



Exponential technologies in manufacturing

Transforming the future of manufacturing through technology, talent, and the innovation ecosystem

Introduction

The manufacturing industry as we know it is fundamentally changing, with advanced technologies increasingly underpinning global competitiveness and economic prosperity. Many leading 21st-century manufacturers are converging digital and physical worlds in which sophisticated hardware combined with innovative software, sensors, and massive amounts of data and analytics is expected to produce smarter products, more efficient processes, and more closely connected customers, suppliers, and manufacturers.

As growing numbers of manufacturing companies look to embark on this transformative journey and navigate through a maze of challenges and opportunities, executives—understandably—have questions: What exponential technologies show the most promise? What is the magnitude of impact that can be expected from adopting and deploying these exponential technologies? How is the manufacturing industry leveraging these technologies in new and distinctive ways to solve current business issues and/or transform our future? What does it really mean to become a Digital Manufacturing Enterprise (DME) of the future, and how might our business model evolve? How do we move toward our future vision without fundamentally disrupting what we do today? What challenges do we face and what incentives will we need to drive change throughout our organization and broader ecosystem?

To better qualify such challenges, provide a reality check in separating substance from hype, and highlight opportunities for manufacturers to embrace exponentials to drive future competitive advantage, Deloitte collaborated with the Council on Competitiveness and Singularity University (SU) to conduct the *Exponential Technologies in Manufacturing* study, and share the resulting insights in this publication.

List of interviewees/executive participants

Dr. Kevin Shaw

Faculty, Networks and Computing,
Internet of Things and Sensors
Singularity University
Chief Technology Officer
and Co-Founder
Algorithmic Intuition Inc.

Andre Wegner

Chair, Digital Manufacturing
Singularity University
CEO
Authentise

Dr. Greg Hyslop

Senior Vice President
Boeing Engineering, Test & Technology
Chief Technology Officer
The Boeing Company

Nathana O'Brien Sharma

Program Director for Faculty Affairs
Faculty, Law, Policy, Ethics and Blockchain
Singularity University
Partner
Crypto Lotus, LLC

Dr. Klaus G. Hoehn

Vice President, Advanced Technology
and Engineering
Deere & Company

Dr. Lloyd Colegrove

Director, Data Services
and Fundamental Problem Solving,
Continuous Improvement Center
of Excellence
The Dow Chemical Company

Henry Cialone

President and CEO
EWI

Shyam Krishnaswamy

Senior Manager, Corporate Strategy,
Innovation and Sustainability
Exelon Corporation

Raymond McCauley

Chair, Digital Biology
Singularity University
Principal
Exponential Biosciences

Michael Vergalla

Faculty, Robotics, Space and Digital
Manufacturing
Singularity University
Founder and Lead Researcher
Free Flight Research Lab

Michelle Bockman

Global Head of 3D Printing Commercial
Development and Expansion
HP, Inc.

Steve Chadwick

Principal Engineer in Manufacturing IT
Intel Corporation

John (Jay) B. Rogers, Jr.

CEO and Co-Founder
LM Industries, Inc.

Jeffrey J. Wilcox

Vice President, Engineering
and Program Operations
Lockheed Martin Corporation

Jim Phillips

Chairman of the Board and CEO
NanoMech

Dr. Davide Venturelli

Adjunct Faculty, Quantum Computing
Singularity University
Quantum Computing Team Lead
and Science Operations Manager
USRA Quantum AI Laboratory
NASA Ames

Dr. Mehmood Khan

Vice Chairman and Chief Scientific
Officer
Global Research and Development
PepsiCo, Inc.

Samuel Bouchard

CEO and Co-Founder
Robotiq

Keren Elazari

Faculty, Cybersecurity
Singularity University

Aaron Frank

Principal Faculty, AR/VR
Singularity University

Ramez Naam

Co-Chair, Energy & Environmental
Systems
Singularity University

Dr. Tiffany Vora

Vice-Chair, Medicine and Digital Biology
Singularity University

Neil Jacobstein

Chair, Artificial Intelligence and Robotics
Singularity University
Distinguished Visiting Scholar, MediaX
Stanford University

Dr. J. Michael McQuade

Senior Vice President, Science
and Technology
United Technologies Corporation

William Sobel

Chair, Technical Steering Committee
MTConnect Institute
Chief Strategy Officer
VIMANA

About this study

The *Exponential Technologies in Manufacturing* study explores how exponential technologies are transforming the future of manufacturing and how global manufacturing companies can best tap into this disruptive shift to evolve, grow, and thrive. Exponential technologies are those that enable change at a rapidly accelerating, nonlinear pace facilitated by substantial progress (and cost reduction) in areas such as computing power, bandwidth, and data storage.

Between May 2017 and December 2017, senior leaders at Deloitte held discussions with more than two dozen senior executives (chief executive officers, presidents, chief technical officers, chief research officers) and subject matter experts (SMEs) at some of the world's largest manufacturing organizations, Singularity University, and several small technology start-ups. These companies—both public and private enterprises—represent large swaths of manufacturing employment, including diversified manufacturing, chemicals and specialty materials, process and industrial products, consumer products, automotive, aerospace and defense, technology, and life sciences. Participating companies included members from the Council on Competitiveness—such as Deere & Company, Intel, PepsiCo, Lockheed Martin, NanoMech, Boeing, United Technologies Corporation, and Exelon Corp.—as well as others, including Robotiq, Dow Chemical, Hewlett-Packard, and Local Motors, to capture the voices of the manufacturing industry and technology domain experts. The interviews were conducted on an individual basis, often face-to-face in the executive's office, but sometimes by telephone. These hour-long dialogues sought the executives' perspectives on:



How exponential technologies are delivering real impact and value for manufacturing enterprises



How exponential technologies are shaping company strategy and new business models



How manufacturers can mitigate risks and realize the potential promise, application, and rewards of adopting these exponential technologies

The interviews were supplemented with detailed perspectives written by SMEs from a dozen technology domains and comprehensive secondary research of data from respected think tanks, key academic institutions, and industry literature.

The study aligns with Deloitte's mission to address industry's greatest challenges and drive lasting impact; with Singularity University's core mission to educate, inspire, and empower leaders to apply exponential technologies to address humanity's grand challenges; and with the Council on Competitiveness's mission to drive long-term productivity and economic growth and increase the living standards for every American.



Key findings and insights from the *Exponential Technologies in Manufacturing* study



Among the exponential technologies that can enable transformational growth in manufacturing are: 3D printing (additive manufacturing); advanced analytics; advanced materials; advanced robotics; artificial intelligence (AI) (including machine learning); biotechnology/biomanufacturing; blockchain; cybersecurity; digital design, simulation, and integration energy storage; high performance computing; Interface of Things (AR/VR/Mixed reality, wearables, gesture recognition); Internet of Things (IoT) (deep dive technology section, page 26).



Talent continues to be a key competitive differentiator within the manufacturing industry. Yet talent shortages and the need for new skill sets remain a critical issue across the globe. Attracting and retaining top talent and exploring new approaches to accessing talent will become more important than ever (page 16).

There is a clear and compelling case for manufacturers to leverage exponential technologies and incorporate digital transformation throughout their organization (page 10). The fourth industrial revolution is enabling unprecedented change, and the pace of this change is no longer incremental; it is exponential, disruptive, and nonlinear. It is imperative that manufacturers quickly move to adopt and use exponential technologies to tap into this disruptive change; the longer they wait, the further behind they may fall (page 10).



Innovation enabled by exponential technologies can help manufacturers grow faster, be more agile, and unlock new forms of value (page 15). But while exponential technologies' roles are more important than ever, the pace of their adoption is seen as relatively slow among manufacturers. Interviewed executives cite several barriers, including structural and cultural challenges, regulatory burdens, talent constraints, and leadership mind-set (page 14).



Exponential technologies are also dramatically changing the "what" (technology and automation), "who" (talent and the open talent continuum), and "where" (workplaces, physical location) of work across manufacturing organizations (page 18). As manufacturers look to increase their pace of change and transformation, they are not only leveraging internal assets in new and different ways but also turning more often to resources outside of their walls, tapping into the broader ecosystem, as there are clear advantages to being close to where innovation is occurring (page 22).





Business and government research and development (R&D) activities, along with venture capital (VC) investments, also play a critical role in company- and country-level innovation pipelines and ecosystems. In addition, more manufacturers are looking outside their four walls to increase innovation and decrease time to market, forming collaboration within and across the broader innovation ecosystem (page 22).



Moving confidently into the future means that manufacturers should develop a culture that is receptive to change and agility, one in which all stakeholders see differently, think differently, and act differently (page 15). It also means adopting an exponential transformation approach that uses an iterative process that begins by determining a company's strategic vision and needs. Once that journey is established, the company can use a portfolio approach to invest its resources and innovate across the core, adjacent, and transformational areas (page 54).



Among interviewed executives' recommendations for developing an exponential mind-set: Know what problems you are trying to solve; entrust small teams to innovate at the edge; operate outside of traditional walls; and raise the national dialogue on system-level competitiveness and innovation enablers (page 55).



Across the global manufacturing competitiveness landscape, US companies lead in R&D spending, but other countries, especially China, are quickly catching up (page 23).



While there are many potential pathways to success, a Digital Manufacturing Enterprise (DME) that has higher leveraged assets, focuses on product platforms to engage customers, and leverages exponential technologies can be highly successful (page 27).



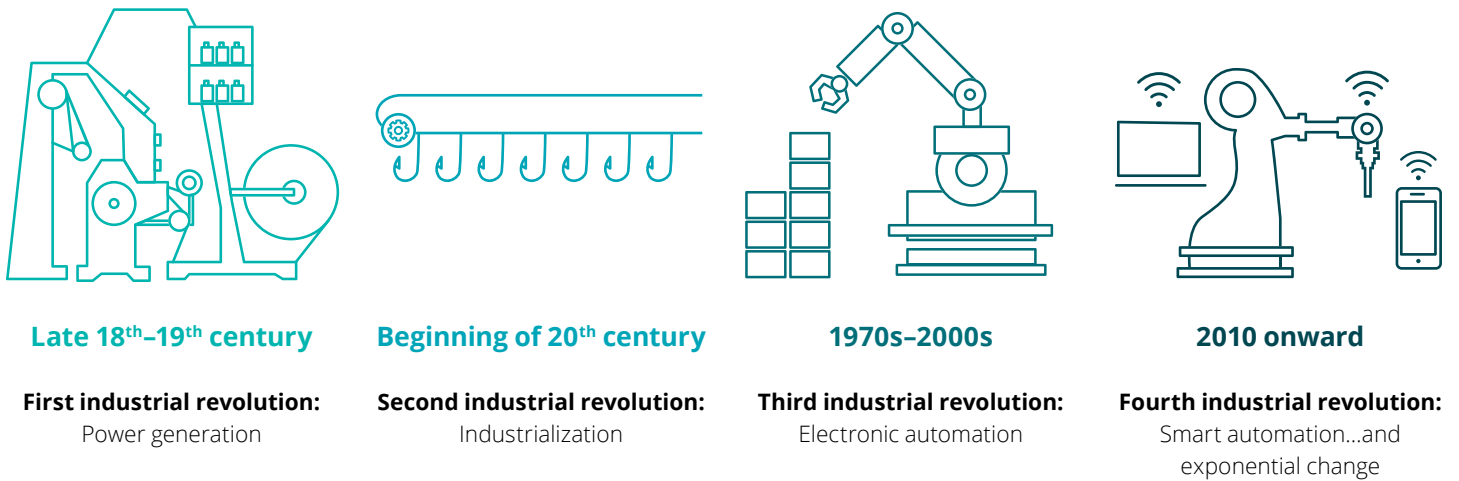
Call to action

Technological disruption is already affecting every part of our lives...every business, every industry, every society... even what it means to be "human." These changes show no signs of slowing down; in fact, they are accelerating rapidly. Manufacturers and the broader manufacturing ecosystem urgently need an evolved mind-set and tool set to navigate through the maze of opportunity and overcome the potential challenges of disruption. The collective goal of this study is to provide insights that empower leaders of major manufacturing corporations, technologists, and others within the manufacturing ecosystem to solve current and future challenges, and to apply emerging technologies to create and capture new forms of value for a prosperous, abundant future.

