and intelligence, human machine interface and digital physical transformation. Included in this schematic diagram are additional topics that fill out the broader technology landscape: advanced materials (encompassing various branches of both nanotechnology and biotechnology); advanced manufacturing processes, which in some respects may be considered traditional manufacturing processes, but whose capabilities could be augmented and extended by new technologies; and what might be termed manufacturing philosophies, which would include things such as design approaches and mindsets geared towards sustainability.

Future technology mapping will provide a more comprehensive visualization of the entire production technology landscape that will take account of technology subcategories that have varying readiness levels in different production contexts, and varying levels of diffusion and adoption within different sectors. Overlapping categories will also be identified.

Within the broader technology radar, five key technologies stand out by their broad applications and impact in countries, industries and value chain steps alike. The five – the internet of things, artificial intelligence, advanced robotics, wearables and 3D printing – have unleashed competition within production systems, forcing companies to rethink and retool everything that they do internally.

The chief executives and chief operating officers who embrace these technologies and rapidly transform their enterprises will set their companies up for success. Moreover, governments will need to re-evaluate their national competitive advantages and sources of economic growth. Those government leaders able to set the right policies to research, develop and diffuse these technologies, and to ready their workforces and supply chains to leverage them, will position their economies for growth. Amid excessive media exposure and charged political and social landscapes, business and government leaders find it difficult to have an accurate understanding of where these technologies can create real value, and to focus successfully on appropriate and timely investments and policies needed to unlock that value.

The five technologies, in different stages of technical readiness and adoption, also come with varied levels of uncertainty about their future direction. Disruptive technologies, especially robotics, 3D printing and augmented reality, have captured the popular imagination with exciting applications demonstrated across all sectors. However, behind the individual use cases, the readiness and adoption of each technology tells a different story. Some, such as 3D printing (or additive manufacturing) and advanced robotics, have a long industrial history and are on the cusp of mainstream adoption, albeit in certain geographies and industries. Others, such as artificial intelligence and wearables, are in a more nascent stage, but present promising use cases.

- The **internet of things** (IoT) is often presented as a revolution, but it is actually an evolution of technologies developed more than 15 years ago. Operations and automation technologies are now blending, albeit conservatively, with sensors, the cloud and connectivity devices of the information technology (IT) industry Information Handling Services (IHS) projects the number of those devices to grow to almost 80 billion by 2025, up from 17 billion today.[4] The immediate opportunities for producers are in smart enterprise control, asset performance management in real time and smart and connected products and services. Cybersecurity and interoperability challenges are hindering producers from embracing IoT on the factory floor and in their supply chains, with 85% of assets still unconnected.

- **Artificial intelligence** (AI) enables producers to make sense of the overwhelming data that their factories, operations and consumers generate, and to transform that data into meaningful decisions. Today, 70% of captured production data goes unused. Applying AI to the connectivity of IoT, producers are able to orchestrate and streamline business processes from desktops to machines, across department walls and tiers of suppliers. The most promising immediate opportunities for applying AI in production systems are in quality management, predictive maintenance and supply chain optimization. AI-enabled products will be a game changer for value propositions addressed to customers, and producers must be ready to orchestrate the value networks required to deliver these.

- **Advanced robotics** have long handled the “dull, dirty and dangerous” jobs, and currently automates 10% of production tasks. Robots were often separated from people for safety reasons, but now, a new generation has “come out of the cage” for 24-hour shifts, working alongside human counterparts. Increasing returns on investment, insatiable Chinese demand and advances in human–robot collaboration will increase their adoption to 25-45% of production tasks by 2030, beyond their use in the automotive and electronics industries. Adopting advanced robotics and AI could boost productivity in many industries by 30%, while cutting labour costs by 18-33%, yielding a positive economic impact of between $600 billion and $1.2 trillion by 2025.[5]

– **Enterprise wearables** (including augmented and virtual reality) make up a nascent, fast-growing market projected to grow from $700 million today to $5 billion by 2020, with devices continuing to mature in terms of comfort, functionality and safety. Pilot programmes of leading companies show proven returns, with up to 25% improvement in operator productivity and significant decreases in the time required for training and upskilling (e.g. from two weeks to one hour for the shipping company DHL), as well as health and safety improvements. Connecting the unconnected with the internet of things

– **3D printing** is revolutionizing traditional production processes, aided by a recent surge in metal 3D printing capabilities. In the near term, 3D printing will be best suited to industries where customization and time to market are key value drivers – typically with low-volume, high-value parts, such as aerospace and healthcare. Today, and for the foreseeable future, the economics and industry dynamics will not support 3D printing replacing conventional manufacturing for long production runs, and for mass localization of production footprints nearer to consumers.

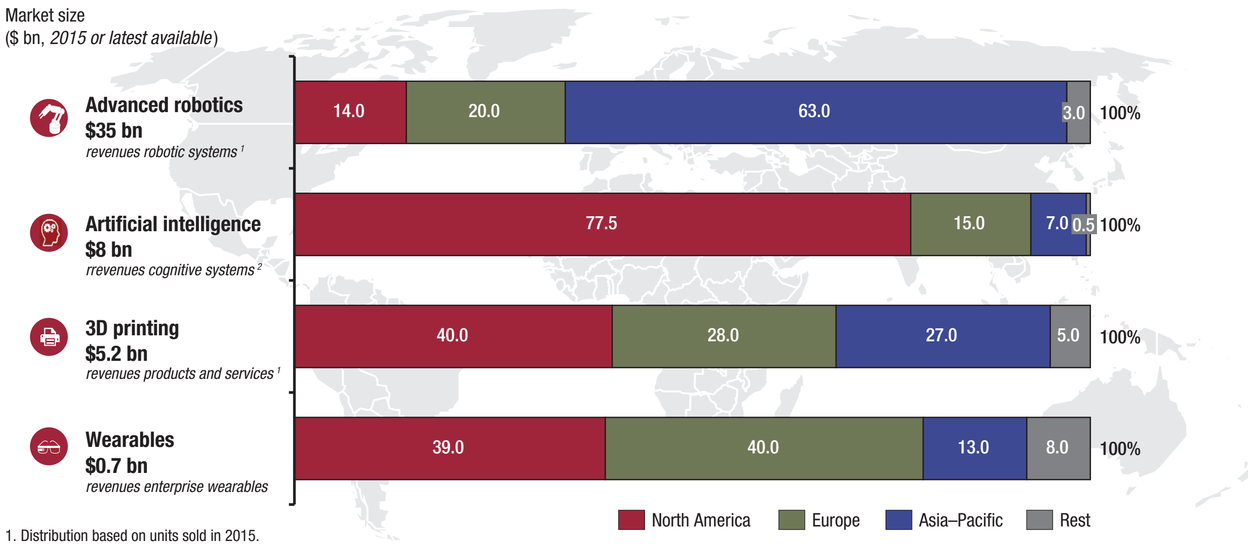
Currently, North America, Europe and pockets of Asia (China, Japan and South Korea) are leading in technological adoption, with the rest of the world lagging behind (Figure 3). Technologies have a greater return on investment in countries with high labour costs, as producers are more encouraged to seek out and experiment with technologies that boost employee productivity. In 2015, North America and Europe together made up 80% of the wearables market[6] and almost 70% of industrial 3D printing units.[7] Moreover, 70% of the record 250,000 industrial robots sold in 2015 went to five countries: four with predominately high labour costs – Germany, Japan, South Korea and the United States (US) – and China, the notable exception as a lower-wage country, making considerable investment.[8]

With the exception of wearables, technologies are currently heavily concentrated in specific industries, with automotive, electronics and aerospace as early adopters in most cases. Technologies have not disrupted all industries in the same way and at the same time. The early adopters across all technologies are industries with a high concentration of innovation and spending on research and development (R&D). Examples are the automotive and computer and electronics sectors and consumer-facing industries, where customization and time to market are the critical value drivers. More than 80% of industrial robots sold in 2015 were installed in just five industries, with automotive and electronics predominant. Additionally, more than half of 3D printing units were installed in only three industries: aerospace, automotive and electronics. Artificial intelligence applications have found a ready home in services industries such as finance, retail and healthcare, with manufacturing gaining momentum (12%). IoT is less concentrated than advanced robotics, 3D printing and AI, with manufacturing taking the largest share. Given their nascent stage, as well as broad cross-industry application, enterprise wearables have been piloted across industries and have yet to focus on a specific industry.

To clearly understand the value and opportunities that technologies offer, business leaders must explore the converging impact of multiple technologies on specific functions. While technologies are disrupting a growing number of industries, they have a radically different impact and value proposition for specific functions. This is particularly true in cases where multiple technologies converge. For example, IoT and AI converge to provide a compelling value proposition for asset management in discreet and high-tech manufacturing, as well as supply chain and fleet management for transportation, logistics and retail industries (Figure 4).

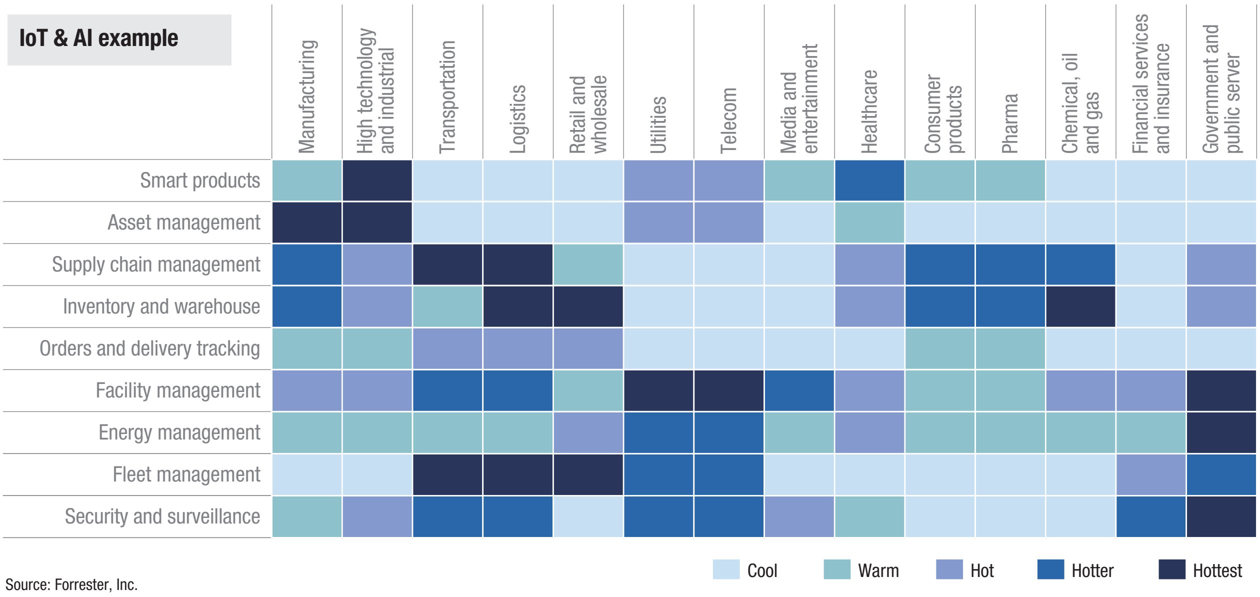
The demonstrable benefits of new technologies will lead to their wider adoption, and failure to invest in them will be fatal for many firms' long-term prospects. While the technologies are at different levels of development and adoption, we identified five cross-technology tipping points

Figure 3: Geographic adoption of technologies



1. Distribution based on units sold in 2015.
2. Estimates for Asia–Pacific and Rest based on International Data Corporation (IDC) data;
Source: International Federation of Robotics, Wohlers Associates, Technavio, IDC, expert interviews, A.T. Kearney

Figure 4: Technology value chain impact



Source: Forrester, Inc.

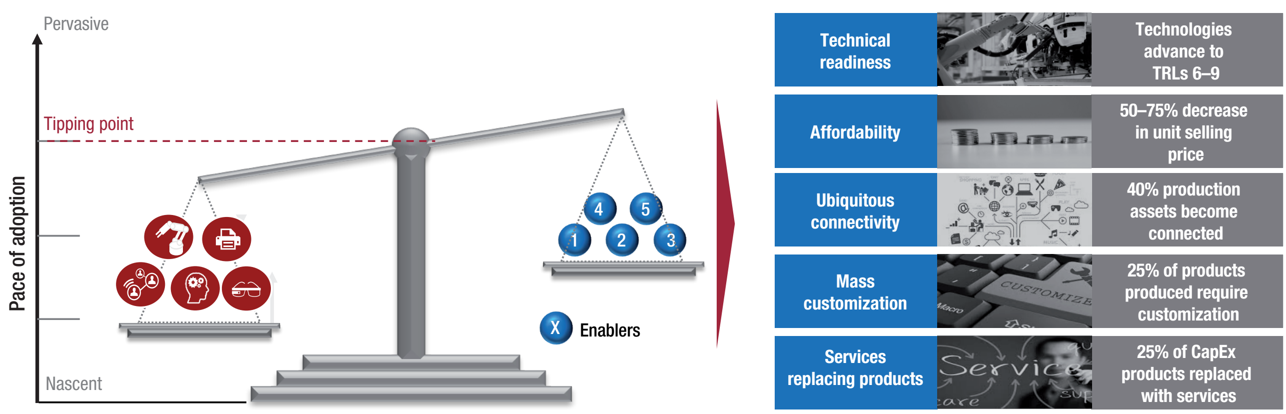
that will indicate widespread adoption, namely:

1. Core technologies advance to readiness levels of 6 to 9
2. Device costs are reduced by one-third of their current selling points
3. 40% of production assets are connected
4. 25% of the product orders require some form of customization to them
5. 25% of current capex spending is replaced with services-based expense spending (Figure 5).