Transforming the future of manufacturing: Technology, talent, and the innovation ecosystem

The world is undergoing a fourth industrial revolution, one fueled by smart, intelligent automation and marked by an unprecedented, exponential pace of change (figure 1).

Figure 1. The fourth industrial revolution is enabling unprecedented change



Source: Deloitte Insights, *Industry 4.0 and manufacturing ecosystems: Exploring the world of connected enterprises*

Across industries and markets, organizations are facing mounting pressure from the rapidly evolving competitive landscape to transform—to shift from product-centric business models to creating and capturing other sources of value—and manufacturing is not immune. Still, most manufacturing executives we interviewed agree they are not preparing or moving fast enough to address the disruptions that are at the heart of Industry 4.0 and becoming Digital Manufacturing Enterprises (DMEs) as quickly or holistically as needed.

Why Industry 4.0 looks, feels, and is different

Why is Industry 4.0 different from previous industrial revolutions, especially for manufacturers? First and foremost, the pace of change we are experiencing is substantially faster than ever before. It is no longer incremental; it is disruptive and nonlinear (figure 2). This is a departure from historical manufacturing practices, which have been linear and based on incremental change and continuous improvement. Players historically were subject to the same relative constraints on assets; winners were those that could optimize within those constraints. Business models assumed a linear, one-way connection between supplier and customer. In contrast, DMEs transforming via Industry 4.0 are beginning to operate much more in ecosystems characterized by multidirectional relationships and “goods” being exchanged inclusive of data, insights, and services.

DME organizations that use exponential technologies to transform via Industry 4.0 enable opportunities to create an efficient, real-time automated feedback loop—data flows from the physical space to digital; capabilities enrich that data and deliver information and insights back to the physical world—that can unlock step-change value and provide insights and visibility to solve for incredibly complex problems and/or previously unknown opportunities. This smart and integrated loop between the digital and physical worlds

is where many manufacturers find much of the unrealized value and opportunity is created.

But **manufacturers have built their successes and legacies on repeatable and predictable processes, creating a culture that embraces an incremental versus a transformational approach.**

This culture often leads to inertia, which, in turn, creates blind spots for traditional manufacturers to adjust quickly enough in an exponentially changing world. Adapting to this new reality requires transformation that puts technology and digitization at the core.

Executives interviewed say that many established manufacturers—especially historically successful ones lacking a strong-enough sense of urgency—may have difficulty becoming flexible and agile enough to shepherd this transformation from concept to realization at the pace this industrial revolution requires.

Meanwhile, barriers to entry are lowering, allowing small, agile new entrants to potentially disrupt the global manufacturing landscape.

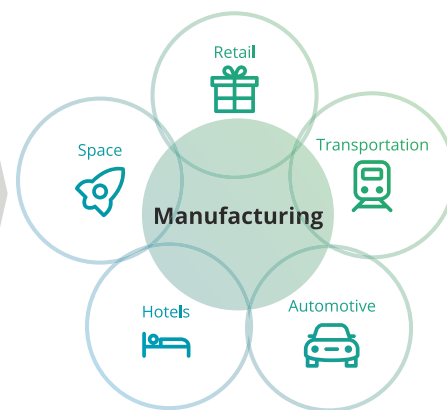
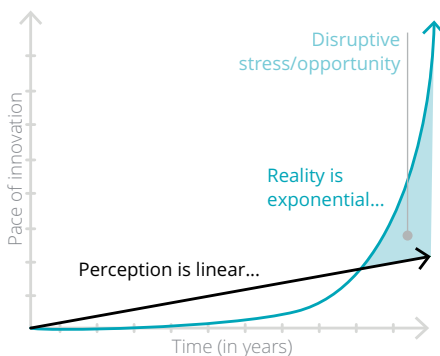
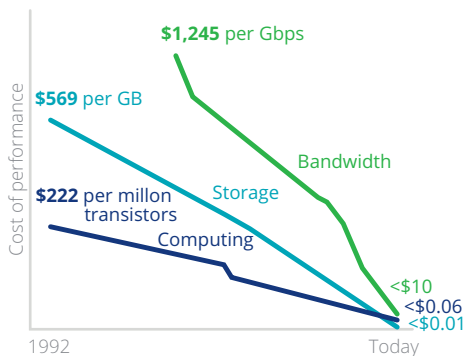
Therefore, nearly universally, executives interviewed indicate this is a critically important issue for all manufacturers and state that there needs to be a clear and compelling sense of urgency within the entire industry to adapt, flourish, and thrive.

Figure 2. The pace of change is exponential, and manufacturers are not immune

Substantial cost reduction across computing power, storage, and internet usage have led to...

...exponential rate of change transcending industry barriers and national borders...

...which is creating opportunity & disruption across multiple industries...



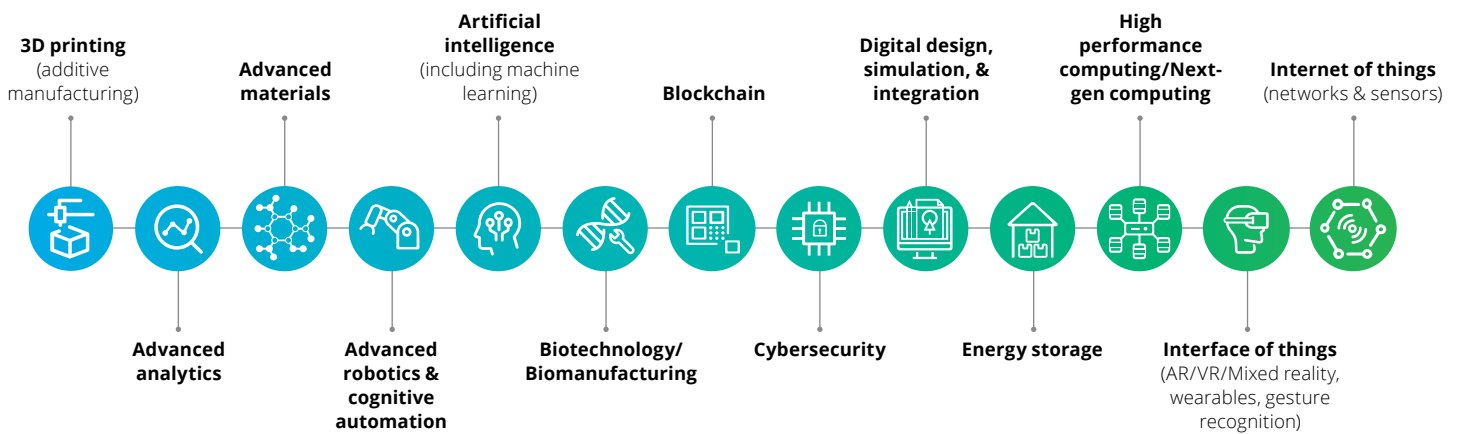
Sources: Deloitte Insights, *The rise of the digital supply network: Industry 4.0 enables the digital transformation of supply chains*; Based on The Law of Accelerating Returns by Ray Kurzweil, *The Age of Spiritual Machines*

Exponential technologies: More important than ever for manufacturers

Exponential technologies are indispensable tools to help manufacturers address the bigger concerns and challenges that are part and parcel of transformation ushered in by Industry 4.0 and to transform into DMEs. These technologies grow and enable change at an accelerating pace, and are often used in conjunction with each other to fundamentally disrupt processes and industries—and create opportunities. Exponential technologies can be used in core operations and markets to move an organization beyond the realm of incremental change, and at the edge to enable true transformational growth and new business models.

Our study examined a number of exponential technologies and their potential disruptive impacts on the future of manufacturing (figure 3). Later in this report we will examine each of these technologies in greater detail (see page 26).

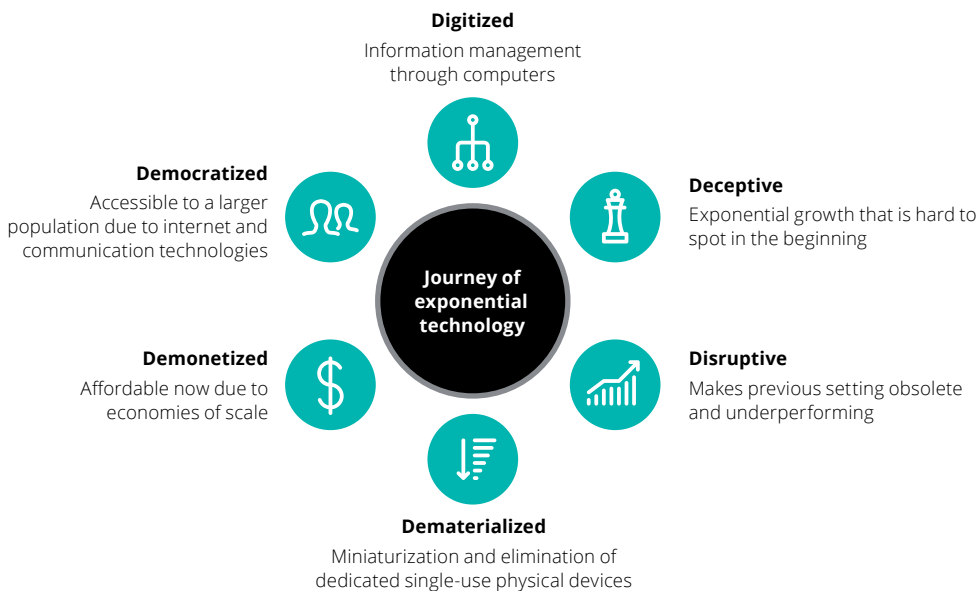
Figure 3. A snapshot of exponential technologies covered in this study



Source: Deloitte analysis

Peter Diamandis’s 6 D’s framework (figure 4) explains the journey that an exponential technology takes.¹ As the technology’s market impact plays out, barriers to entry dissolve and industry lines blur; competition emerges from nontraditional sources often looking to gain advantages beyond the product itself (customer proximity and knowledge, access to higher-order levels of data, etc.). Ultimately, small players that are more agile and adept at leveraging multiple exponential technologies may scale up, outperform, and outcompete larger industry heavyweights.