Connecting the unconnected with the internet of things

The basics. The internet of things (IoT) – the embedding of

Figure 5: Cross-technology tipping points



Note: TRLs: Technology readiness levels
Sources: A.T. Kearney analysis; A.T. Kearney/World Economic Forum workshop, November 2016; expert interviews

physical devices with sensors, network connectivity and other components so they can collect and exchange data – is often presented as a revolution, but it is actually an evolution of technologies developed more than 15 years ago. During the last decade, sensor costs declined twofold, bandwidth costs fell by a multiple of 40 and processing costs dropped by a multiple of 60. The plummeting costs of sensing technologies, enhanced computing power, advances in data connectivity in the cloud and machine-to-machine communication are combining to drive the convergence of previously separate production technologies – IT, operations technology (OT) and automation technology (AT) – to create the future of production, expanded from the factory floor to connected products, services and supply chains – the industrial internet of things (IoT). Figure 6 illustrates how this process has been under way for several decades, and is now accelerating due to rapidly advancing capabilities. IoT platforms are still evolving and there are no clear winners in this space. Rival technology companies creating competing platforms are targeting many industrial sectors.

Use in production. Proponents of IoT highlight its potential to revolutionize production, not only by transforming operations on the shop floor, but also by enabling end-to- end visibility across the supply chain in real time, all the way to the end user, as well as developing new products and services to customers. IoT investment in production is expected to double from $35 billion to $71 billion by 2020, with three key functions driving investments: asset tracking, condition-based maintenance and robotics processing. North America leads today's IoT adoption. However, the Asia-Pacific region is projected to have a larger market share by 2020 (in excess of $2.5 trillion).

IoT has three distinct uses in today's production systems:[9]

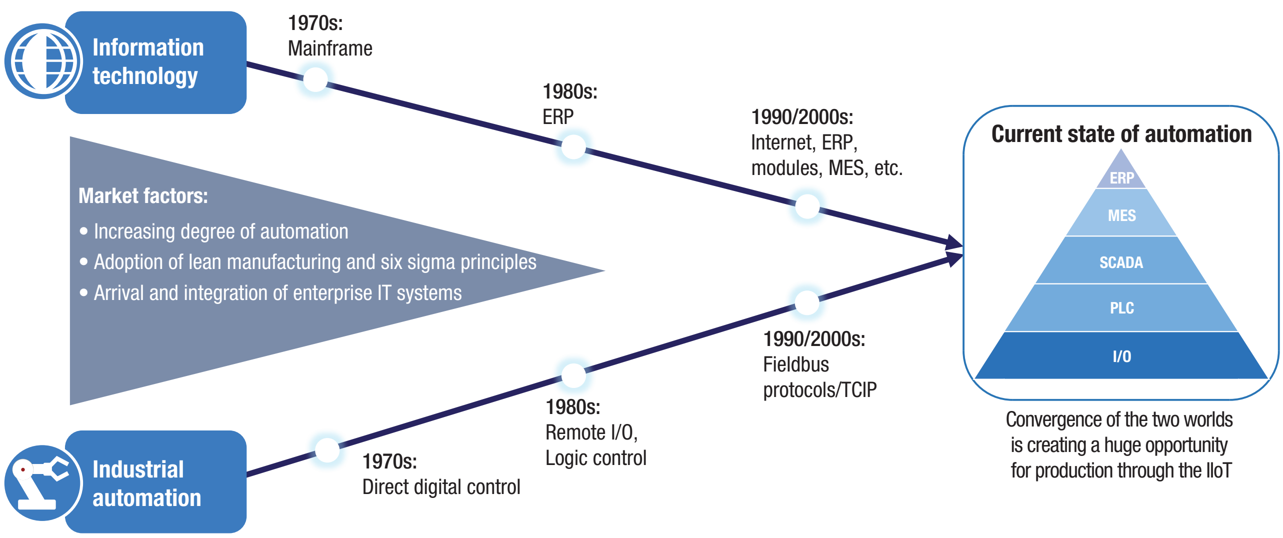
– **Smart enterprise control**: IoT technologies enable tight integration of smart connected machines and smart connected manufacturing assets with the wider enterprise. This facilitates more flexible and efficient, and hence profitable, production. Smart enterprise control can be viewed as a mid-to long-term trend. It is complex to implement and will require the creation of new standards to enable the convergence of IT and OT systems.

– **Asset performance management**: Deployment of cost-effective wireless sensors, easy cloud connectivity (including wide area network or WAN) and data analytics improves asset performance. These tools allow data to be gathered easily from the field and converted into actionable information in real time. The expected result will be better business decisions and forward-looking decision-making processes.

– **Augmented operators**: Future employees will use mobile devices, data analytics, augmented reality and transparent connectivity to increase productivity. As fewer skilled workers are left to man core operations due to a rapid increase in baby boomer retirement, younger replacement plant workers will need information at their fingertips. This will be delivered in a real-time format that is familiar to them. Thus, plants will evolve to be more user-centric and less machine-centric.

However, IoT is not just a collection of technologies added on top of current automation systems. It is also a philosophy requiring an entire change in mindset, where the potential lies in the ability to link automation systems with enterprise planning, scheduling and product lifecycle systems. One example of this technology's deployment is the "digital twin", which uses sensor data to create a dynamic software model of a physical object or system – whose myriad benefits will include predictive maintenance, improved operational efficiency and enhanced product development – and which will become ubiquitous in the next few years. In fact, IoT is maturing more quickly than predicted, indicating a more

Figure 6: Converging of information technology and operations technology



Note: ERP: Enterprise resource planning; MES: Manufacturing execution system; TCIP: Transmission control internet protocol; I/O: input/output.
Sources: IoT analytics, A.T. Kearney

imminent widespread implementation. A phase is beginning where the sheer availability of real-time information across the production value chain will redefine how companies produce goods, provide services and conduct business.

Barriers to further adoption. IoT take-up is still nascent and has not occurred extensively anywhere in the world. Currently, 85% of potential assets remain unconnected and several barriers need to be overcome by governments and companies to enable widespread adoption, most notably the establishment of industry standards around IoT and cybersecurity protection. Standards are required to allow smart connected products, machines and assets to interact in a transparent fashion. This goes beyond the simple communication protocols, and involves the creation of standard semantics and mechanisms that will allow smart devices to discover each other and interoperate. Security needs to be built in industrial control systems and designed into the components that make up the automation system, not added on later. The adoption of industrial security standards with certification will be essential to the advancement of IoT because it will ensure the security not just of individual assets but also of the larger systems and systems of systems.

Governments will also face new challenges. Omnipresent IoT deployment, with its necessarily attendant infrastructural sunk costs, could create barriers to entry and exacerbate disparity between the haves and have nots. Monopolies could arise, especially in high-volume commodity industries, while regulating distributed production (i.e. at the individual level) could be exceedingly complex.

Advanced analytics and artificial intelligence coming of age

The basics. The analytical engine powering all aspects of the connected economy is transitioning from rigid rule-based algorithms to flexible, intelligent ones. These are solutions that learn and evolve on their own over time, with the appropriate training data. Machines no longer simply answer the questions posed by people; they guide people to ask better questions in the first place, and offer faster and more insightful answers. This transition to AI, or machine intelligence, will profoundly affect both the nature of consumption and the structure of firms, supply chains and production. AI technologies could fundamentally impact society, along with jobs, wealth distribution and resource sustainability. Major technology companies are heavily increasing their mergers and acquisitions activities to improve their products and services, using AI solutions.

AI has achieved recent performance breakthroughs across numerous cognitive applications (Figure 7), from image classification to pattern recognition and ontological reasoning. This progress is due largely to convergent advances across three enablers: computing power, training data and learning algorithms. To illustrate this, automated image recognition and classification has improved in accuracy over the past decade, from 85% to 95% (a human averages 93%),[10] allowing such algorithms to progress from being novelties to enablers of real innovations, such as autonomous transportation for warehouse order picking. Solutions are currently trained on millions of image data, a 100-fold increase compared with a decade ago. They are powered by specialized graphics processing unit chips that are more than 1,000 times faster, and five to ten times more complex (based on a 150 to 200-layer neural network) than those of previous generations. Computing and storage costs have declined commensurately by an average of 35% year on year.[11] In the near future, AI will build on adoption enablers to unlock faster, smarter and more intuitive applications, although progress will probably be confined to broad

Figure 7: Development of AI and its future state

Level of human involvement	100%				0%
Illustrative examples	Rule-based computing	Machine learning			Machine intelligence
Cognitive mode	Rule-based inference	Supervised learning	Unsupervised narrow learning	Unsupervised context-aware learning	Self-aware unsupervised learning
Natural language processing	• Spell and grammar check	• Voice to text dictation	• Personal assistant apps for basic voice-based Q&A	• Real-time dialogue and translation	• Idioms, sarcasm, nuance articulation, intonation
Computer vision	• Inspection of fruit defects with infrared images	• Facial recognition • Identifying verification by fingerprints	• Complex classification (e.g. video segment search)	• Vision systems for self-driving vehicles	• Digital security agents • Autonomous exploration agents
Pattern recognition	• Industrial inspection based on rules on faulty functioning	• Fraud detection (e.g. based on historical fraud patterns)	• Product recommendation based on customer preference	• Automated real-time clinical diagnosis	• Disease development and prediction of infections
Reasoning and optimization	• Diagnostic maintenance	• Predictive maintenance for machinery and vehicles	• Failure prediction in mission-critical systems	• Automated recommendations based on inputs in value chain	• Search engine answering questions instead of giving search results
	Over 5 years ago	5 years ago	Current	2030 and beyond	

"AI will be good at specific computational tasks, but we are far away from general intelligence."

"Every object will become context-aware, reactive to your needs and ultra-personalized thanks to progress in AI."

"General intelligence requires a different set of non-deterministic computing architecture than what exists today."

Sources: Company websites; A.T. Kearney; A.T. Kearney/World Economic Forum workshop, November 2016; expert interviews adoption of narrow, context-aware intelligence across domains. The chasm separating narrow and general intelligence is believed to represent a fundamentally different set of learning algorithms and non-deterministic computing architecture compared with what exits currently.

Use in production. The rise of AI-as-a-service platforms, with lower barriers to entry, will allow companies to scale cognitive solutions in a zero-marginal cost setting and reshape industry dynamics. And while it is hard to predict the specific AI technology adoption paths over the next 10 to 15 years, the overarching impact themes are easier to envision, with AI technologies creating and changing the value proposition across all domains. Products and services will compete based on hyperpersonalized, cognitive features. Firms will leverage AI to process customer preferences in real time, so as to rapidly scale personalized products and services, as consumers become brand agnostic and more willing to pay for hyperpersonalized offerings. Organizations will also become efficient hierarchies (companies typically face a trade-off between efficiency of scale and hierarchical nimbleness). Large global firms and institutions, with economies of scale that have never been unleashed due to the complex coordination required, will benefit from AI; they will use AI applications to rapidly assess, predict and simulate decisions across silos, spans and layers.

Industrial companies are moving rapidly into the AI domain, investing in R&D around the "industrial internet". Analytics is being deployed for asset performance management and operations optimization, AI is improving safety and accessibility in the automotive industry and intelligent scheduling software is being adapted to real-time production variability. AI systems are enabling new levels of production system optimization, such as predictive maintenance and improved quality management.

Natural language processing can be adopted to create task-specialized personal assistants, as well as platforms for conversational technologies that can be provided as a service and integrated in various applications. Computer vision capabilities enhance visual navigation for self-driving cars as well as 3D scanning. Pattern recognition can identify customer preferences and be deployed to aid drug discovery. AI reasoning and optimization technologies are penetrating the value chain in various industries, such as the automotive sector, and currently inform 75% of consumer picks on Netflix. AI is used to optimize the multi-robot fulfilment system in Amazon warehouses.

Barriers to further adoption. Key ethical, regulatory, legal and economic questions about AI remain, and these may hamper its ability to become mainstream. Concerns about cybersecurity are a further critical issue in adopting AI; moreover, cybersecurity, as an industry in itself, will need to expand in tandem with AI and analytics (and IoT), to address inevitable vulnerabilities.

Advanced robotics emerging from its safety cage

The basics. Of the many digital technologies driving progress in the Fourth Industrial Revolution, advanced robotics has already shown that it can significantly alter the entire value chain. An estimated 1.8 million industrial robots are operating in global production systems today, representing a global market of approximately $35 billion. Penetration is markedly pronounced in Asia, with China being the largest robot market in the world. Robotic capabilities are still increasing while costs continue to fall (by about 25% over the last decade), allowing smaller factories to achieve increased outputs. Greater robot flexibility and intelligence supports proliferation across industries where they have not been deployed traditionally, including food and beverage, consumer goods and pharmaceuticals. The electronics sector is currently a significant driver of robot sales.

However, the impact of any given technology cannot be observed through an operational lens alone. A balance of fostering innovation and having appropriate regulations is required to ensure that robotic technology continues to progress and provides the widest possible societal and economic benefits.

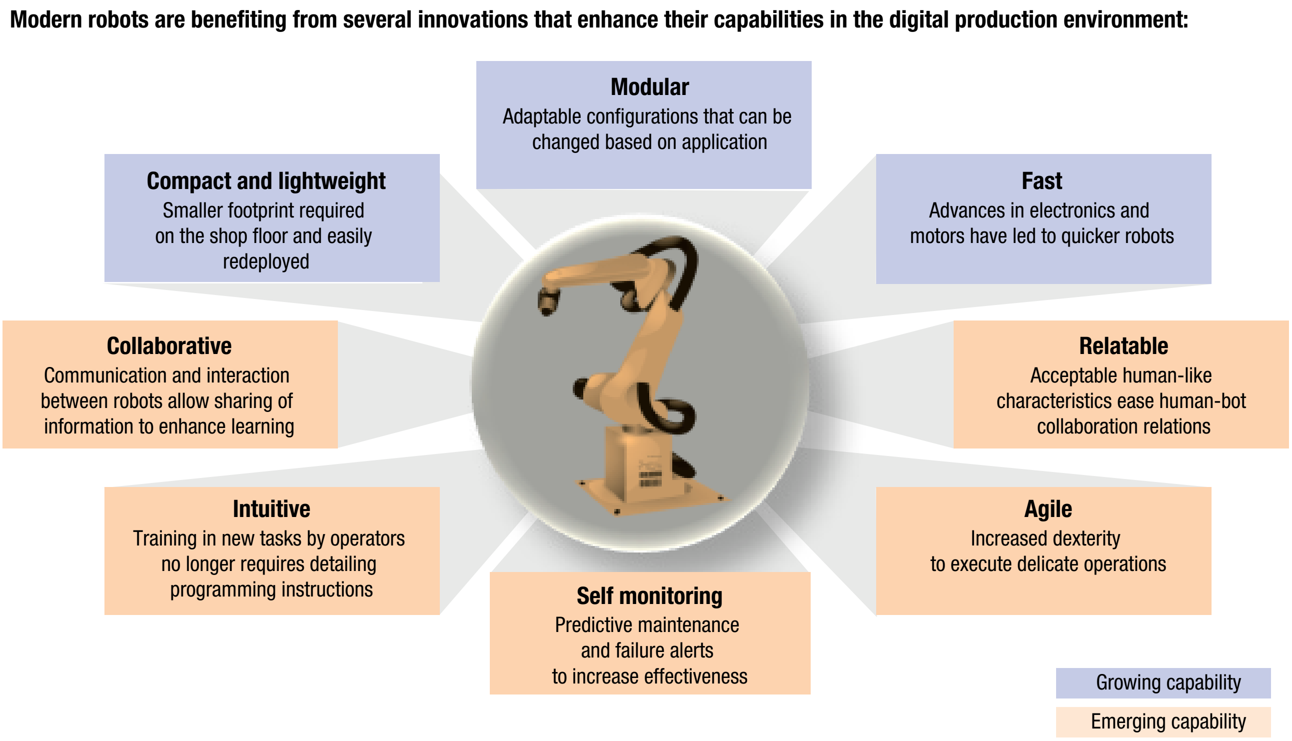
Use in production. The ambition is for robotics to become collaborative, intuitive, self-monitoring, agile and relatable, exhibiting human-like characteristics (Figure 8). Ultimately, the vision is to "uncage" robots, enabling them to move on from being traditionally separated from people for safety reasons and allowing them to work alongside their human counterparts. Sophisticated vision systems can lead to higher robotic self-awareness, by improving workplace safety in a collaborative robotic environment. Improved gripper technology that more closely mimics human hand function will greatly increase the functionality of robotic end effectors. In addition, enhanced machine-learning capabilities will harness AI and allow for improved recursive manufacturing processes.

Within production applications, handling has both the highest number of units installed in 2014 (almost 40% of the 1.7 million) as well as the highest annual growth rate (11% compound annual growth rate [CAGR] for 2010–2014), with packaging, picking and placing dominating the process usage for handling. The second biggest application is welding, primarily driven by countries that are also major car producers (China, Japan and USA). Assembly applications are another fast-growing segment (10% CAGR 2010–2014) due to an increase in electronics/electrical industry products decreasing in size and a need for increased precision quality.

Public discussion about adopting robotics is inextricably tied to the future of employment. One of the key rationales for using robotics in production is its growing ability to perform dull, dirty and dangerous operations. Moreover, the drivers for adopting advanced robotics are rapidly overcoming barriers to implementation. Removing people from these operations could create a safer workplace, with companies

Wearable technologies digitize the workforce

Figure 8: Innovations in advanced robotics



Source: International Federation of Robotics, World Robotics: Industrial Robots 2015

able to redeploy workers to higher-value tasks on the shop floor. Across the supply chain, robotics and automation could bring exceptional efficiencies that are increasingly vital to maintaining or increasing a company's competitive advantage – so much so that a company failing to embrace these advances might go out of business entirely. Another key point about the impact on employment is that adjacent industries, both existing ones and those not yet foreseen, will continue to create new jobs along the production value chain. Among robotics' other benefits in a digital economy is a connected, synchronized supply chain that enhances the ability to react to changing consumer demands and to produce "just in time". Moreover, robotics offer a major impetus to the changing mindset of moving from large manufacturing facilities to smaller, more localized manufacturing that is closer to demand.

Barriers to further adoption. Three key barriers obstruct widespread adoption: technology constraints, high costs of implementation and workforce limitations. This technology needs improvements especially since it relates to advanced vision and gripping systems and connectivity to "feel" and "work" in unstructured environments. Some firms are fearful of adopting a rapidly evolving technology before it is mature for an industry or application, which can delay investment decisions. High investment costs could prevent many emerging economy small- and medium-sizes enterprises (SMEs) and firms from implementing robotics solutions. The average cost for a spot-welding robot is projected to decrease by 22% by 2025 and robots-as-a-service models are beginning to appear; however, additional progress is needed to reduce the costs of the robots, supporting infrastructure and implementation. Additionally, at the workforce level, the fast evolution of robotic advancements will outpace the workforce skill level. In many cases, a lack of educational programmes and a shortage of the required technical skills sets pose significant barriers to implementing robotics successfully. Human acceptance of robotics and the allowance of collaboration can further stifle their adoption.

Several enablers working in conjunction have the ability to influence the tipping point for advanced robotics. These include government incentives and standards, education and workforce training programmes, decreasing costs and technology improvements in advanced vision systems and gripper technology, and integrated design learning.

The basics. Technology for augmented reality (AR) and virtual reality (VR) could become the next computing platform, following personal computers and smartphones. In the specific case of production, AR and VR could enable people to thrive and harness their capabilities more fully.

These technologies fundamentally shift the way that information is relayed to the user, offering immediate access to critical data. Distinct enterprise applications are now emerging across a variety of wearable technologies, with more of the human senses being tapped. Wearables, AR and VR present valuable use cases for quality inspection, work instructions, training, workflow management, operations and safety, logistics and maintenance. Producers of all three are now preparing the technologies for accelerated adoption and the most effective implementation possible. Early adopters are proliferating across many industries, including construction, automotive, logistics, aerospace, industrial equipment, mining, oil and gas.

Use in production. One of the key value propositions for wearables in the context of production is that they can offer value across multiple value dimensions (Figure 9). Wearables can help to improve margins through increased output, with further productivity improvements due to increased accuracy. Their astute deployment can reduce safety incidents. Quality variation can be pared down through reductions in downtime, defects and waste, while simultaneously reducing lead times. Design augmentation by means of wearables can reduce product lead times and R&D

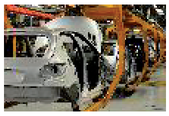
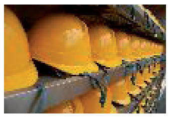
costs, while improving product reliability and providing a more efficient manufacturing process.

A particularly persuasive value proposition for wearables focuses on enhancing training and reconfiguring how the workforce acquires new skills. Demographics are fundamentally shaping the future workforce of production. The average highly skilled US manufacturing worker is 56 years old, while in India, 10 million young people enter the labour market every year. For many global producers, the growing priorities are to upskill talent and to quickly and effectively pass the knowledge of experienced operators to young talent that is often lacking relevant factory-floor skills. In the past, operators were taught by using a paper-based manual or flat human-machine interface visualization screen. Now, with AR and VR programmes, the worker can be fully immersed in the environment. With these enhanced training platforms, the workforce itself can be more flexible and configurable.

Barriers to further adoption. While wearables have some compelling value propositions, companies must deal with numerous factors when considering whether to adopt them for their enterprises. Potential end-users are typically interested in four main issues regarding wearables, AR and VR. One is the appropriateness of the technology; industries with a high labour cost or high cost of mistakes have the greatest potential to achieve a significant return on investment with these technologies. Job functions with strong opportunities are those in which people use their hands, yet need information to proceed.

Another concern is the timing of adoption. The technologies are continually becoming faster, lighter, safer, more efficient, more affordable

Figure 9: Value dimensions for wearables, augmented and virtual reality in production

Value dimensions		Value chain implications	
Productivity improvement	Wearables will lead to productivity improvements through communication, data digitalization and IoT integration	Allows for disruptive impacts to logistics and warehousing, medical, military, manufacturing and many other industries	
Health and safety development	Health and fitness wearables, combined with the IoT, will lead to improved health, fewer safety incidents and reduced insurance premiums	Provides a breakthrough opportunity to reduce ever-increasing health and medical costs while reducing safety incidents	
Reduced quality variation	AR and wearable devices will lead to step changes in quality through capabilities such as remote verification, automatic mistake proofing and live, step-by-step instruction/documentation	Improves quality, which will lead to reduced lead times, improved customer satisfaction, and improved cost and reliability	
Training enhancement	Virtual reality and wearable advancements will allow training opportunities to rapidly expand from the medical and military fields to broader industrial applications	Leads to significant reduction in training costs, increased training effectiveness for skilled trade jobs and, in some cases, training reduced to just the device itself	
Design augmentation	Virtual reality will be an integral part of design methodology and design for manufacturability	Allows for measurable reduction in time to market for new products, and real-time incorporation of manufacturing design changes	

Sources: A.T. Kearney; A.T. Kearney/World Economic Forum workshop, November 2016; expert interviews and more comfortable, making them increasingly practical for widespread use by enterprises. While they are currently ready for multiple applications, knowing their capabilities and limitations will ultimately determine, on a case-by-case basis, if now is the right time to adopt one or all three.

The third problem is that firms need to weigh the costs and benefits of implementation. Many pilot-use cases demonstrate a favourable return on investment. However, adoption will depend on decision-makers' confidence in the projected value created by using wearable technologies in their companies' operations.

Finally, there is the issue of the approach used for implementation. Most companies employing wearable solutions have started with pilot programmes. The technology requires a piece-by-piece, function-by-function launch, with specific areas where the hardware, software and content interconnect to add value. Ideal use-cases will be reusable across the enterprise, and subsequent implementation will build and improve on the initial pilot.