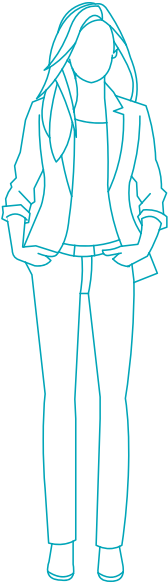
Figure 4. Exponential technologies’ role is more important than ever: 6 D’s of an exponential technology



Source: Peter H. Diamandis and Steven Kotler, *Bold: How to Go Big, Create Wealth and Impact the World*

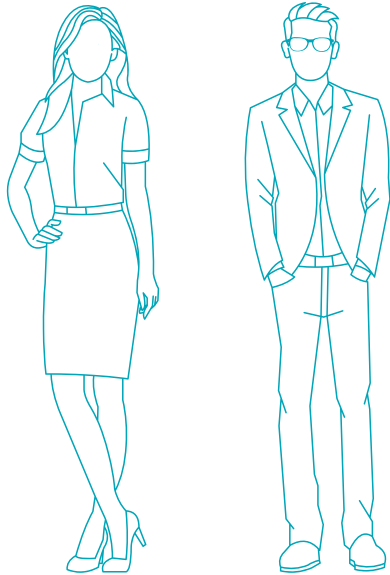
Our interviewed executives overwhelmingly agree that being able to leverage innovative, exponential technologies is a matter of survival in the increasingly “disrupt or be disrupted” manufacturing industry:

“Exponential technologies are essential; whether to cut energy use or to shorten supply chains, or in making devices and products connected across the board.”
—
Technology domain expert



“Exponential technologies are right at the top of our radar. Both our CEO and CFO are driving this strategy, and the best way to judge its importance is how much time the board has given it—whether you call it digital transformation or Industry 4.0—it is one of the top three on their list, and is going to be there for a while, for sure.”
—
Company executive

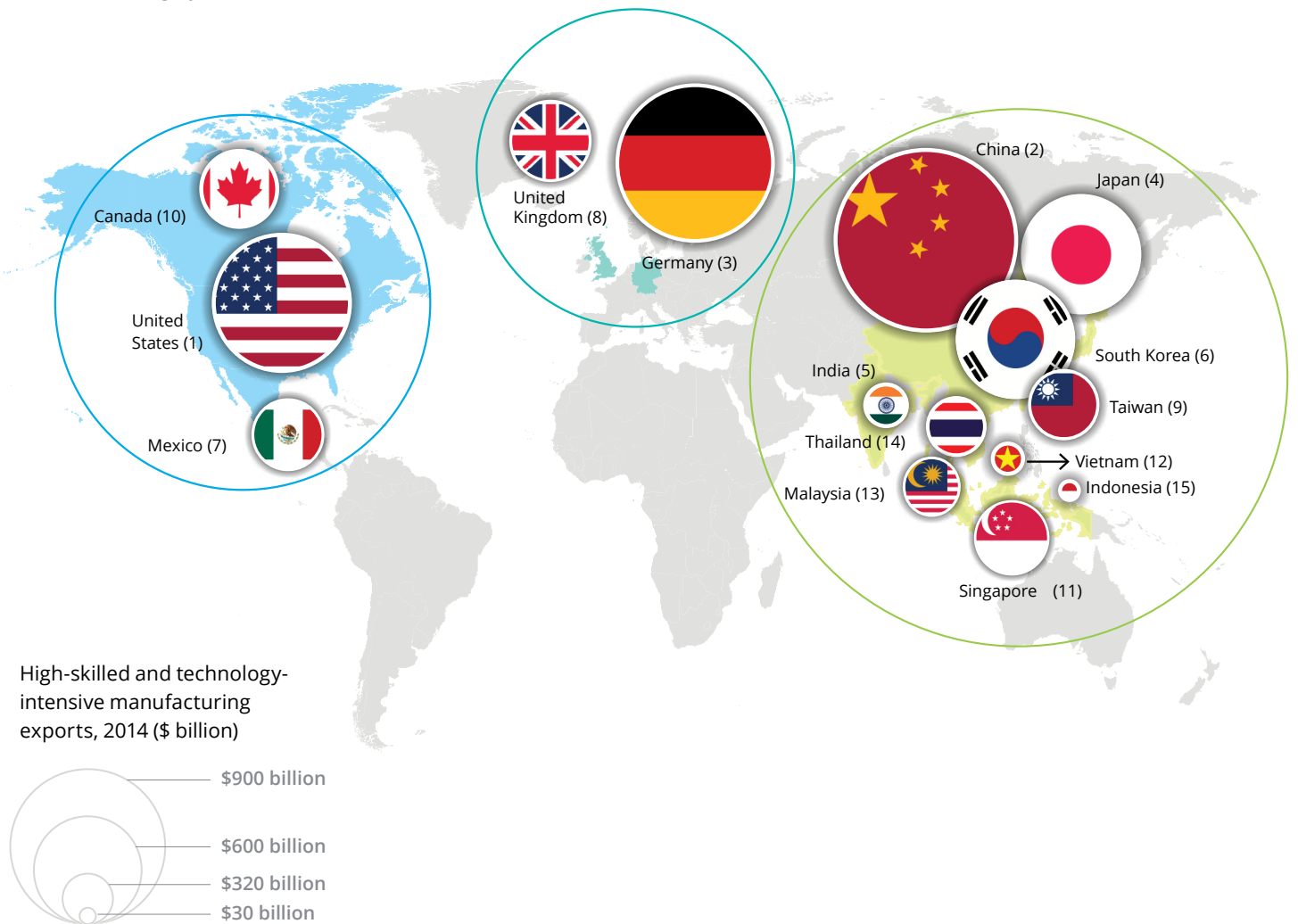
“Vitaly important, I can’t stress how important. Our industry is driven by innovation—it’s how we build products—and industry is becoming more and more competitive and is a ripe environment for innovation to happen.”
—
Company executive



According to the hundreds of global manufacturing CEOs and executives that took part in our latest *Global Manufacturing Competitiveness Index* (GMCI) study with the Council on Competitiveness,² exponential manufacturing technologies are key to unlocking future competitiveness. Leading 21st-century manufacturers are fully converging the digital and physical worlds, in which advanced hardware combined with advanced software, sensors, and massive amounts of data and analytics can result in smarter products and processes, and more closely connected customers, suppliers, and manufacturers. Top technology investment areas for manufacturers include advanced analytics, cloud computing, modeling and simulation, Internet of Things (IoT) platforms, and optimization and predictive analytics.³

As the manufacturing industry continues to develop ever-more-advanced products and processes, future competitive advantage in manufacturing will likely tilt back to advanced manufacturing nations with robust innovation ecosystems (figure 5) versus the cost-competitive nations of the past. The GMCI revealed that traditional 20th-century manufacturing powerhouses that invested in exponential manufacturing technologies and innovation ecosystems—the United States, Germany, Japan, and the United Kingdom—were among the top 10 most competitive nations in 2016 and are projected to remain there until the end of the decade. Meanwhile, the United States and China are expected to continue battling it out for the top spot in the future of manufacturing, according to our GMCI study as well as many manufacturing executives interviewed for this effort. Ultimately, the role of exponential technology increases, at both the company and country level, as the manufacturing competitiveness battleground shifts to higher-value, advanced products and processes.

Figure 5. A look at the global manufacturing competitiveness landscape: Top 15 nations projected to be the most competitive in manufacturing by 2020

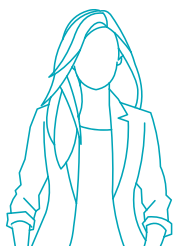


Note: Figures in parentheses represent the projected 2020 GMCI rank by CEOs

Source: Deloitte Touche Tohmatsu Limited and US Council on Competitiveness, 2016 Global Manufacturing Competitiveness Index

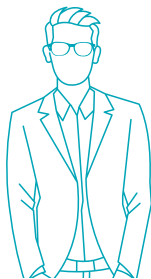
**Setting the stage:
Digital transformation**

There is a clear and compelling case for manufacturers to leverage exponential technologies and incorporate digital transformation throughout their organizations. Nearly 90 percent of respondents to a Deloitte and MIT Sloan Management Review global survey anticipate that digital trends will disrupt their industries to a great or moderate extent. Yet only 44 percent of respondents say their organizations are adequately preparing for the disruptions to come.⁴ This view is supported by insights from our exponential technology interviews, which reveal that the manufacturing industry's pace of digital adoption is relatively slow (figure 6).



“How many manufacturers have successfully integrated exponential technologies? Only a small percentage.”

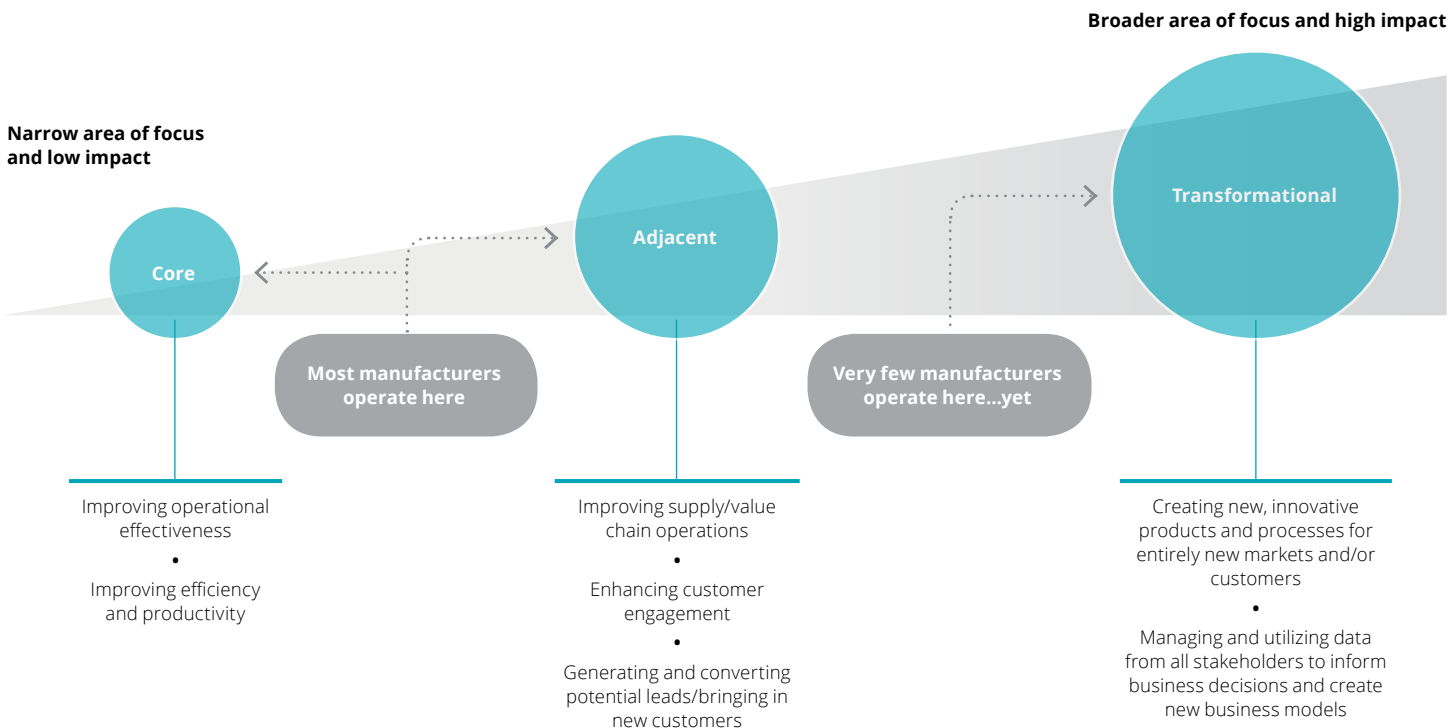
Technology domain expert



“I think similar to other folks, we have incredible depth of adoption in pockets, but shallow in many other places.”