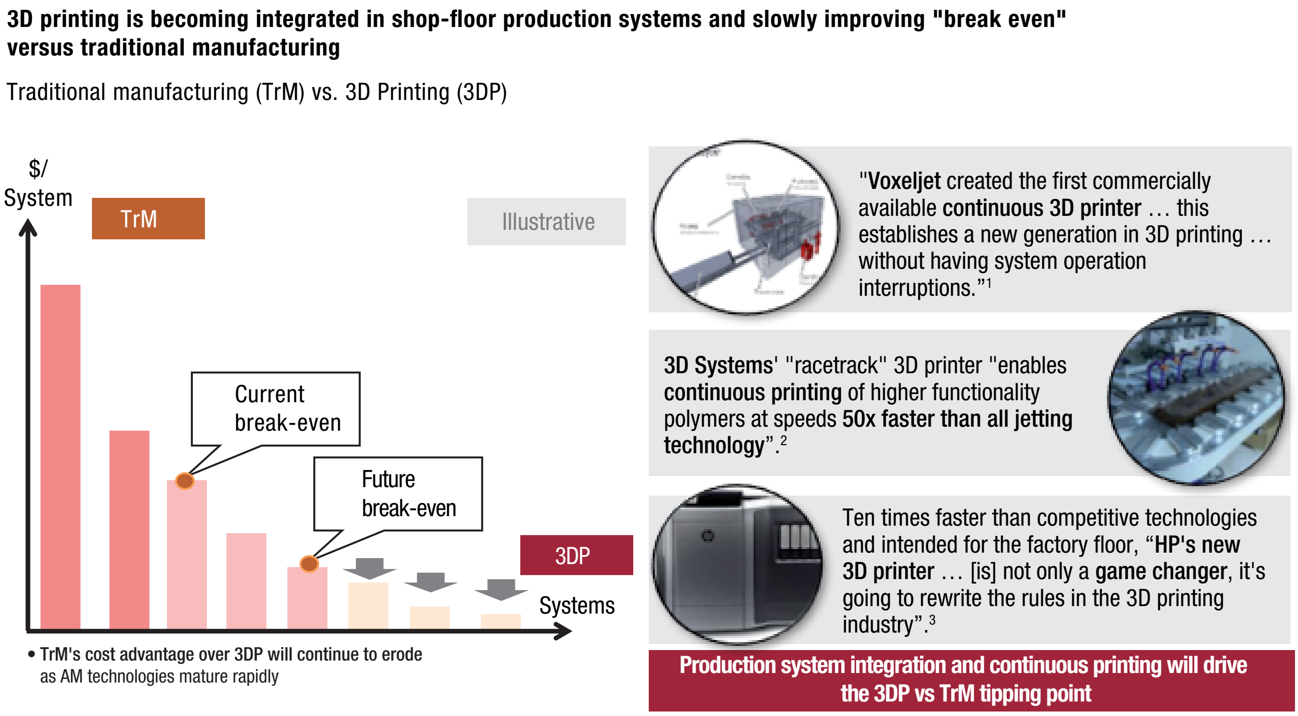
AR is approaching a tipping point in global adoption, while wearables are hindered by certain constraints on use and VR is limited to niche uses. The user experience, together with advancements in hardware (battery life and physical characteristics), software (the cloud and storage, AR platforms and tracking technology) and content (app stores), will aid in elevating wearables to mass adoption. In addition, increased awareness of wearables – currently mostly concentrated in North America – will contribute to expanding their use.

3D printing shapes the future one layer at a time

The basics. 3D printing is increasingly being adopted for industrial use, as it helps to deliver better products, and as value chains become ever more connected, simplified, automated and decentralized. 3D printing drivers include a growing library of materials conducive to manufacturing techniques, an ability to produce complex geometries (e.g. engine parts), a lower number of components required to make a product, and a streamlining of workflows. 3D printing is revolutionary, but not because it can replace conventional manufacturing, render traditional factories obsolete and localize all production (the economics will not support this currently and in the foreseeable future). It is revolutionary due to its ability to complement traditional manufacturing processes, revolutionize product design and create new value. 3D printing works best in industries where customization is critical, typically those with low-volume, high-value parts. Consumer products and the automotive, medical and aerospace industries are leading the use of 3D printing technologies, with North America being the dominant region, accounting for 40% of the industrial 3D printing units in use.

Use in production. 3D printing has improved and become more versatile to the extent that it is now transitioning from rapid prototyping to scaled production for select products and extending to other applications, such as tooling and patterns as well as repair and maintenance. Its impact can be felt increasingly across the entire enterprise value chain as it becomes integrated with shop-floor production systems and moves inexorably towards a break-even point versus traditional manufacturing (Figure 10). Although experts

Figure 10: Traditional versus additive manufacturing (3D printing)



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3 The Motley Fool, HP's 3D Printing Technology: How Concerned Should Stratasys Ltd. (SSYS) Investors Be?, http://www.fool.com/investing/general/2014/11/09/hps-3d-printing-technology-how-concerned-should-st.aspx

disagree on what will happen in the next 5-15 years, the general consensus is that desktop printing applications will outpace industrial ones. 3D printing is already in mainstream use to produce highly customized medical devices, such as hearing aids and dental structures. 3D bioprinting is still early in the hype cycle, with 5-10 ten years until mass adoption. Within the next 2-5o five years, 3D printing for prototyping is likely to be joined by many technologies that will spur its wider use beyond specialist fields.

Current 3D printing activity is concentrated overwhelmingly in the US, the EU and the Asia–Pacific region. Simplified supply chains and other cost benefits of 3D printing could lead to significant reshoring of manufacturing to traditionally higher-wage countries. For fully 3D-printed products and parts, design files will command a high trading value, with trade in intellectual property (IP) potentially replacing goods trade in large part.

Barriers to further adoption. While trade in IP seems a logical progression, 3D scanning and copyright infringement are a significant threat to this type of trade. Establishing laws and regulations for controlling IP infringement is necessary to support and encourage further investment and innovation in 3D printing.

As a process that has the potential to produce little to no waste and is capable of recycling materials, 3D printing could help to create a circular economy. However, it has to overcome the cost and product design barriers already faced by traditional technologies for existing recycling and sustainability efforts. Moreover, big gaps and fragmentation in standards and protocols need to be addressed, as standards are an important requirement in providing a framework for development. To reduce variability in the new technologies and methodology, industry leaders must establish material and hardware quality control specifications, characterize materials and mechanical properties of manufactured parts, and standardize methods for measuring and monitoring reliability and accuracy.

Implementing 3D printing effectively will require reskilling the workforce since a workforce specialized in digital design, printer operations and maintenance is required to successfully adopt new technologies. To ensure success, it will be important for developing nations to foster these capabilities in their workforces. Governments can help to redirect engineering and technical educational programmes to increase the focus on design education that emphasizes simplified manufacturing structures. In addition, government funding and tax incentives can encourage growth, while enabling more competitive cost structures for 3D printing.

The promise of converging technologies: New opportunities to create value

This work on technology is underpinned by the World Economic Forum's Fourth Industrial Revolution principles and systems approach:

– Systems, not technologies

– Empowering, not determining

– By design, not by default

– Values as a feature, not a bug.

The focus is not solely on individual technologies, but on their converging impact on the entirety of global production systems: from the factory floor and technologies' impact on a given firm, to repercussions for the broader industry, society and individuals. We look at technologies through the lens of their ability to solve broader societal problems and propose courses of action for business and governments to reflect values of growth, innovation inclusivity and sustainability in production (Figure 11).

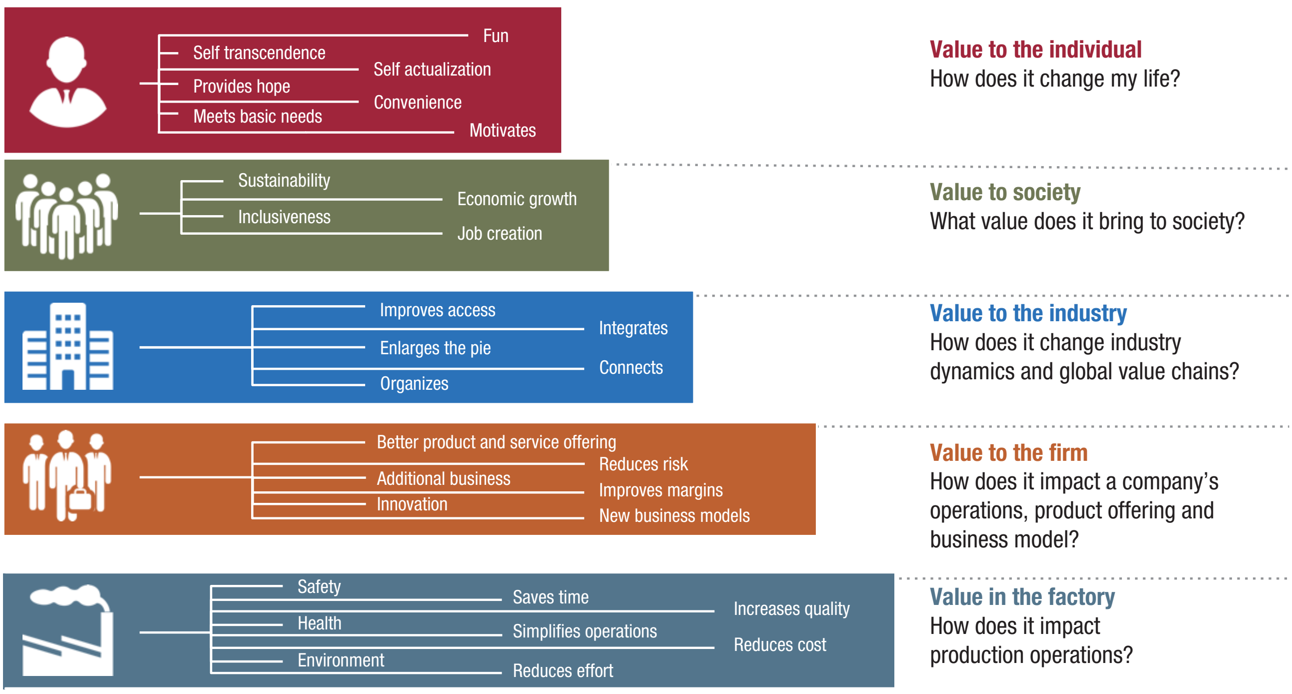
The following sections capture key insights on how technologies converge and create value at five levels: factory, firm, industry, society and the individual. It also sets out a framework to define the key questions on which the Forum Future of Production teams will be working in 2017, as the scope broadens to include more technologies and specific industries and geographies.

Over shorter time horizons, new production technologies will work alongside more traditional ones, complementing and improving them. Disruptive technologies offer distinct benefits that traditional production systems cannot deliver: mass customization; new capabilities to create products without high fixed capital investments and long lead times, and at greater speed; supply chain simplification and integration; and waste reduction. While multiple industries will use these technologies in specific business cases, their roles will grow in settings where these dimensions are critical for success.

Combined and connected, the five key technologies are opening up opportunities and changing decades-old mechanisms for creating and distributing value in 13 important ways (Figure 12).

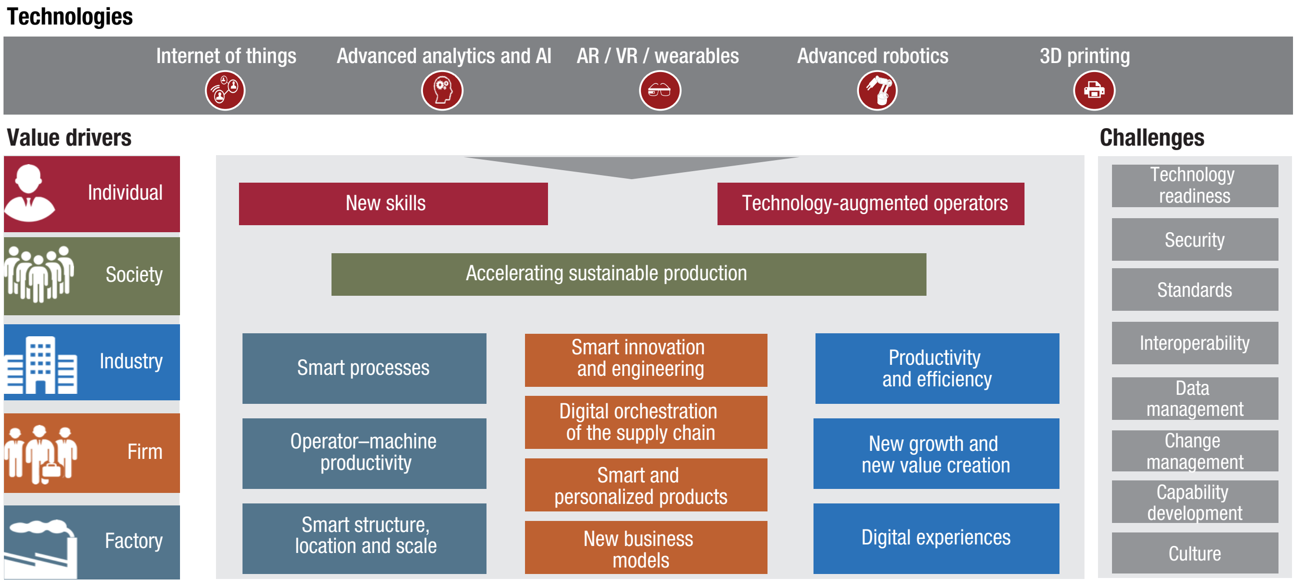
– **On the factory floor**: Technologies are providing the most immediate opportunities to create value, enabling the hyperefficient and flexible factory of the future Converging technologies are projected to increase efficiency and reduce costs by up to 30% across all operations, driven primarily by a 10% improvement in overall operating efficiency, 20–30% lower inventory carrying costs, 25% lower costs of consumer packaging, a 25% reduction in incidents involving safety, a 20–30% reduction in energy consumption, and a 40% reduction in water usage.[12] Additionally, factories can shorten

Figure 11: Value dimensions from converging technologies



Sources: A.T. Kearney; A.T. Kearney/World Economic Forum workshop, November 2016; expert interviews

Figure 12: Creating value from converging technologies



Sources: A.T. Kearney; A.T. Kearney/World Economic Forum workshop, November 2016; expert interviews

production runs to "batches of one", with high-quality, single-piece production at the price of current mass-produced goods. By integrating IoT, analytics, wearables and 3D printing, factories can compress product development and production cycles with a 20–50% reduction in lead times, and become responsive to external events as well as to changes in the supply chain and consumer demands.

The key questions are: At what pace will changes occur on the factory floor? How will those changes spread across networks? What implications of disruption need to be closely monitored on the corporate executive and global policy- maker agendas? To realize this vision, producers must make the factory of the future a core focus of strategy and investment, upgrade legacy facilities, ready their workforce with new sets of skills required to perform technology-production tasks, and invest in a lagging IT infrastructure.

– **For firms:** Technologies drive value by augmenting four capabilities: smart innovation and engineering, digital orchestration of the supply chain, delivery of smart and customized product offerings, and innovation of business models. The economic impact of serving customers through smart and customized products is tremendous, as future spending will be on personalized (both physical and digital) offerings; this could make up over 50% of consumer spending by 2030. Revenues from new smart, connected and customized products, and new business model innovations such as pay per performance, can contribute revenue increases of 25% at the firm level and 25% in adjacent industries.[13] With vertical integration falling to about 20% of the value added among original equipment manufacturers, digital technologies provide an opportunity to synchronize supply chains and reduce risks. This integration will require companies to adapt their strategy and leadership philosophy to embrace a new digital way of thinking and prepare for the new cyber-risks to which this integration will expose their companies.

– **For industries:** While the specifics differ across all four industries (automotive, chemicals, pharmaceutical and consumer), technologies will create three sources of value: on the demand side, they will "enlarge the pie" and create new value and profit pools; on the supply-side, technologies will unlock industry-wide efficiencies and productivity; lastly, technologies will allow for new experiences and value propositions that combine both growth and efficiency.

– Data-driven processes will generate $371 billion in net industry value for production over the next four years streamlining supply chains.[14] By lowering costs of capital and delivering extra flexibility, technologies change the economic equation of production locations, enabling production facilities to shift closer to the point of demand. In many cases, technologies will also lead to drastic changes in the "rules of engagement" and disrupt the equilibrium that has existed for many years in traditional industry verticals. This happens to traditional value chains when several verticals converge to create new services and value for customers and intermediaries will find themselves challenged by new entrants who lower transaction costs and provide new value.

– **For society:** There is fierce debate on the impact that technologies will have on economic growth, employment and wealth distribution. Optimists point out that the technologies that enabled the past three industrial revolutions have unlocked productivity gains and lifted billions of people out of poverty. Others are quick to counter that today's exponential pace of converging technologies may cause disruptions that companies and governments will be ill-equipped to manage. One of the most under-discussed aspects of technological progress is the great potential it has for the environment. It is estimated that technologies could accelerate sustainable production and deliver 26.3 billion metric tons of net avoided CO_2 emissions from 2016 to 2025. By 2025, this will amount to 8.5% of global emissions.[15]

– **For individuals:** As global production systems experience a new wave of technological advancement and innovation, a new production workforce and work environment is on the horizon. While automation technologies are replacing human operators on the factory floor, they are also generating a new set of jobs that require a different skills set. Future operators on the factory floor require fewer mechanical skills and more technical competencies in IT and data science combined with a lifelong learning capacity and potential for reskilling. The technical competency profile will be T-shaped (broad in terms of general knowledge and narrow for specialized knowledge) and interdisciplinary rather than specialized. Analytics specialists, engineers and programmers will need to think across business models, production processes, machine technology and data-related procedures. Technologies are creating a new relationship between people and machines. They will contribute to the technology-augmented Operator 4.0 – a vision for the smart, skilled operator performing cooperative work with robots – and work aided by machines and advanced human–machine interactive technologies, leading to better skills, wages and working conditions.

Value in the factory

The hyper-efficient and flexible factory of the future

Factories have long held a place in the popular imagination, in some cases as sources of employment and community prosperity, but in others as hectic, grimy and polluting facilities, where thousands of people are employed in low-skilled line positions.

The factory of the future is a more digital, virtual and resource-efficient space. It is an environment that is more connected – in terms of both information availability and machines speaking to and directing each other – and one where automation, simulation, visualization and analytics are deployed more widely to eliminate waste and increase efficiency in material yields, energy consumption, effort and time. **In particular, the factory of the future has three common overarching characteristics: connected, automated and flexible digital shop floor processes; new relationships between operators and machines; and the structure, location and scale of the factory.**

1. **Digital shop floor processes that are connected, automated and flexible.** IoT combined with analytics and AI will improve asset efficiency, decrease downtime and unplanned maintenance, and allow manufacturers to uncover new sources of value in services. By employing digital twins, simulations and virtual reality, designers and operators will be able to virtually harness interactive media to optimize design, production processes and material flows. 3D printing is allowing for the development of exciting new products, with vast potential to create new product designs and functional capabilities as well as greater customization. It seems likely that we will see large "batches of one" in more industries, making traditional production and assembly lines a thing of the past.

Figure 13: Characteristics of the hyperefficient and flexible factory of the future

Source: A.T. Kearney

While the Fourth Industrial Revolution may not fully change the production paradigm by 2030, it will address all value drivers on the factory floor, from higher customer satisfaction, quality, innovation and agility to better economics and value creation, as shown in Figure 13. Advances in technologies will reduce energy consumption by 20–30%, while lead times can be cut by 20–50% by integrating IoT and analytics in operations. With increased transparency, manufacturing and product design can become responsive to external events, changes in the supply chain and consumer demands. Depending on the type of industry and production, geographic location and maturity of adoption, factory managers can achieve cost reductions of between 5% and 30% of the total cost base by adopting a combination of technologies, with the main drivers of value being quality, inventory, asset utilization, employee productivity and maintenance.[16]

Digital tools will be used to plan, simulate and optimize the entire product development and production process through VR technologies and data computing. The factory walls will dissipate, as remote processes and other activities become seamlessly integrated along each stage of the value chain all the way to the end user.

2. **New relationships between operators and machines.** Technologies are changing the nature of the work and skills required of operators. Robotics is automating most dull, dirty and dangerous tasks, and increasingly collaborative robots are moving out of the cage to work side by side with operators. Augmented reality and wearables are also changing the ways operators train, assemble and make decisions on the shop floor, increasing flexibility, productivity and quality.

Data is be at the heart of this factory revolution, as product design, factory coordination and process optimization will require less human intervention. Overall, the proportion of technology will continue to increase and the proportion of labour will decline. However, labour will actually remain cost-effective in many arenas, as technology allows workers to significantly improve their productivity, even as overall numbers decline. In developed markets, where populations are ageing out of the workforce, and lower-cost markets, where workers will need increasingly better skills, technology will offer a valuable step towards quickly unlocking productivity gains and enabling the use of untapped labour pools.

3. **The structure, location and scale of factories.** The factory of the future is hyper-efficient and sustainable, increasingly modularized, with interchangeable lines that can be reconfigured easily for multiple production batches. Digital production technologies will allow software developers, product designers and production technicians to work in open, airy environments. Since technology diminishes the role of low-cost labour and lowers the threshold of economies of scale, distributed manufacturing will become the norm, with producers augmenting their traditional production footprints with smaller and more flexible units located next to points of consumption, allowing them to meet local requirements with a more responsive supply chain. These more localized, energy-efficient and lower-waste factories will contribute to advances in the circular economy.

Modes of manufacturing will in some ways begin to come full circle and resemble artisanal, in-home production. However, there will be digital twists, changes won't be universal, and their pace will be uneven. There are several substantial barriers to overcome in order to expand this paradigm beyond a few niche pockets. Expensive dedicated and specialized equipment is required to achieve cost-effective production, and the advantages of existing production ecosystems limit the range of production flexibility and practicalities of a distributed global production footprint, especially with expensive last-mile transportation costs still in the equation.

While these general trends seem likely, the factory of the future will not follow a single paradigm. The model of the large-scale production facility that emerged in the wake of the first industrial revolution, or the complex, many-tiered supply chains resulting from the third revolution, could continue to prevail in some industrial sectors. Change will come more quickly in some places, or look different in others, as industry sectors and developing versus developed economies seek their own paths. In the meantime, manufacturers need to reconsider their capital investment strategies in the light of rapidly changing capabilities that will make historical investment horizons obsolete. In time, advancements in technology will result in a vastly improved and more affordable digital infrastructure, increased human and machine collaboration and the rise of real-time communication and integration, both within the production system and with the outside world.

To realize this vision of the hyperefficient and agile factory, producers must bring forward the required skills and infrastructure as technology redirects the flow of jobs, eliminating scale-oriented, low-cost labour-based employment, distributing higher skill-based jobs to regional market centres. This is where policy-makers must take the lead – in partnership with business, academia and societal organizations – in preparing their communities and ensuring they prosper in the process. Whereas previous industrial revolutions evolved over the course of multiple generations, the pace of the Fourth Industrial Revolution requires a more rapid response if communities do not want to be passed by.

The factory: Key questions in 2017

1. What are the paradigms that the factory of the future will follow in different industries?

2. How can producers realize the vision of the hyperefficient and agile factory of the future? How can they integrate their network of factories within their operations?

3. How can local governments support the development of high-tech production facilities and workforces? How can societies prosper in the new factory towns?

Value to the firm

In addition to value in factories, new technologies create value for firms through four levers: smart innovation and engineering, digital orchestration of the supply chain, delivery of smart and customized product offerings and innovation of business models. The impact on firms can occur in three stages:

– First, the use of technologies to bring their factory and supply chain operation costs down. They will use many of these technologies in their existing business models.

– Second, new business models will evolve, driven mostly by a shift from products to services, ecosystems and long-term relations between producers and consumers.

– Concomitantly, this transformation will require companies to adapt their strategy and leadership philosophy to embrace a new digital way of thinking and ready themselves for the new choices (e.g. global production footprints, investments) and risks to which this integration will expose their companies (namely cyber-risk).

1. Smart innovation and engineering

Technologies allow producers to move from designing for manufacturing to designing for speed and performance. Product development has traditionally followed a sequential process, from R&D, product concept and design, along with product engineering and supply chain management, to marketing and after-market services. Digital product lifecycle management techniques, combined with advances in 3D printing, allow for rapid and multidirectional data flow. They thereby create an iterative, agile product development paradigm to reduce development cycle times and respond faster to changing market needs, creating better products more quickly. For example, using a lean, agile product development approach called FastWorks, GE Appliances was able to develop a refrigerator with ten iterations and active customer feedback in 18-24 months. Traditional product development would have resulted in a single iteration of the product over a five-year period, at a significantly higher cost.

To fully exploit the freedom to design and personalize, engineers will have to create products that operate within systems, with a growing information-systems component. Progressively, more product value will be derived from a product's digital rather than its physical components. Innovation and engineering departments will need to make higher levels of investment in electronics hardware, sensors, software and connectivity components, as well as in acquiring the necessary talent and skill sets.

2. Digital orchestration of the supply chain

A large-scale producer's size can be a benefit in terms of efficiency of scale, but can be a hindrance due to the formation of silos, the cost of coordination and the inefficient orchestration of value chains. As such, large firms are less agile and never realize their true advantages of scale (e.g. due to delays, wrong information at moment-of-truth decision-making, information silos). Additionally, producers have been outsourcing a larger share of their operations in recent years, pushing costs and complexity outside company walls. In Germany, for example, vertical integration in the automotive industry has fallen to about 20% of value added among original equipment manufacturers and, with further digitization and lower transaction costs, the proportion may drop to between 10% and 15% in the not-so-distant future. As a result, producers have to manage and coordinate a more complex supply chain.

The convergence of technologies will create new ways for large firms to unlock synergies and become increasingly nimble at a large scale. This can be done by increasing the levels of synchronization, transparency and trust among all players in the value chain through some key dimensions:

– **Smarter insights and collaboration**: AI and smart algorithms will allow more real-time and faster data-driven decision-making among leaders. For example, using digital twin tools, companies can simulate actions and explore complex trade-offs in real time before making a decision and they can monitor feedback results (e.g. digital twin for capital projects, simulation for sourcing decisions).