Company executive

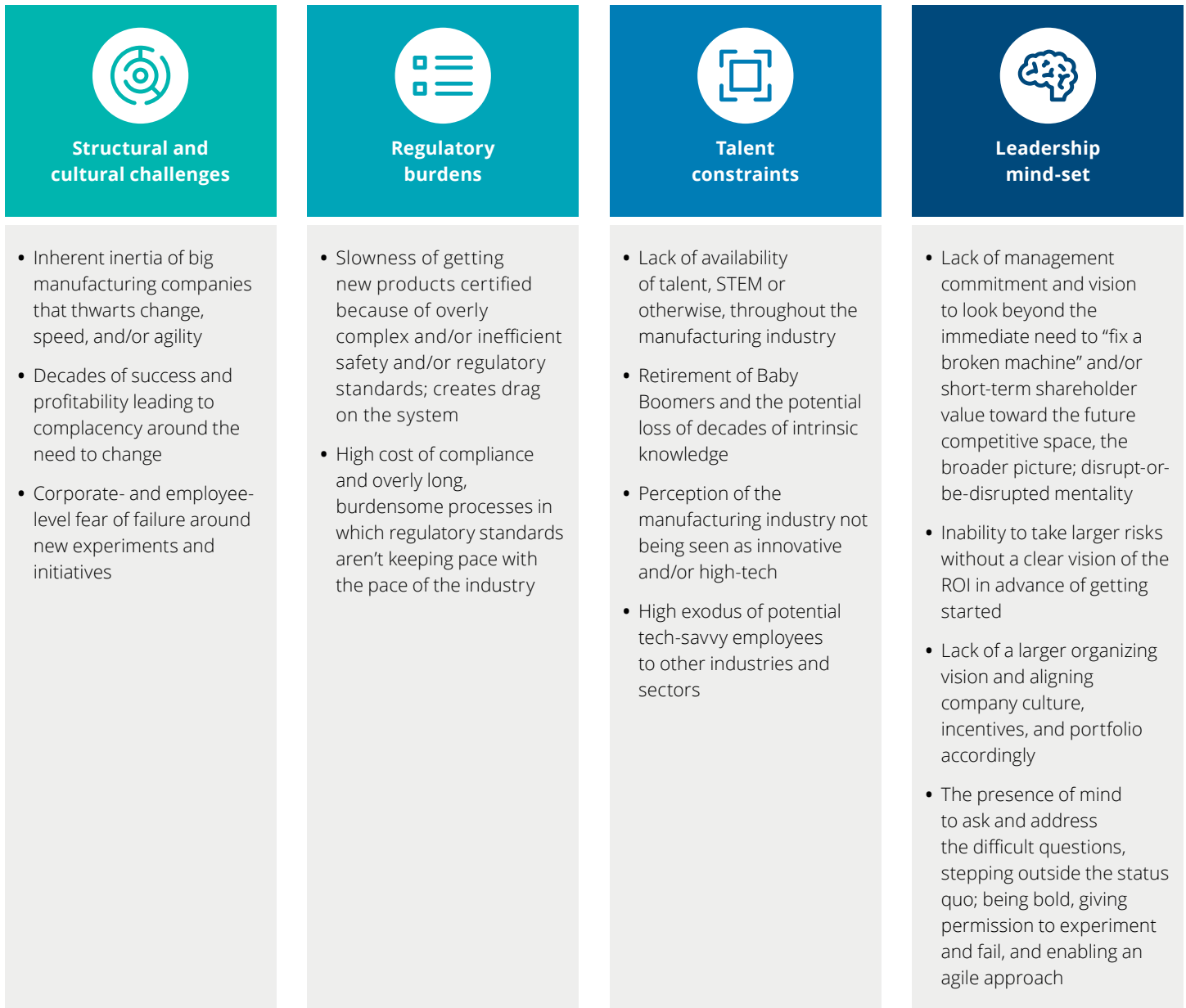
Figure 6. Pace of adoption is seen as relatively slow among manufacturers



Source: Deloitte analysis

Why the sluggish uptake? According to our interviewed executives, several barriers exist—some logical, some psychological (figure 7).

Figure 7. Why are manufacturers slow to adopt exponential technologies?



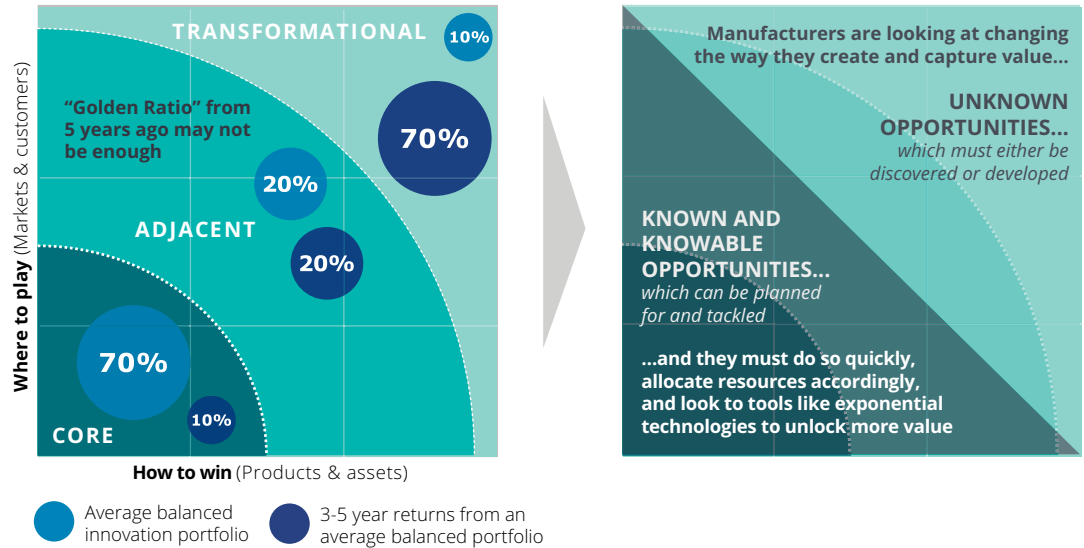
Source: Deloitte analysis

The future of manufacturing will likely require companies to innovate in fundamentally new ways. While exponential technologies can and should be leveraged in core, adjacent, and transformational areas, focusing a larger portion of energy and resources at the transformational edge may help manufacturers capture innovation opportunities, grow faster, be more agile, and unlock novel forms of value for long-term prosperity (figure 8).

Figure 8. Innovation enabled by exponential technologies can help manufacturers grow faster, be more agile, and unlock new forms of value

Exponential technologies can be leveraged in each of the three areas: core, adjacent, and transformational.

Increasingly, to stay alive, companies need to more aggressively explore “above the line.”



Source: Harvard Business Review, *Managing Your Innovation Portfolio*

But embracing exponential technologies and innovation alone does not translate to digital-driven success. Interviewed executives indicate that moving confidently into the future means that manufacturers will need to develop a culture that is receptive to change and agility. Examples include building a corporate culture in which all stakeholders:

SEE DIFFERENTLY

Cultivate an outside-in perspective of the business. Identify opportunities based on current trends to create and explore multiple “provocations” that can help deliver the company’s future vision: connectivity, innovation, automation, experience, risk management, and data intelligence.

THINK DIFFERENTLY

Detail the future state, and the competitive, economic, and customer impacts that can be achieved through the provocations. This helps determine the organizational capabilities needed for future success in the areas of ecosystems; new business and service models; experiences and engagement; ambitions and aspirations; value enhancement; branding and values; organization and talent; enterprise operations; and customers, platforms, and data.

DO DIFFERENTLY

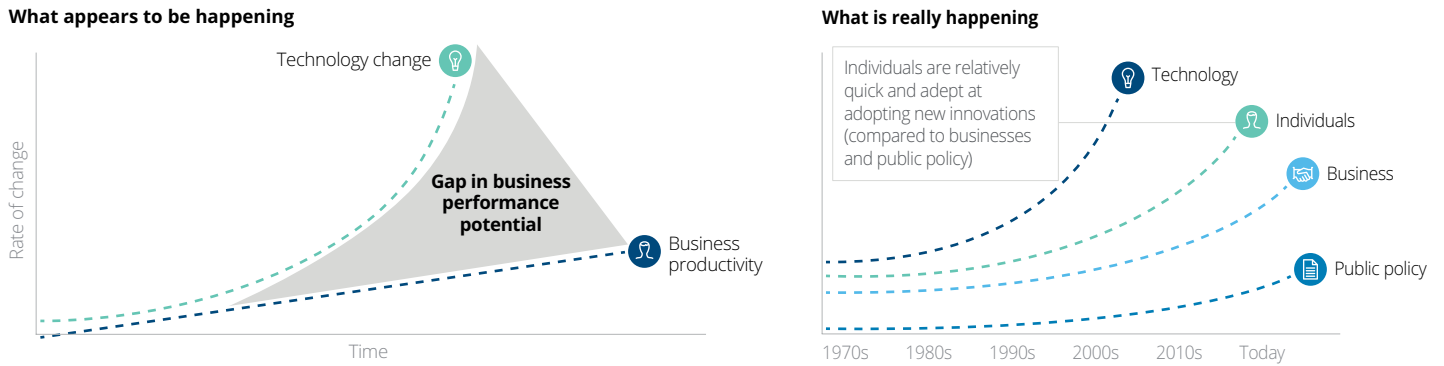
The key here is to think big, start small, act fast. Pick tangible and discrete elements that align to the future state to capture quick wins and/or learn from failing fast. Create a culture that accepts risk in order to reach the ultimate future goals. For instance, approach product and service delivery from a differentiated perspective, with an emphasis on understanding human interaction with technology and the training/retraining that is likely required; finding new areas of opportunity; and refining products through rapid in-market prototyping.

Part and parcel with the need for change in the manufacturing culture is the need for change in the manufacturing workforce that will develop, adopt, and deploy exponential technologies. The future workforce will likely need to apply a new digital mind-set to leverage emerging technologies to their fullest potential. Possessing a digital mind-set can be an important lever. According to results from a recent MIT/Deloitte study, cultures of digitally progressive companies share important characteristics.⁵ They engage in rapid experimentation, take risks, invest in their own talent, and value soft skills in leaders more than they do technical prowess. Manufacturing organizations striving to become more digitally mature should consider modeling these characteristics.

Talent: Top driver of manufacturing competitiveness in an exponential age

As manufacturers transition to an agile, technology-powered culture in an era defined more and more by exponential possibilities, companies will increasingly turn to one of their most important assets—people—to achieve new levels of output and success. Individuals are quicker and more adept at adopting new innovations than businesses—and society—as a whole. The goal, therefore, when managing future talent-related opportunities and challenges (figure 9) is to encourage individuals to seek change rather than resist it, especially as roles evolve from focusing on routine processes and tasks, to educate and retrain workers in new skill sets that focus on innovating and problem solving to unlock new forms of value in an exponential ecosystem and economy. This proactive approach will help enable businesses to better leverage employees’ capabilities to build innovative, exponentially oriented, digital products and services that capture customers’ attention and share of wallet.⁶

Figure 9. Exponential rate of change is creating new challenges and opportunities: Talent is key in closing the gap and increasing the rate of change

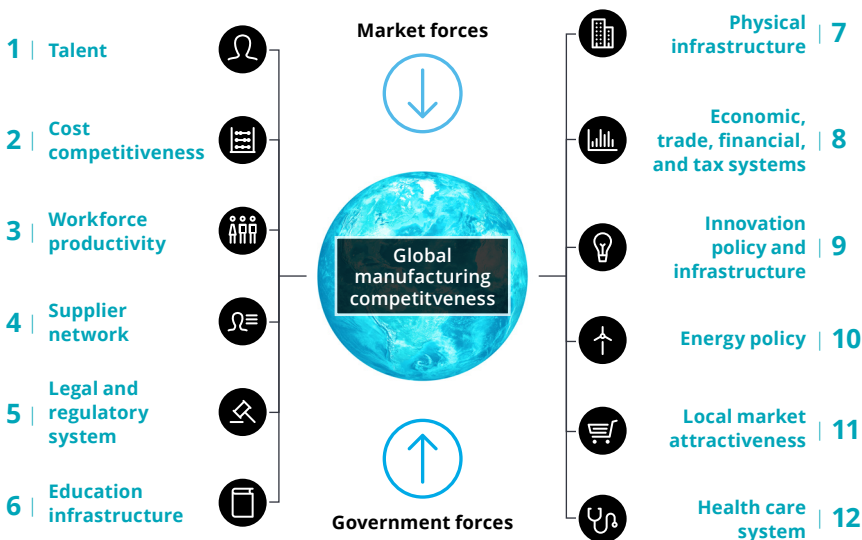


Source: Deloitte Insights, 2017 *Deloitte Global Human Capital Trends: Rewriting the rules for the digital age*

In fact, global manufacturing CEOs already consistently recognize talent as the top driver of manufacturing competitiveness (figure 10). Yet talent remains a critical issue across the globe, and manufacturing is competing with other industries for the best and brightest employees: More than 80 percent of US manufacturers are having difficulty finding qualified talent.⁷

Figure 10. What drives manufacturing competitiveness?

Global manufacturing CEOs consistently point to **talent** as the top driver of manufacturing competitiveness

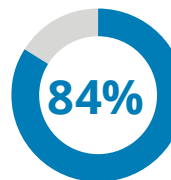


But...



2 Million

manufacturing job openings are expected to go unfilled due to the skill gap in the next decade



of executives agree there is a talent shortage in US manufacturing industry

Six out of ten open skilled production positions are unfilled due to talent shortage



Sources: Deloitte Touche Tohmatsu Limited and US Council on Competitiveness, *2016 Global Manufacturing Competitiveness Index*; Deloitte and The Manufacturing Institute, *The skills gap in US manufacturing: 2015 and beyond*

A persistent talent shortage is a major hurdle to the sustainability and growth of manufacturing companies. What are the reasons behind the shortage in manufacturing?



Increasing Baby Boomer retirements:
2.7 million Baby Boomers in the US manufacturing industry are expected to retire during 2015-2025.⁸



Shortage of qualified labor:
People in skilled trades, technicians, and engineers are the most difficult to recruit in the United States.⁹



Changing skill sets needed for advanced manufacturing:
Companies are increasingly looking at workers with STEM skills—software engineers, process engineers, automated systems engineers, and supply chain engineers are a few key manufacturing job roles with a future.¹⁰



Perceived attractiveness of manufacturing among public:
While the US public believe manufacturing is vital to the economy and the standard of living, many Americans are reluctant to choose careers in manufacturing.¹¹

Many opportunities exist to attract and retain the best and brightest in manufacturing, especially with the dawn of Industry 4.0. Interviewed executives say that highlighting the future skill set that manufacturing will require, training and/or mentoring through new forms of apprenticeship and training models, and tapping into a more tech-savvy workforce and culture will help the industry become a destination of choice for top talent.

Future of work will require human-machine collaboration

We heard from many manufacturing executives and technology leaders that the next industrial revolution will be centered on new combinations of humans and machines, not the replacement of one with the other. While some pundits have voiced fears that artificial intelligence (AI) could replace humans altogether, insights from our two dozen interviews indicated that is not likely. A more valuable approach may be to view machine and human intelligence as complementary, with each contributing its unique strengths to the equation.

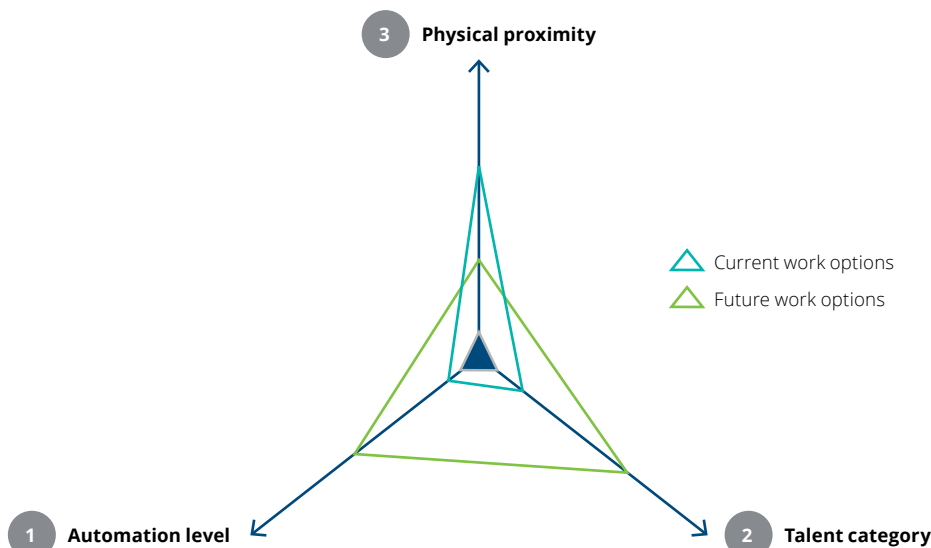
Still, the relationship between technology and talent is, and is likely to remain, complex according to the *2017 Deloitte Global Human Capital Trends* study: 41 percent of companies report they have fully implemented or made significant progress in adopting cognitive technologies within their workforce but only 17 percent of global executives say they are ready to manage a workforce with people, robots, and AI working side by side.¹²

Driven by accelerating connectivity, new talent models, and cognitive tools, the nature of work—and of workers—is changing. We see exponential technologies sparking the creation of new manufacturing industry jobs (requiring both new hard and soft skill sets) to flourish in the new digital and high-tech world, such as digital twin architect, collaborative robotics specialist, and predictive maintenance system specialist, while the gig economy and crowdsourcing grow the “augmented workforce.” Both developments will likely appeal to Millennials, who now constitute the largest segment of the US workforce (~34 percent) and continue to dominate decisions related to the future workplace. For example, Millennials increasingly are requesting state-of-the-art technology from their employers, thus enabling a digital workplace.¹³

We envision the “what,” “who,” and “where” that are changing the future of work as spanning three dimensions (figure 11), around which manufacturing executives should address many strategic questions:

Figure 11. The three dimensions changing the future of work

The “what” (technology & automation), “who” (talent & the open talent continuum), and “where” (workplaces, physical location) of work are dramatically changing.



Source: Deloitte Consulting LLC

- What parts of a job can we automate, and what is the human “value add” that can complement automated work? For example, factory workers that are freed-up from routine tasks can concentrate on proactive problem solving and provide greater value to companies.
- How can we re-skill and retrain people to learn technology and tools faster, and how can we design technology so it requires less training?
- How can we crowdsource activities—and use contingent, freelance, and gig economy talent—to access scarce skills and resources, save time and money, increase quality, staff peaks in production demand, and improve operational flexibility and scalability?
- Where does the work—and, more specifically, each individual task—need to be done? What physical proximity is required to serve customers and to design and develop products and services?
- How can we redesign the workplace to be more digital, open, and collaborative, yet provide opportunities for employee development and growth? Considerable research shows that the highest-performing teams (and leaders) are those that are the best-connected within and across a company.¹⁴ Does our organization have enough open, collaborative, physical and digital spaces to facilitate people-to-people engagement?
- How can we evolve and, perhaps, separate the functions of multiyear (three to five years) strategic work, workforce, and workplace planning on the one hand, and annual workforce planning (headcount) on the other, to explore scenarios that include more crowdsourcing, greater automation, and the increased use of robotics?
- What is our organizational and work design capability?
- How do we need to change and adapt our organization, leadership, career and learning models, rewards, and workforce experience to empower the new categories and types of workers required?

Manufacturers should seize the opportunity to attract top talent

We are at an inflection point for manufacturing and the future of work: due, in large part, to the application of exponential technologies, manufacturing is rapidly moving in a direction that is more innovative, creative, and high tech and, therefore, could be better positioned to attract top talent. The industry should seize this opportunity and make manufacturing companies employers of choice for top talent—but how to begin? Elevating public awareness of manufacturing’s advantages to help dispel false perceptions about the industry is an important first step to plug the skills gap.¹⁵ Companies should share good news about the pay, stability, security, and career trajectory of manufacturing jobs to develop a robust talent pipeline (figure 12), as it is likely to be one of a company’s biggest sources of strategic advantage in the current and future landscape.

Figure 12. Addressing the manufacturing skills gap: Sharing the good news to attract and retain top talent

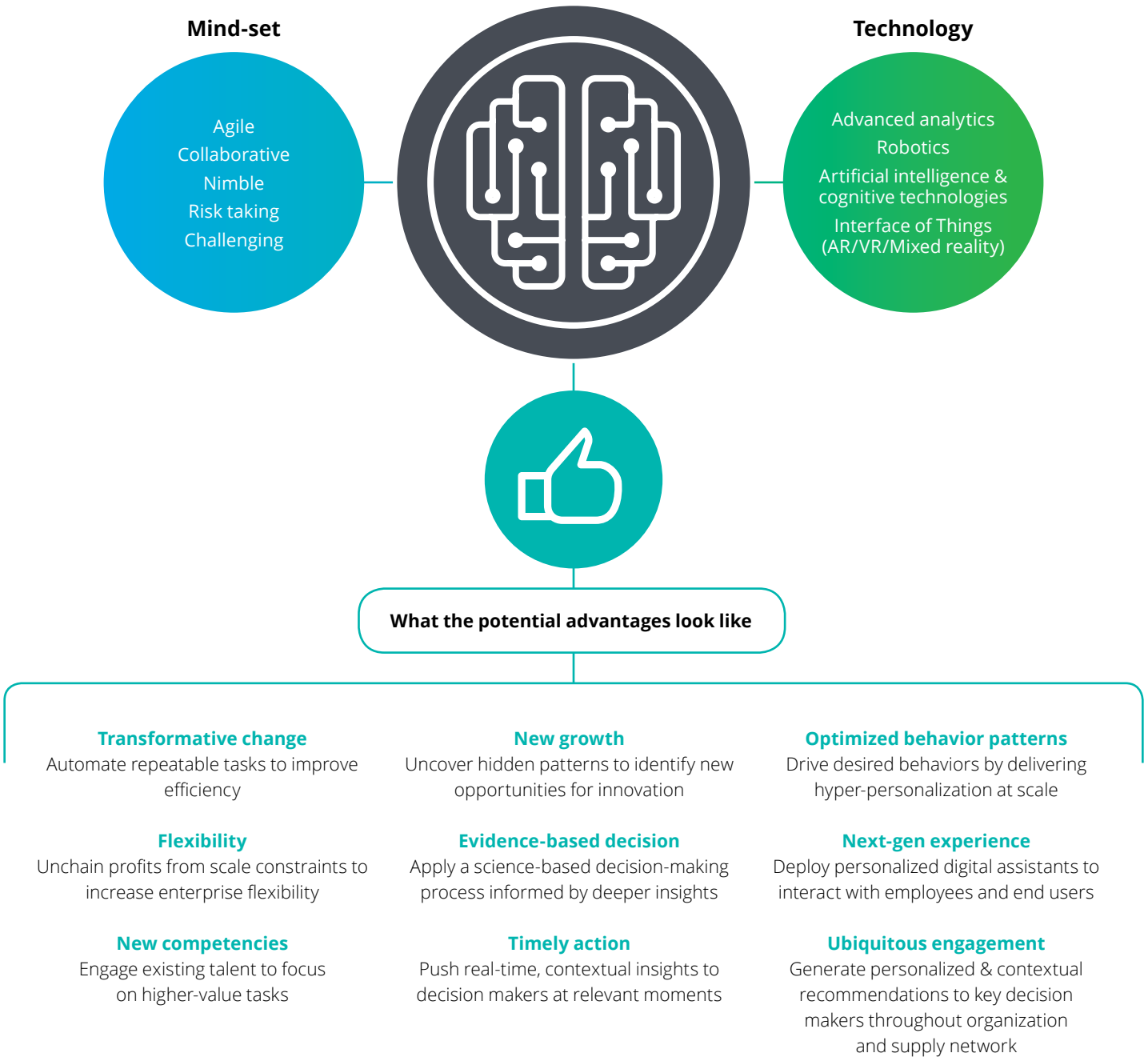


The virtuous cycle of improving the existing image and recruiting the best talent can help reshape the US manufacturing industry and better enable it to compete in these fast-paced, innovative, and transformative times.

Source: Deloitte and the Manufacturing Insitute, *A look ahead: How modern manufacturers can create positive perceptions with the US public*

Building a continuous and virtuous cycle of leveraging exponential technologies and recruiting the best talent can help reshape US manufacturing, fuel innovation ecosystems, and provide advantages that will likely better enable companies to compete in these fast-paced, innovative, and transformative times (figure 13).

Figure 13. What the future of work in manufacturing might look like



Source: Deloitte analysis

**Innovation ecosystems:
Creating and capturing value**

Companies and nations around the world understand the strong correlation between a vibrant innovation ecosystem and economic prosperity. Many executives interviewed state that a strong foundation of R&D through basic science is required for innovation to truly flourish in the long term. Many breakthrough exponential technologies are actually seeded through decades of R&D investment. Yet many interviewees share that investment over a multiyear horizon is becoming more and more challenging, both in the private and public sector. The executives also realize that today's highly connected, fast-paced world requires more collaboration within and across more potential players than before. Many indicate that partnering in the pre-competitive space helps the industry at large, as well as individual companies that no longer have the patience or ability to solve grand challenges alone. Some examples of the benefits of a vibrant innovation ecosystem our interviewees cite include:

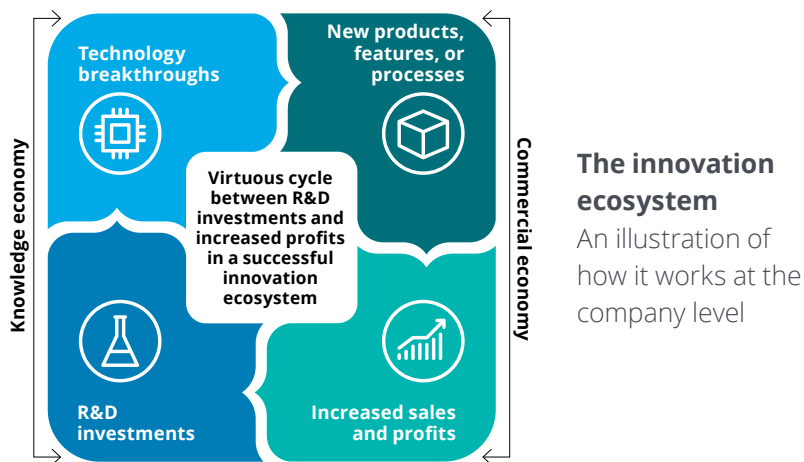
- Companies that operate across one or more innovation ecosystems— environments that create and capture

value by leveraging external assets and expertise—can aid differentiation by developing premium products, processes, and services that capture higher margins and anchor future growth strategies.