– **Economies of skill**: Insights and knowledge often end up being tacit and are lost when employees leave a firm or units restructure. Advances in analytics, AI and AR, among others, can help ramp up new employee training (e.g. factory floor, contact centre, planning functions), as well as augment staff capabilities through embedding best practices.

Consequently, digital technologies will allow firms to achieve their true economies of scale while increasing agility, as the traditional trade-off between size and agility becomes less relevant. Winning firms must embrace this structural and, ultimately, cultural shift. Producers that can unlock the full potential of smart orchestration and efficiency can transform the traditional cost/optimization curves. In fact, the traditional single-digit "incremental optimization" of 2-8% of costs can become a 10-30% cost reduction, leading to an aggregate trillion-dollar-plus impact on global value chain efficiencies.

3. Smart and personalized products

The convergence of production technologies is opening the door to a long-time business aspiration: mass personalization. Previously, business economics dictated that production costs correlated strongly with production volumes.

Personalization meant losing some volume and, hence, came at a significant premium. This paradigm is shifting. IoT, analytics, artificial intelligence and 3D printing equip producers with new capabilities to create smart, connected and personalized products that enable a richer customer and user experience.

Smart and personalized offerings will come in two distinct forms: physical personalization, where technologies create distinctive forms, fits and functions; and smart personalization, where sensors and connectivity create special digital offerings. In the pharmaceutical industries, 3D printers will be able to manufacture drugs with a dosage unique to a patient's condition and genetic code. In other contexts, product personalization will materialize through the configurability of goods. Smart fabric is changing the textiles industry, whereby garments will become increasingly configurable by the user. Google and Levi's are collaborating on Project Jacquard to transform fabric and clothes into interactive surfaces. This partnership aims to mass-produce connected clothing to enable the user to interact with their environment. Clients' willingness to pay for personalized products is typically greater, which has translated into margin increases for producers.

The economic impact of serving customers through smart and customized products is substantial, as future spending will be on personalized offerings (both physical and digital). By 2030, this could account for more than 50% of consumer spending, as smart products expand beyond use in electronics and entertainment to playing a role in cars/ transportation, housing, healthcare services and even food.

4. Business model innovation

For many producers, the advent of smart and customized products provides opportunities to alter the business model and sell products as services. The ability to design and manufacture bespoke products beyond current specifications will progressively open up a range of associative services, once the product is sold. It is an expansion of the value chain beyond maintenance, upgrades and other traditional services. For example, the automotive industry is already embracing connecting technology and automation. To take one case, Swedish car producer Volvo and US-based transportation service Uber have joined forces to develop a self-driving car service in San Francisco. Such a combination has the potential to change consumers' relationships with their cars, including in-car entertainment and car-sharing marketplaces. In another example, US-based heavy equipment manufacturer Caterpillar is using a combination of wearable and IoT technologies to enhance its rental experience.[17] By providing wearable devices to the renter of the equipment, Caterpillar enables its clients to make maintenance accessible to less qualified staff. The wearable video and communication technologies facilitate diagnostics of particular conditions and, when the situation is complex, it enables remote Caterpillar experts to assist client staff, who remain on the work site. Such augmented reality applications are developed increasingly by third parties, opening up new roles in the after-sales value chain and highlighting the importance of a flourishing production innovation ecosystem where producers, service providers and clients can interact.

Revenues from new smart, connected and customized products, as well as from new business model innovations such as pay per performance, can contribute up to 25% revenue increases at the firm level, and up to 25% increases in revenue in adjacent industries.

The firm: Key questions in 2017

1. What specific business models are enabled by technologies across multiple firms?
2. How can producers transform their operations and culture to embrace the technology? How do SMEs take advantage of the opportunities offered by technologies?
3. How can tailored industrial policies support national producers?

Value to industry

The combined effect of technologies on factories and firms can cascade into new sources of value creation, not only within an industry, but also across industries (Figure 14). The convergence of new production technologies will have profound implications on industry value chains by, for instance, opening up new revenue opportunities, transforming the drivers of cost, changing the nature of the relationship among participants, deepening understanding of customer segments, or generating new business models.

The insights below are based on a new value chain economics model and the existing value-at-stake model[18] created by the World Economic Forum, whose purpose is to provide input on how converging technologies will create new value and (re)distribute it within four industries: the automotive, chemicals, pharmaceuticals and consumer sectors. In 2017, the Forum will work with stakeholders will continue to increase the number of industries and apply these insights to specific representative products and services in their associated value chains. The aim is to map how value was created and distributed in developed and developing economies in 2015, while exploring how technologies could change that picture by 2030 in incremental and disruptive scenarios.

1. Demand drivers of value – growth and new business models

The technologies underpinning a network of connected and personalized products and services are fundamentally altering the creation of value and value-capture paradigms across all industry verticals (where vendors offer goods and services specific to an industry). In many cases, they are also leading to drastic changes in the "rules of engagement" and disrupting the equilibrium that has existed for many years in traditional industry verticals. Traditional value chains are disrupted when several verticals converge to create new services and value for customers. The rise of connected cars and mobility services has led to value pooling and sharing across multiple verticals, including automotive, telecom and mobility service providers.

In the automotive industry, for example, active safety systems have necessitated a move beyond traditionally rule-based embedded control systems towards systems that scan and monitor their environments and can take semi-autonomous action to prevent collisions and minimize human error. As autonomy increases, advanced sensors, artificial intelligence algorithms and vehicle-to-vehicle connectivity will provide self-driving vehicles with an awareness of their surroundings.

The automotive industry is moving rapidly towards this future and customer value is increasingly augmented through software features and functionality that is continually upgrading the vehicle. Tesla is creating new paradigms in the industry by using over-the-air (the wireless delivery of new software or data updates to products) upgrades and frequent software updates for vehicles to push new functionality and features. Smart and connected products are growing rapidly across all industry sectors, including healthcare and home appliances. However, in an environment with multiple devices, extracting higher value will be limited until standards for interoperability are established and adopted.

Figure 14: Technology drivers of value across industries

Automotive	Chemicals	Pharmaceuticals	Consumer
Vehicle infotainment	Molecules plus services	Personalized medicine	Data as an asset
E-hailing / mobility services	Outcomes-based services	Outcome-based care	Data to improve experience
Usage-based insurance	Clean technology growth (e.g. batteries)	Intelligent wearables	
Multimodal transportation		Digital medicine – 'Chip on a pill'	
Telematics-based services			
Additive manufacturing	Process automation systems	Continuous manufacturing	Physical store transformation
Digital retail / online dealers	Digital supply chain	Digital discovery of molecules	E-commerce
Digital supply chain	Digital twins / remote operations	Process automation systems	Sharing economy
Digital product development	Additive manufacturing / synthesis	Drug 3D printing	Smart supply chains
Digital aftermarket services	Digitization of end markets	Virtual care experiences	Smart factories
Autonomous driving	Green chemistry enablement	Mobile health solutions	Hyper-personalization
Assisted driving		3D tissue modeling / digital testing	Products to services and experiences
Vehicle diagnostics and maintenance		Counterfeit protection on drugs	Health and well-being goods and services

- Growth through technologies (revenues)
- Productivity and efficiency through technologies (profits)
- Experiences (growth and efficiency)

Sources: World Economic Forum Digital Transformation of Industries, A.T. Kearney; expert interviews, Accenture

In the pharmaceutical industry, a growing shift towards personalized medicine and innovative drug delivery systems is reshaping the industry. With greater focus on the cost of healthcare, governments and insurance providers aim to control expenditure while delivering outcomes. This has led to a movement beyond pills and towards digital solutions that supplement drugs with sensors to monitor patient condition between dosages and clinical visits, offering the capacity to alert or intervene as necessary. Digital developments are paving the way for increased rigour in adherence to prescribed treatment. Digital pill dispensers that adjust treatment and dosage based on data are currently undergoing clinical trials.

2. Supply drivers of value – productivity and efficiency Enhanced efficiency.

The convergence of production technologies will enable producers to obtain significant efficiencies across production processes. For example, the pharmaceutical industry is transforming its manufacturing approach from a discrete batch model to a continuous manufacturing model. Essentially, drugs will be produced through a continuous and uninterrupted process, as opposed to the current step-by-step approach. This transformation is enabled by innovation in advanced automation and sensor technologies. According to the Novartis-MIT Center for Continuous Manufacturing, technology for continuous manufacturing will save 30% in operating costs and up to $150 million in savings per plant investment,[19] as the required facilities are smaller for a comparable output.

Democratized production. Decreasing transaction costs have also levelled the playing field by significantly lowering barriers to entry and allowing local and regional producers to operate on a global scale, which is critical to creating the sharing economy. Technologies help to democratize production, allowing small- and medium-sized producers access to previously unavailable processes and know-how. New hardware and software tools make it easier than ever to turn a creative idea into a functional prototype. Desktop 3D printers were an initial part of this trend, but innovative software and integration tools have further simplified the creation of complex parts. The advent of distributed manufacturing and its focus on producing closer to the consumer provides opportunities for SMEs to capture value through last-mile customization, or to completely redefine their business models.

In the pharmaceutical industry, the first 3D printed drug – Spritam, used to treat epilepsy – was approved by the US Food and Drug Administration in 2015. Entire pharmaceutical chains will probably need to be revamped to adopt 3D printing technology for select drugs. Dentists already use replica jaws and dental implants as part of normal operations, and have disrupted the value chain for dental implants. Many pharmaceutical companies are investing heavily in artificial intelligence, not only to focus on genomic research, but also to use digital simulation to accelerate drug discovery and research.

3. Experience (growth and efficiency)

Information asymmetries and lack of real-time alignment of demand and supply led to typical value chains that required several intermediaries – wholesalers, distributors and retailers – between the producer and the consumer. These intermediaries facilitated the two-directional flows of market demand and signals deeper into the value chain, and the flow of goods and services towards the end customer. Across every stage of the value chain, information asymmetries manifested as capital tied up in inventory and the operational cost of the intermediaries. The final cost to the customer included the incremental profit pools of all the value chain intermediaries, the costs of capital tied up in inventory and waste from obsolescence. In addition, the customer's choices were limited to the risks that value chain intermediaries were willing to take.

Platform-based value chains. Platforms such as Amazon reflect the trend towards disintermediation to drastically lower the transaction costs traditionally required to connect customers with products. In addition, digital platforms give customers access to a large variety of product choices offered at a lower cost, and allow producers to have access to large market segments and higher profits enabled through disintermediation. Digital enablement has thus had a direct impact on reducing inefficiencies in transaction costs and information asymmetries inherent in traditional vertical value chains.

Industries: Key questions in 2017

1. What specific business models are enabled by technologies across multiple firms?
2. How can tailored industrial policies support national industries?
3. What are the immediate actions and partnerships that industry and government can make to unlock the true potential?

Value to society

Accelerating sustainable production through technology

The global economy is built on unsustainable foundations. Production and consumption are currently 1.5 times the natural capacity of the planet, which is by definition unsustainable. It has not yet been possible to decouple economic growth from growth in emissions and use of resources. The trend has been that for every 1% increase in global gross domestic product (GDP), CO2 emissions have risen by approximately 0.5% and resource intensity by 0.4%.[20] Economic growth entails increased use of inputs, materials and fossil fuels, which generate environmental pollution and degradation. Current business practices will contribute to a global gap of 8 billion metric tons in supply of and demand for natural resources by 2030, translating into $4.5 trillion in lost economic growth.[21] With growing pressure on the world's resources and an urgent need to cut emissions, technology has an important role to play.

However, technological advancements also come at a significant environmental cost. Industry must act to tackle the rapidly increasing environmental impact of new technologies. For example, growing mountains of electronic waste are posing a threat to human health and the environment, while increasing energy use by data centres is contributing to pollution and emissions. Analysis conducted by the World Economic Forum Digital Transformation of Industries initiative suggests that technological transformation could make a positive contribution to this challenge. Technological disruptions in the industries examined (automotive, consumer, electricity, logistics and healthcare) could deliver an estimated 26.3 billion metric tons of net avoided CO^2 emissions from 2016 to 2025. By 2025, this will amount to 8.5% of global emissions.[22] Ensuring that this potential value can be realized and scaled up even further requires a number of hurdles to be overcome, not least in terms of accepting new, circular production models and other sustainable manufacturing practices.