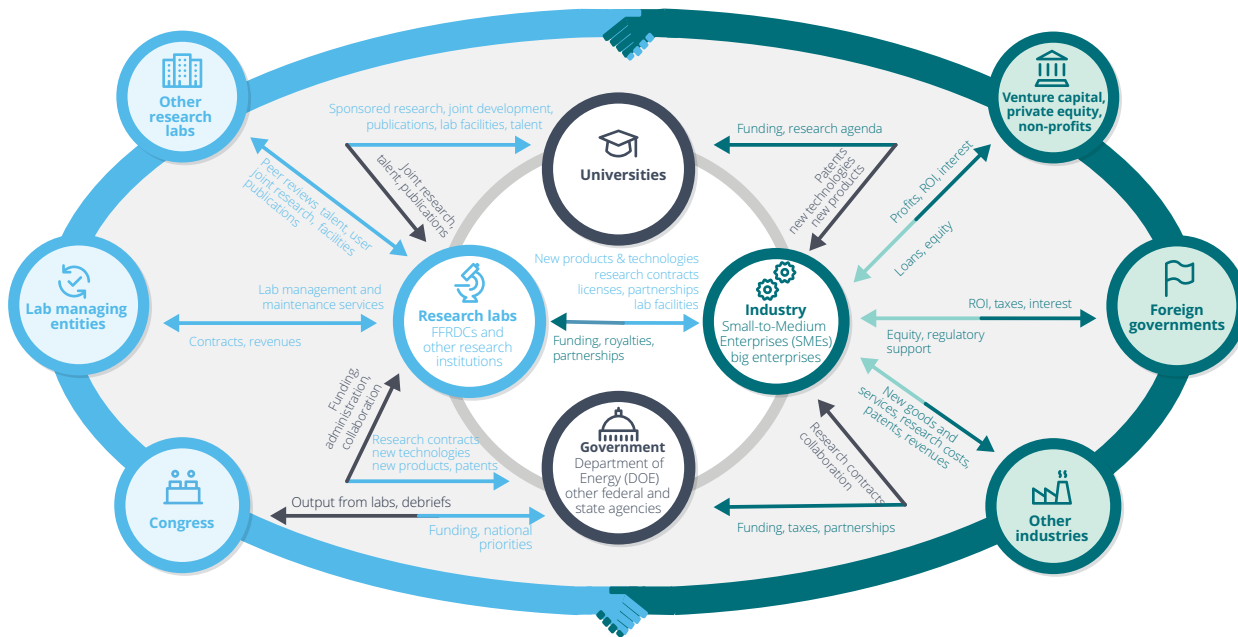
- At the national level, innovation ecosystems can strengthen economies by fostering an atmosphere in which new and existing companies can thrive, generating demand for a skilled workforce that earns higher wages, growing the total number of jobs in the value chain, and producing a higher overall standard of living.

Over the last century, the United States has been a vibrant innovation machine. Many executives attribute strong company- and country-level manufacturing competitiveness to the strength of the US innovation ecosystem. Though the players and their roles, relationships, and technical focus have changed over the years, as the physical and digital worlds are converging, the historically “siloeed” approach has become more collaborative (figure 14).

Figure 14. Talent and exponential technologies fuel innovation ecosystems



An illustration of the current US innovation ecosystem—A by-product of historical legacies and new market dynamics

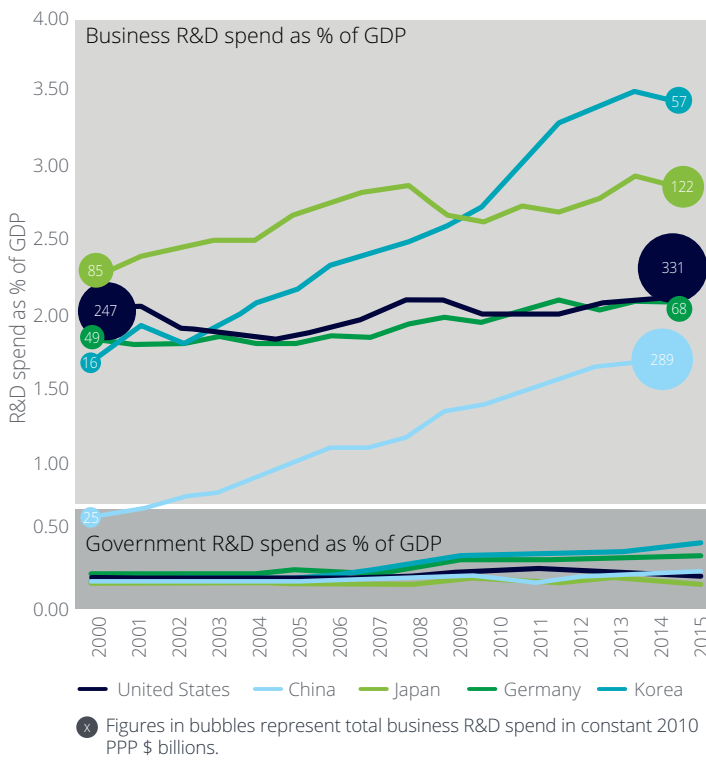


Source: Deloitte Touche Tohmatsu Limited and US Council on Competitiveness, *The Advanced Technologies Initiative: Manufacturing & Innovation*

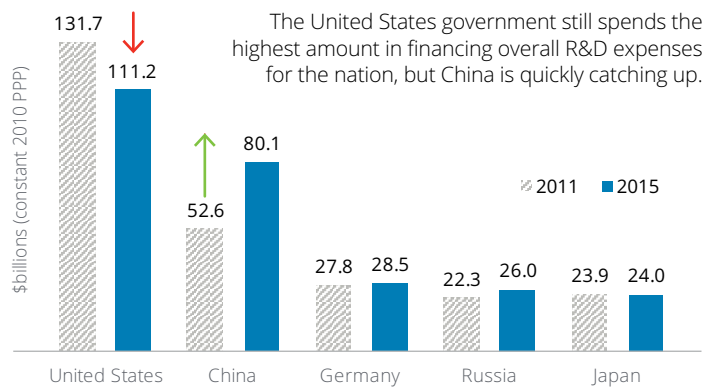
Many executives we interviewed say that as they increasingly look to increase their pace of change and transformation, they are not only leveraging internal assets in new and different ways but also turning more often to resources outside of their walls, as there are clear advantages to being close to where innovation is occurring. Many have formed partnerships and/or collaborate with other companies as well as universities, venture capitalists (VCs), research organizations, and/or industry consortiums in order to inform and fuel their innovation pipeline. They also feel, for the most part, that the US innovation ecosystem has a leadership position, but others are quickly catching up. Secondary research showed that, within the global competitive manufacturing landscape, both businesses and government research and development (R&D) play a major role in innovation ecosystems (figure 15), and are committing significant resources to R&D in advanced manufacturing.

Figure 15. Both businesses and government R&D play a major role in innovation ecosystems

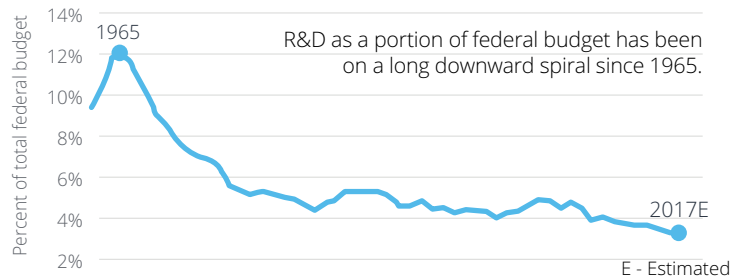
Business and government R&D spend as % of GDP, 2000–2015



R&D financed by government, Top 5 nations, 2011 and 2015



R&D budget as % of total federal budget, United States



Source: Deloitte analysis based on data from Organisation for Economic Co-operation and Development (OECD) and American Association for the Advancement of Science (AAAS)

The United States remains the biggest spender, especially in foundational areas like basic and applied research, but China is quickly closing the gap.

At the current pace, China is expected to surpass the United States in terms of R&D spend before the end of the decade. Already, many other nations have moved past the United States in terms of R&D spend as a percentage of GDP.

Though US federal funding of R&D is highest among nations, its basic and applied research spending has been flat or declining over the last decade.

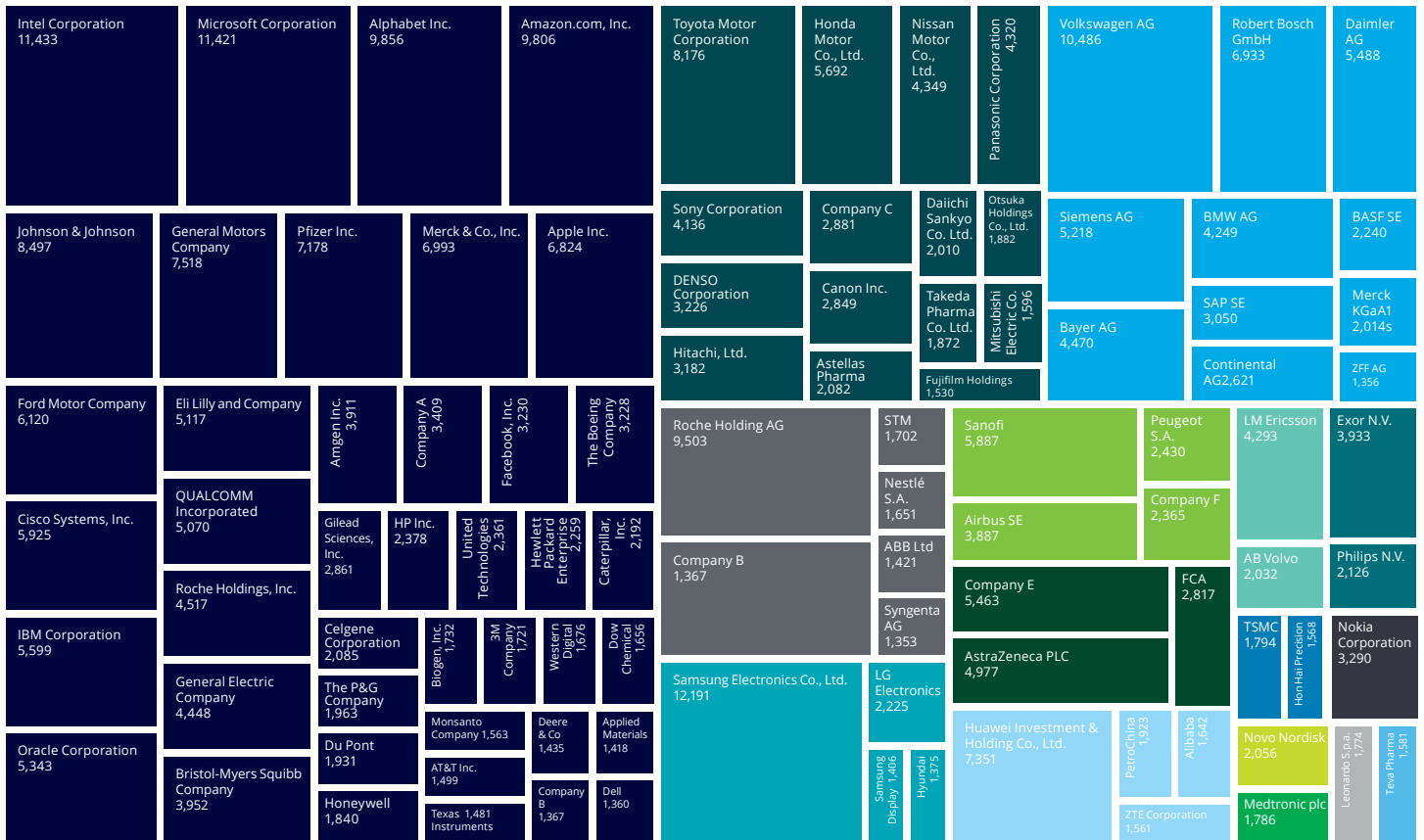
This federal funding plays a critical role in upstream technology development: Individual companies often have neither time nor budget to conduct exploratory research and must rely on national laboratories, universities, and/or other research institutes to close the gap.