Disruptive technologies could potentially transform traditional materials-reliant production systems and accelerate a new form of sustainable production. For example, 3D printing could reduce manufacturing costs by $170 billion to $593 billion, cut energy use by 2.54–9.30 exajoules and reduce CO_2 emissions by between 130.5 and 525.5 metric tons by 2025. The range within the savings is due to the immature state of the technology, and the associated uncertainties in predicting market developments.[23]

However, technologies are not a universal panacea for sustainability and their impact needs to be assessed on a holistic level to ensure net positive gains of "shared value". With such value, economic profits are anchored to social benefits for people and the planet. Sustainable production aims to "do more and better with less", increasing net welfare gains from profitable economic activities for the planet (by reducing use of resources, as well as degradation and pollution along the whole lifecycle) and for people (decent jobs, safe working conditions and a higher quality of life). All five technologies can be facilitators for both driving sustainability and fostering the emergence of a new working contract between employers and employees.

Technologies drive three key phenomena that accelerate sustainable production: hyperefficiency, dematerialization and the elimination of waste.

– **Hyperefficiency**: From an environmental point of view, firms have a natural tendency to seek efficiency in using resources. During structural change, the transition from medium-tech industries to high-tech industries is beneficial from a macro perspective, as it implies a lower level of environmental pollution. However, despite these positive dynamics, the current trend of technological change does not guarantee that a sustainable path will be followed in the future.

– **Dematerialization**: Disruptive technologies accelerate the dematerialization of production systems. Sensors, data, algorithms and advanced machines, and all the other digital tools of the Fourth Industrial Revolution, help to bring about a significant reduction in the number of atoms used throughout global production systems. 3D printing technologies allow designers to create lighter products with 30% less input materials, and to produce them closer to demand centres. IoT, advanced analytics and algorithms enhance visibility and precision along the value chain, eliminate waste and increase product lifespans. Advanced robotics in warehouses and on assembly lines can pack goods very tightly and so use less space. Autonomous cars, when – not if – they come, will lead to fewer vehicles in total and fewer parking garages in cities.

– **Elimination of waste**: Technologies provide clear opportunities to eliminate the annual $1 trillion of waste[24] in global manufacturing supply chains by matching supply and demand more efficiently. Each year, an estimated one-third of all food produced – equivalent to 1.3 billion tonnes – ends up rotting in the waste bins of consumers and retailers, or spoiling due to poor transportation and harvesting practices.[25] E-waste is also growing, resulting in lost potential value from reusing or recycling devices, ever-growing mountains of landfill and increasing volumes of toxic chemicals being released into the environment. According to a United Nations study, 40 million metric tons of e-waste was discarded in 2014.[26]

Technological advancements will define the future of production systems. Such advances could create green, clean, equitable and sustainable systems. The ability of individual firms and industries to upgrade their technological capabilities depends in part on the functioning of national innovation systems. In this perspective, learning and innovation must take place between cross-sector actors, not just in the network of customers and suppliers, but also within the technological infrastructure, institutional and organizational framework, and knowledge-creating and diffusing institutions. As these innovation systems improve, all actors will be able to tap into international sources of technological knowledge, which will circulate rapidly among industries and firms of different sizes.

To mainstream sustainable technological applications, knowledge must be disseminated broadly throughout the global economy. This will require strong public policies to diffuse new technologies, with institutional infrastructures that include, among other features, extension services, industrial clusters, metrology standards, productivity standards, technical information services and quality control institutions. The systems will further require educational and training programmes to ingrain sustainable thinking in future generations.

Society: Key questions in 2017

1. What partnerships can truly unlock the potential of sustainable production?
2. How do technologies impact employment and wealth distribution within societies?
3. Which countries stand to gain and lose most from technological diffusion?

Value to the individual

As global production systems experience a new wave of technological advancement and innovation, a new workforce and work environment is on the horizon. Many voices claim that the production workforce (both white- and blue-collar) will be negatively impacted by disruptive technologies. The research, however, signals many reasons to be optimistic about the production workforce of the future.

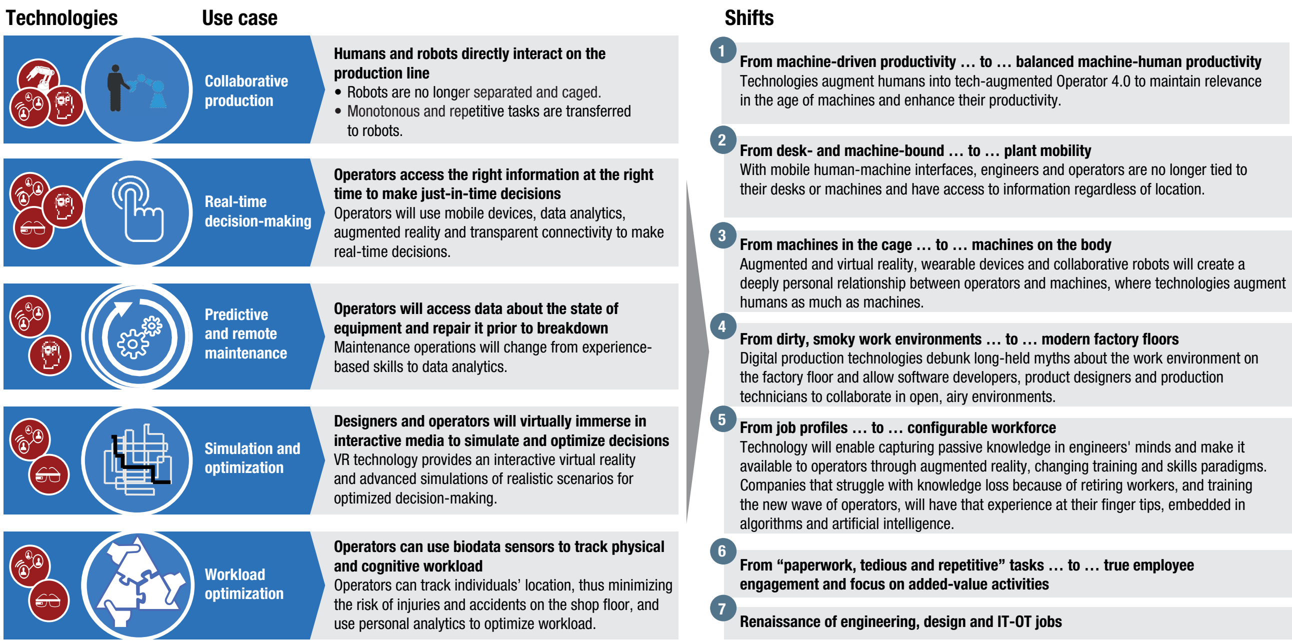
The current debate on the impact of technologies on the production workforce has been driven by the interplay of "replacement-creation" dynamics in each industry, occupation, job and task family. Economists and pundits across the world have researched, forecast and fiercely debated the net impact on jobs and the economy, as machines and factories become smarter with the inherent capability of displacing human tasks. Some suggest that unemployment will soar, and focus on the potential for disruptive technologies to replace jobs, with estimates ranging from 15% to 47% of tasks and jobs. Optimists point out that, after more than two centuries of innovation, the global economy has always proved able to create more and better jobs, although transitions and adjustments have come with a measure of pain. The findings herein reveal two types of dynamics:

- **Replacement dynamics:** The portion of technology will continue to increase in factories and the portion of labour will decrease. Compelling economics and high returns on investment indicate that technologies will be adopted increasingly, reducing the number of employees needed on the shop floor to generate the same output. In particular, wider use of robotics and digital technologies will reduce simple, repetitive tasks, as these activities can be standardized and performed by machines. Manufacturing, assembly and maintenance operations in all industries will probably lose part of their human workforce.
- **Creation dynamics**: Technologies allow producers to generate growth and employment through customization, building the service and new business models. By adopting these disruptive technologies, producers are able to introduce new products and services in existing and new markets, increase their competitiveness and expand their workforces, as well as increasingly relocating production and jobs closer to demand centres.

While the debate about whether technologies will replace more jobs than they create is ongoing, it is much more certain that the nature of work on the factory floor will be transformed, and that companies will need operators with a new skills set. Figure 15 highlights the most influential cases and seven key shifts in the changing nature of work on the factory floor.

Given the changes in the nature of work, future operators will require an essentially different skill sets. According to a Manpower study, more than 80% of North American production executives agreed that they struggled to access the talent they needed, and over 70% agreed that the talent gap issue was increasing in severity and would continue to do so.[27] Due to the convergence of the physical and digital worlds, operators on the shop floor will be working with a new set of technologies and tools, performing different tasks in different organizational structures, and will thus require a different set of skills (Figure 16). Irrespective of the industry, technologies are increasingly demanding more jobs in IT, software, analytics, research and design. The technical competency profile will be T-shaped and interdisciplinary rather than specialized. Analytics specialists, engineers and programmers will need to think across business models, production processes, machine technology and data-related procedures. New job titles will emerge, such as virtual reality designer and cybersecurity guard.

Figure 15: Shifts in the nature of work on the factory floor



Sources: A.T. Kearney; Schneider Electric; expert interviews

Figure 16: Competency and skills to enable 3D printing production technologies

Workforce implications

● High ○ Low

Function	Importance to increased adoption	Degree of skill change required	New skills required to drive 3DP adoption	Evolution of existing skills to drive 3DP adoption
Engineering	●	●	• **3DP asset operations:** able to operate and perform end-to-end tasks to run new 3DP assets • **Finishing capabilities:** shift focus to finishing of parts vs removing material from bulk block	• **Maintenance repairs and training:** leverage current skill set to support 3DP assets
Education	●	◑	• **3DP teaching:** understand fundamentals and trends, both technical and business	• **3DP curriculum:** create courses at each entry point (kindergarten – university) to teach concepts and applications
New product design	◕	◕	• **3D design:** convert product idea to 3D vs 2D • **3DP fundamentals:** understand process and capabilities	• **Design velocity:** produce computer-aided designs quickly to support mass customization
Material research and development	◕	◑	• **3DP materials development:** identify/develop new 3DP material required to support business needs	• **Material testing:** create the capabilities to test the properties of 3DP vs traditional materials
Software and hardware development	◕	◔	• **3DP asset design:** improve new hardware to match required functionality (print size, velocity)	• **User interfaces:** increase ease of use for manufacturing and maintenance, and for non-tech-savvy workforce
Sales and marketing (S&M)	◑	◕	• **3DP market education:** promote and sell 3DP products, and realize new business opportunities	• **S&M activity velocity:** quickly support new product launches at a more rapid rate
Human resources	◔	◑	• **3DP high-level understanding:** communicate capabilities and strategies to potential employees	• **Employee retention:** create new 3DP-specific strategies to maintain talent in tight labour market
Procurement	◔	◔	• **Sourcing strategy:** understand the supply market for materials, software and hardware	• **Supplier qualification:** use new criteria to support rapid 3DP-specific qualification plans

Sources: Press search; A.T. Kearney

The technologies of the Fourth Industrial Revolution are augmenting human workers, increasing their physical and cognitive capabilities. To successfully embrace the Fourth Industrial Revolution paradigm in a socially sustainable way, manufacturing enterprises will need to accompany technological transformations with training and development programmes for their workforce. New tools and technologies for skilled labour use are also needed, by which the operators are directly and indirectly affected.

The Operator 4.0 is defined as a smart and skilled (human) operator who performs not only cooperative work with robots, but also work aided by machines, as and if needed, by means of human cyber-physical systems, advanced human-machine interaction technologies and adaptive automation.[28] The Operator 4.0 vision will create trusting and interaction-based relationships between humans and machines, making it possible for smart factories to capitalize on smart machine strengths and capabilities, and empower their smart operators with new skills and gadgets to fully capitalize on the opportunities being created by Fourth Industrial Revolution technologies.

Indeed, as the Fourth Industrial Revolution unfolds, tech-augmentation will enable production operators to assume many machine capabilities, transcend their physical and cognitive abilities to perform at "superhuman" levels and stay in the workforce longer.

For example, one paper presented at last year's CIE46 Proceedings in Tianjin, People's Republic of China, envisions three types of "augmentation":

– **Exoskeletons**. Workers will be fitted with a "human-robotic exoskeleton to increase the strength of a human operator for effortless manual functions." These augmentations will "increase the social sustainability of factories in the long-term, especially with the outlook of a larger proportion of elderly workers due to changing demography."

– **Augmented Reality**. Operators will be provided "digital information and media that is overlaid in real-time in his/her field of view…reducing the dependence on printed work instructions, computer screens and operator memory, which need to be interpreted first by a skilled worker." In other words, AR could soon make any operator a smart operator.

– **Enterprise Social Networking Services**. More expansively, the future of production will include "use of mobile and social collaborative methods to connect the smart operators at the shop-floor with the smart factory resources." Such connections will infinitely expand capacity to "interact, share and create information for decision-making support… empowering the workforce to contribute their expertise across the production line, accelerate product and process innovation, revolutionize planning, and facilitate problem-solving by bringing together the right people with the right information."

The Future of the Operator lies not in what workers can do better than machines, but in what the technology-augmented Operator 4.0 collaborating with machines will be able to do better.

The individual: Key questions in 2017

1. What are the specific tasks, skills and job families in future production systems?
2. What are the curricula, labour and training policies that governments and companies need to collaborate on to develop the new workforce?
3. What policies need to be put in place to support disruptions within the current workforce?

Implications for leaders

Avoiding the perils

Widespread adoption of the five technologies will augment elements of operational performance, but the broader impact on the economy and society will be mixed.

Not every company and country in current value chain will capture the value unlocked by these technologies equally. Laggard producers and economies dependent on labour arbitrage are at highest risk of encountering negative impact from technologies. The most productive OECD producers (frontier firms) have grown at a rate of 3.5%, compared with an anaemic 0.5% for the laggards.

Technologies will accentuate a reallocation of scarce resources to productive firms and a growing divide in competitiveness.29 Additionally, economies dependent solely on labour arbitrage will see their source of economic growth decrease, as technologies increasingly enable competitive production in higher-cost environments. Reshoring is unlikely to occur across the board; it will be predominantly in capital- intensive sectors with high transportation costs, where proximity to consumers is a key value driver.

Technologies will exacerbate current inequalities. Most survey respondents worried that white- and blue-collar workers, as well as developing economies dependent on labour arbitrage for their economic viability, will be the most negatively impacted.

Unlocking the value

Many of these technologies have yet to realize their full potential and contribution to inclusive global productivity. Unlocking their value will depend largely on the ability of businesses and governments to improve the technical readiness of the technologies, educate the necessary skilled workforce, foster inclusive diffusion and adoption, ensure availability of underlying infrastructure and address issues of data governance and cybersecurity.

– **The speed and cost of overcoming technical limitations**: While most technologies have viable commercial solutions, technical restrictions limit their utility, and the cost of entry, especially for smaller producers, is prohibitive.

– **Diffusion and adoption**: Most technologies are restricted to large-scale producers. Adoption is a bigger challenge than readiness, both within the supply chain and geographically. Within the supply chain, 99% of firms are SMEs that struggle to understand and take advantage of these technologies. A recent study of 4,500 German SMEs found that fewer than 20% had heard of Industry 4.0, much less taken steps to implement it. This highlights the challenge many countries will face in assisting their small and medium-sized producers to reap the value of technologies.[30]

– **Availability of skills**: While industry value chains are evolving rapidly to adapt to the new digital normal, a key determinant of speed and success is the ability of players in the value chain to rapidly transform their strategic mindset and digital capabilities. New skills and capabilities across most organizational functions are required to support technology adoption. The number of open production jobs in the US has been rising; in fact, 2016 stands at the highest level in 15 years, as producers struggle to find the talent required in the market. For example, of the nearly 200 million workers in the US workforce, only one in ten is self-rated as digitally savvy. This gap should concern companies and governments, given that digital capabilities are critical to innovation, growth and productivity. In developing economies, digital savviness is presumably much lower, potentially creating a digital divide in the workforce.

– **Availability of underlying infrastructure**: To compete in future production chains, nations must have quality infrastructure. Developing it to underpin these technologies depends on countries' ability to support the infrastructure in various areas, from reliable energy sources to adopting fifth-generation mobile networks or wireless systems (5G). While infrastructure alone will not suffice for global leadership, lack of it will cause nations to fall behind and will create serious obstacles for company networks of supply chains.

– **Governance gaps**: Sustainable diffusion and adoption of all five technologies depends on a viable and defensible global governance system for data, cybersecurity and ethics. As IoT and distributed production take hold, existing policies and regulations are not enough to cover the commercial/non-commercial transmission of data, ownership of data, taxation of revenues, value-added tax, tariff applications and treatment of IP. Challenges of cybersecurity and interoperability are hindering producers from reaping the benefits of digitalization and automation. According to IBM, production was the second most hacked industry in 2015, behind healthcare. Automotive producers were the top target, accounting for 30% of all attacks among manufacturing industries. No established frameworks or best practices currently exist for managing and resolving conflicts associated with AI applications and systems.

Various difficulties associated with how to anticipate potential conflict complicate framework development. For example, AI research is not regulated, although products that employ AI applications may be, thus placing the regulatory burden at the product level.

A few companies and countries have already launched significant transformation and policy initiatives, unleashing a whole new wave of industrial and geopolitical competition. Industrial giants are waging a fierce war for industrial platform dominance and extracting higher value from their large production footprints.

Recognizing the importance of production to their industrial future, countries have launched programmes that support deploying these technologies to their domestic producers. Most notable among these are the US network of institutes as part of Manufacturing USA, Germany's Industrie 4.0, the UK High-Value Manufacturing Catapult, the Chinese Made in China 2025 programme (with more than $3 billion in advanced manufacturing investments), the EU's €7 billion Factories of the Future programme and India's Make in India.

An agenda for action

The transformation journey for producers

Technologies compel producers to invest in and transform their operations, business models and culture; not doing so would risk their firms' long-term prospects. The rationales for business to invest in new technologies include getting products to market more swiftly, improving efficiency and productivity, differentiating product offerings and, crucially, making better products. The demonstrable benefits brought by new technologies mean their deployment is inevitable. Most large-scale producers have already contemplated and experimented with technologies through pilots. They will increasingly move from "visioning" and experimentation to full scale transformation and implementation of the digital and technology agenda to create value.

For companies, speed is the defining factor for this transformation, and the key to being successful in adopting it. If companies cannot develop at a pace that allows them to win, they will fall behind very quickly. Effective, long-lasting transformation in the new context requires an immediate, intense focus on understanding the technologies and how they can create value within the business, while developing the necessary culture and skills to execute the transformation.

Successful producers will move quickly from weighing up and comparing different technologies for the best business case to embedding the technology in their vision and developing a path for the journey from vision to value. Producers will increasingly adopt a lean approach to innovation with a quick succession of ideation, prototyping and scaling-up stages.

However, many producers, regardless of scale, struggle to take advantage of these technologies. Producers must evaluate the level of integration, speed of adoption and organizational alignment to benefit from the technologies' potential (Figure 17).

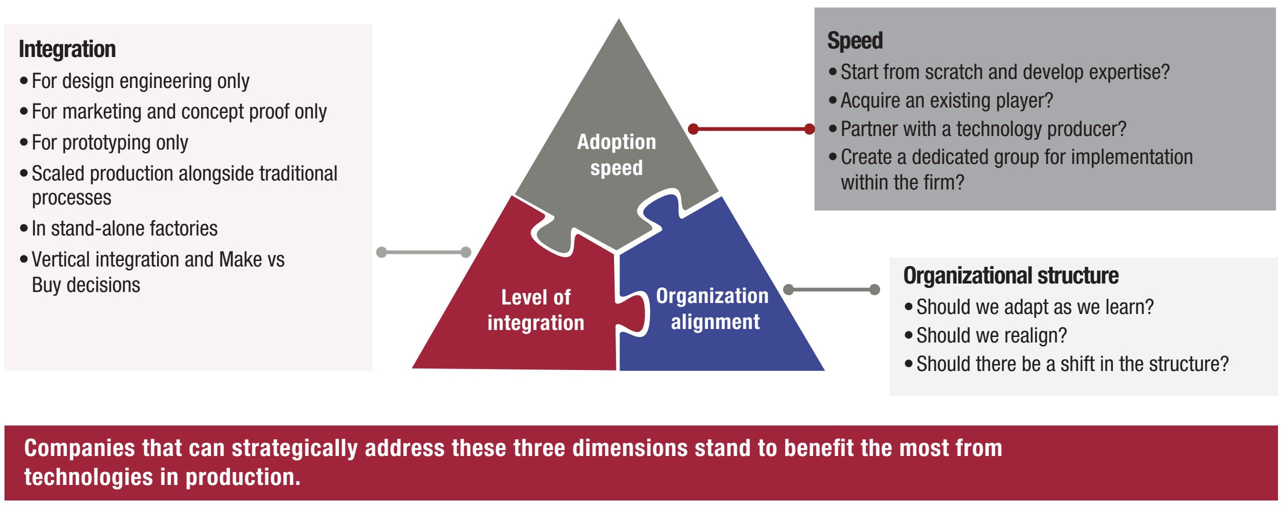
To jump-start the digital transformation of production and operations footprints, companies initiate experiments and build enablers for scaling up:

- Initiate iconic experiments
- Communicate with and energize teams to increase awareness
- Acquire leading-edge external capabilities
- Build a collaborative network of partners
- Upgrade the operations and information technologies and systems.

A new role for governments in stimulating production

When it comes to technological progress, policy-makers are challenged to define the right regulatory and policy frameworks that stimulate innovation, while protecting the interests of citizens. Throughout most of the world, policy-makers have been caught unprepared by the broad economic and societal changes that technologies create for global production systems.

Figure 17: Considerations when implementing technologies



Source: A.T. Kearney

For countries potentially threatened by trends towards reshoring, what opportunities and niches can they strive to exploit and occupy? And what measures can they adopt, whether in trade policy, education or capital expenditure?

Narrowly prescribed Fourth Industrial Revolution strategies will not work for governments. While its effectiveness is disputed, industrial policy has become fashionable again in the past 5-10 years, with governments using increasingly sophisticated and assertive policies to stimulate activities and promote structural change. Narrowly prescribed Fourth Industrial Revolution strategies that pick winners and save losers may not yield the greatest chances of success, given the uncertainties about technological development and where the likeliest prospects of monetizing particular innovations and sectors lie.

In fast and exponential technological growth, the government's role shifts towards that of an orchestrator of comprehensive production ecosystems. Success in the future of production requires a broader framework covering research, technology, innovation, education, labour, industrial and trade strategies, which need to track and move with the external environment.

Irrespective of specific national production and industrial strategies, governments, businesses and members of civil society can implement four cross-industry and cross-technology areas of action. These can drive inclusive adoption of technologies and foster a growing production system:

– **Focus on research and innovation, and improve technological readiness**: Many technologies have yet to be fully developed and, indeed, many have yet to be conceived. Presumably the current, prevailing picture will not last forever, or even over a relatively short time frame. As a result, the multiple roadmaps to development will themselves be altered or supplanted over time. That makes it more critical for all areas of civil society to participate with policy-makers, innovators and business managers in making decisions about using technology in production. Joint efforts and joint investments require all relevant voices to be considered, and those forums and other conversations should become a continuous process of engagement.

– **Democratize production knowledge**: Many makers, entrepreneurs and SMEs have a limited grasp of production knowledge (principles, technologies and tools). This knowledge is spread across tradespeople, books, suppliers, engineers, firms and many other sources, which creates a major barrier to scaling up production for SMEs. Governments can help to coordinate and centralize access to this information.

– **Create pathways to production careers, including education and skills**: The production industry suffers from a global talent gap. Preparing for a career in advanced production requires both formal education and plenty of hands-on training. A diverse skill set is essential, as the new production paradigm requires workers to show creativity, adaptability and inventiveness as they produce highly complex and evolving products.

  Governments and companies need innovative partnerships that address primary and secondary school education, as well as apprenticeships, internships, higher education and workforce reskilling and upskilling programmes.

– **Prioritize public–private partnerships on business formation, innovation and growth**: Global competition and domestic barriers are challenging the ability to set up and develop successful production enterprises. In addition to basic policy recommendations that emphasize ease of doing business, governments and companies can work together in innovative partnerships to encourage growth of home-grown enterprises; they could tap into the purchasing power of national governments, develop collaborative production partnerships with other firms that have complementary capabilities, and develop specialized niche skills.

Next steps for the System Initiative on Shaping the Future of Production

The future of production raises important questions for governments, companies and society, and requires global dialogue to shape a vision of production that promotes economic growth and innovation in an inclusive and sustainable way. Leaders will be forced to examine a series of "what if" questions regarding the sources of global economic growth, innovation through technologies, national competitiveness, skills and jobs for the workforce and sustainability.

In 2017 and 2018, the World Economic Forum will continue to provide a platform for discussion and debate through a series of projects, such as in-depth industry, sectoral and regional studies that will, in time, fill out the global production picture.

The Technology and Innovation for the Future of Production project will focus on technologies that, both individually and in combination, are reshaping the way we make things. It will assess the impact of these technologies and develop innovative and unique insights and tools to help governments and companies better understand ongoing and future technology-driven transformations, inform investment and policy decisions and foster a common understanding among stakeholders. Efforts so far have been directed towards five key ICT-enabled technologies. Yet there are other important categories of research within the production landscape, such as advanced materials, design for sustainability, energy, biotechnology and nanotechnology.

The top technologies and the global research agenda that require investment for production to stimulate innovation and sustainability will be identified. The foundation concepts of interoperability, cybersecurity and new business models in production will be explored (e.g. platforms for industrial manufacturing), the impact of technology on the "factory of tomorrow", and how SMEs can benefit from technology diffusion. This project is being conducted in collaboration with the System Initiative on the Future of Digital Economy and Society. The Forum welcomes input to this global conversation.

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