Businesses account for the lion's share of R&D spending, an accelerating trend across leading nations.

Of the top 100 companies by R&D spend, the overwhelming majority (86) belong to the manufacturing sector, and 42 are from the United States (figure 16).¹⁶ Also, 62 of the top 100 manufacturing companies by revenue belong to the top four future competitive manufacturing nations. It makes sense for nations to create an environment that attracts and retains top-performing manufacturing companies, as manufacturing has the highest multiplier rate across industries.

Figure 16. Among all nations, US companies lead the global R&D spending landscape

Top 100 global R&D spending companies (based on five-year average) by country, 2012-2016



Country (HQ)

- United States
- Japan
- Germany
- Switzerland
- South Korea
- France
- United Kingdom
- China
- Sweden
- Netherlands
- Taiwan
- Finland
- Denmark
- Ireland
- Italy
- Israel

Note 1: Figures inside the boxes are "Average R&D spend more than 2012–2016" in \$ millions.
 Note 2: Company A – a major pharmaceutical firm; Company B – a major health care firm; Company C – a multinational industrial conglomerate; Company D – a global health care firm; Company E – a major pharmaceutical firm; Company F – a global automotive OEM.
 Source: Deloitte analysis based on data from S&P Global Market Intelligence; S&P Capital IQ

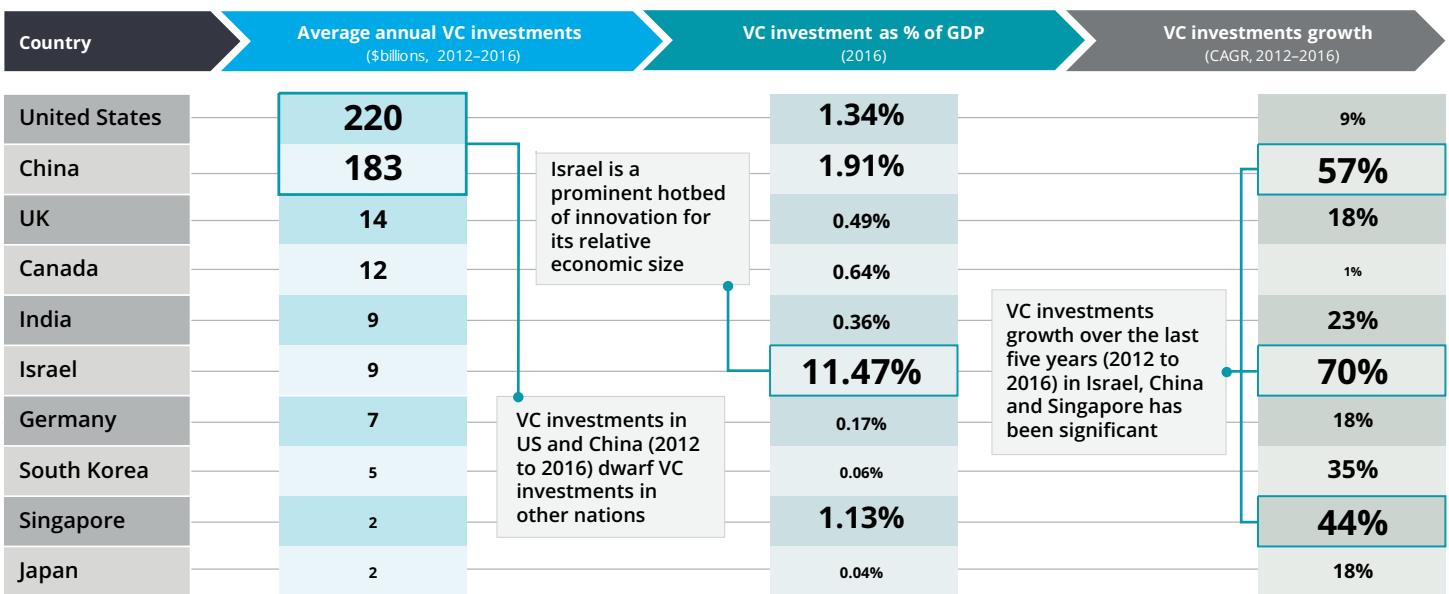
Venture capital investments feed innovation pipelines

Like businesses and government R&D, VC investments play a vital role in feeding the innovation pipelines within top manufacturing nations (figure 17). There was concern by some interviewed executives about the short-term, near-horizon timeline some VCs currently cite as deterrents for heavier VC activity in capital-intensive manufacturing. Some indicate more focus is needed in the mid-term horizon (e.g., five-ten years) within manufacturing technology and innovation to help further tech transfer and to close potential “valley of death” commercialization issues. A longer-term view is needed to create value (versus destroy it via a short-term activist mindset). Overall, many feel that more could and should be done to increase VC levels within the manufacturing technology space. Therefore, executives also indicate they are increasing venture capital activities internally, a growing trend for industrial companies, with some setting up their own venture funding arms to supplement traditional in-house capabilities.

“Venture capital-backed companies generate more sales, pay more taxes, generate more exports, and invest more in research and development (R&D) than other public companies, when adjusting for size.”

National Venture Capital Association

Figure 17. VC investments feed innovation pipelines within top manufacturing nations



Source: Deloitte analysis based data from Thomson Reuters and Organisation for Economic Co-operation and Development (OECD)

VC investments can serve as fuel for future competitiveness and increase the efficacy of innovation ecosystems for both companies and nations. For instance, Israel is a prominent hotbed of innovation for its relative economic size, as indicated by its high VC-investments-to-GDP ratio. It is also interesting to note that in the US-China race to dominate the high-tech space, VC firms from both countries have been acquiring Israeli high-tech firms at a rapid pace over the last five years or so. Overall, the United States and China dwarf all other nations in terms of VC investments size.

Manufacturers need to plug into the innovation ecosystem

Many executives agree that exponential technologies are changing the global competitive manufacturing landscape too quickly and dramatically for any single company to keep pace in the innovation ecosystem by trying to “go it alone.” Instead, many executives indicate manufacturers should plug into an innovation network and create bilateral or multilateral relationships that:

Facilitate two-way dialogue about what problems need to be solved and what types of solutions may be viable

Keep network players apprised of applicable industry and technology developments

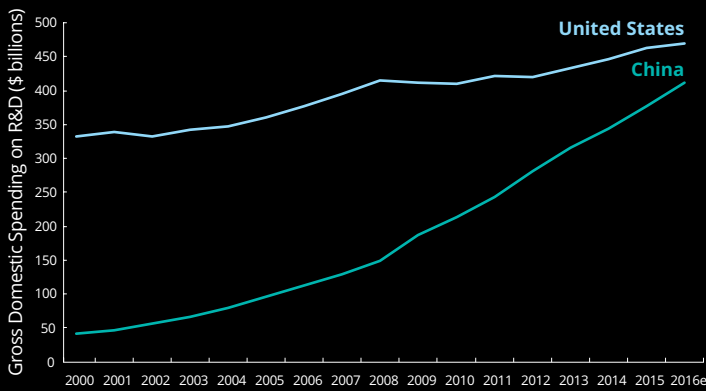
Serve as a feeder system for ideas/building blocks for the iterative development of breakthrough innovation

Keeping an eye on the competition: United States and China

The race for the title of top manufacturing and advanced technology nation is on. Our interviewed executives overwhelmingly indicated that the United States' biggest competitive threat continues to be China, which is rapidly moving ahead as an advanced manufacturing nation. Against this backdrop, the role national governments play in global manufacturing competitiveness is coming into focus. As nations look to create an environment that attracts manufacturing and bolsters their economic prosperity, they should keep a watchful eye on how others are playing the game.

According to its "Made in China 2025" initiative, China has indicated its ambition is to dominate high-tech manufacturing and become self-sufficient in producing high-tech goods to meet both domestic and global demand.¹⁷ Already, China has surpassed the United States in terms of manufacturing output, and it is rapidly closing the gap in critical long-term indicators, including R&D spend (figure 18).

Figure 18. In terms of R&D spending, China is aggressively closing the gap with the United States

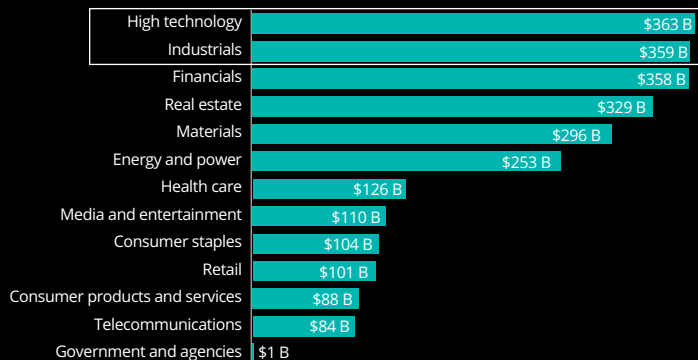


Note: Gross domestic spending on R&D is defined as the total expenditure (current and capital) on R&D carried out by all resident companies, research institutes, university and government laboratories, etc., in a country. It includes R&D funded from abroad, but excludes domestic funds for R&D performed outside the domestic economy.

Source: Organisation for Economic Co-operation and Development (OECD), *Main Science and Technology Indicators*

Figure 19. Over the last several years, Chinese companies have completed significant acquisitions in the high-tech and industrial space across sectors and regions

Total China-led M&A deal value (\$ billions), by target sectors, 2013-2017



Source: Deloitte analysis based on data from Thomson Reuters, Thomson ONE

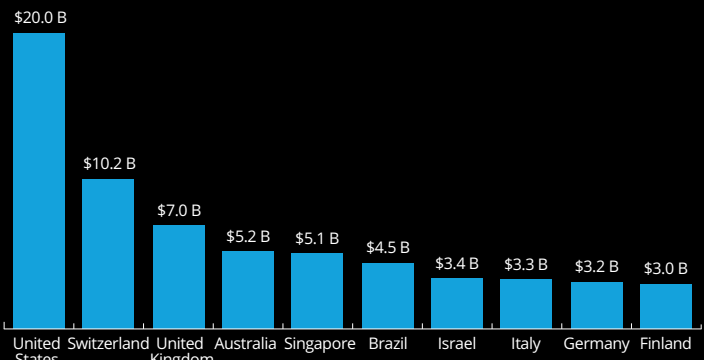
Backed by the government's massive financial muscle and resource mobilization, the "Made in China 2025" initiative intends to increase the domestic market share of Chinese suppliers for "basic core components and important basic materials" to 70 percent by the year 2025. Developing and commercializing Industry 4.0 technologies is the centerpiece of the strategy, influenced by the German concept of Industry 4.0 and the Industrial Internet formulated in the United States.¹⁸ According to Mercator Institute for China Studies (MERICS), the government also supports Chinese enterprises by:

- Heavily subsidizing Chinese products while excluding foreign alternatives, particularly in the fields of electric vehicles and robotics
- Making direct capital injections and preferential loans in industries like steel and machinery
- Using national investment funds such as the semiconductor industry's National Integrated Circuit Investment Fund (National IC Fund) to directly invest in enterprises
- Closing the public procurement market to foreign enterprises, like in information technology

Looking to leapfrog into the digital and exponential age, China has aggressively acquired assets across high-tech domains (such as wearables, artificial reality/virtual reality, robotics, and semiconductors),¹⁹ and regions (primarily, the United States) (figure 19).

Efforts by the Chinese, US, and other governments to promote and/or protect their high-tech bastions may play an even greater role in the future manufacturing competitiveness arena. Yet increasing protectionist policies may prove to be a slippery slope. When carving out their competitive position, countries and companies should seek to create an environment that fuels healthy, market-based competition.

Chinese external M&A deal average annual value (\$ billions), by target country (top 10 nations), 2013-2017



Exponential manufacturing technologies: A deep dive

Throughout over two dozen interviews with manufacturing executives and technology luminaries, there was clear and resounding consensus that the role of exponential technologies is more important than ever before. The executives we interviewed affirm that manufacturing companies are already beginning to realize the transformative effects of exponential technologies and see significant potential across a variety of dimensions:

“Exponential technologies have enabled us to be more efficient at what we do—a massive impact of 30–40 percent in terms of efficiency and distribution costs—which could not have been done otherwise.”

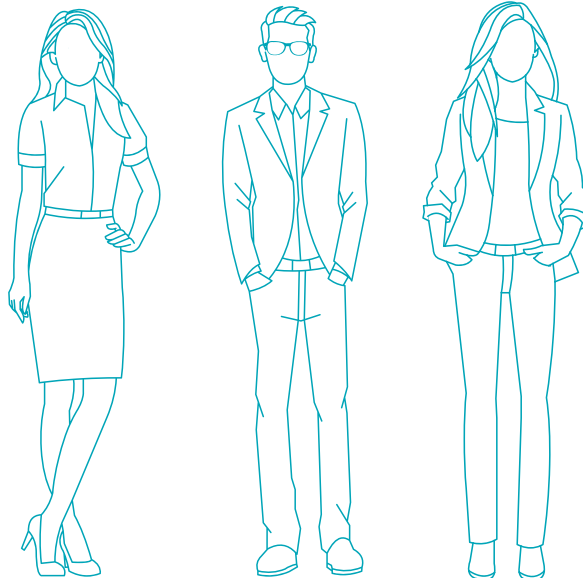
—
Company executive

“Using advanced analytics and machine learning, the solutions we have figured out have been transformative—in minutes we can go through millions of variables, and this has turned into millions of dollars saved.”

—
Company executive

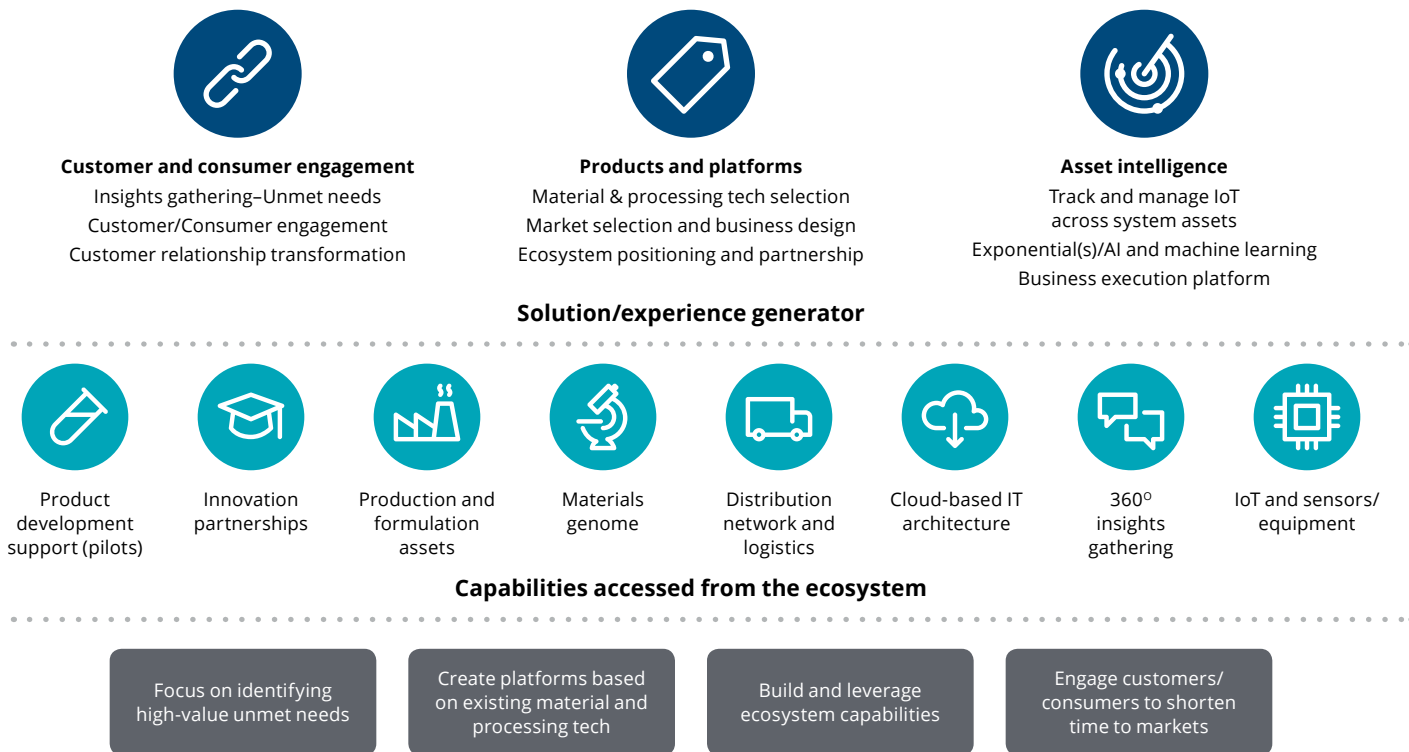
“The traditional manufacturing model has been product-centric. In the last two years we’ve seen new business models to capture value in services/solutions and data. Manufacturers have woken up to companies—even those outside their industry, who play the game differently; who have a platform approach—a shift from being product-centric to the product as a platform to create and capture other sources of value.”

—
Company executive



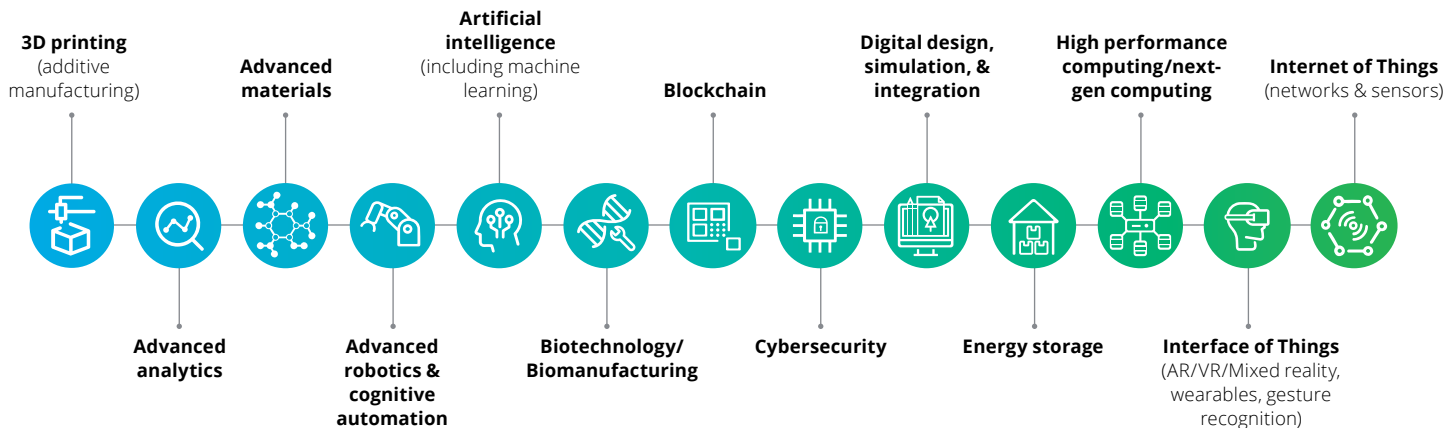
Manufacturing companies and industries can unlock the full power of exponential technologies by using them in unison to help transition from a product-centric business model to a platform model, developing and capturing value in fundamentally new ways. Figure 20 illustrates how exponential technologies can come together to create a smart, connected, Digital Manufacturing Enterprise and the types of capabilities and benefits that can be realized.

Figure 20. Example of a Digital Manufacturing Enterprise (DME) transformed by exponential technology



Source: Deloitte, *The chemical multiverse 4.0: Promising future for the strong, decisive, and persistent*

A future manufacturing company with higher leveraged assets, focusing on product platforms to engage customers, and leveraging exponential technologies, can be highly successful. The following deep dives look at 13 of the most promising exponential technologies that are unlocking new forms of value for manufacturers and transforming the global manufacturing industry.



Source: Deloitte analysis

3D printing (additive manufacturing)

Description:²⁰ 3D printing is an additive process of building objects, layer upon layer, from 3D model data as opposed to subtractive manufacturing methodologies like machining. 3D printing helps in creating intricate designs that are difficult to make through traditional methods, saves enormous amounts of time during product design and development stages, and eliminates scrap.

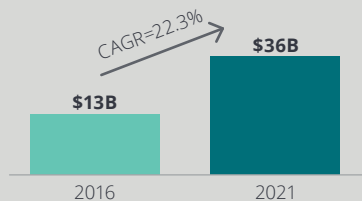
Market size and growth²¹

During the forecast period (2016-2021):

Largest segments: Automotive design–rapid prototype printing and aerospace and defense parts printing.

Fastest-growing segments: Dental printing, medical implant and device printing, and product creation and prototype printing.

Highest-spending regions: United States, Western Europe, and Asia-Pacific (excluding Japan).



Potential issues/challenges²²

1. Ensuring consistent manufacturing-grade product quality coupled with requirements for better material properties.
2. Lengthy and costly pre- and post-processing steps in the 3D printing production chain, such as model setup, support removal, and material recycling.
3. High machine and materials costs.
4. Security and intellectual property protection, regulatory challenges, and societal concerns around bio-printing of organ tissue and 3D-printed items, such as handguns.
5. Lack of industry-accepted manufacturing and engineering standards.

Current applications²³



Concept modeling and prototyping; printing structural and nonstructural production parts; printing low-volume replacement parts.



Prototyping, tooling, and functional end-use parts manufacturing in various manufacturing industries, including aerospace and defense.



Making new 3D materials for a wide variety of applications like batteries and fuel cells, electromechanical actuators, etc.

Potential future applications²⁴



Combining new types of novel materials to make improved automotive and aerospace parts and accessories.



Increasing availability of 3D materials to sectors such as housing and construction; widespread use of 3D tooling and increases in 3D manufacturing speed will enable faster production of 3D-printed products.



On-demand printing of customized products by using open-source designs and 3D scan codes.



Did you know? By 2020, 75 percent of manufacturing operations worldwide could use 3D-printed tools, jigs, and fixtures for the production of finished goods.²⁵



My take | 3D printing (additive manufacturing)

Andre Wegner

CEO, Authentise

Chair, Digital Manufacturing, Singularity University

Welcoming the new age of additive manufacturing

General Electric's late-2016 purchase of two large additive manufacturing (AM) equipment suppliers²⁶ signaled that the 3D printing market has shifted for a second time. The first shift came around 2008 as original patents to underlying technology started to expire, prices for simple 3D printers collapsed, and more potential users (companies and individuals) gained access to the tools. Now, with major manufacturers understanding and acting on the strategic importance of the technology, the age of AM as a production technology has well and truly arrived, particularly for industries such as health care, aviation, and aerospace.

While GE's initial use of AM to produce sensor housings and fuel injection nozzles signaled the opportunity, the company's recent announcements are transformative: The 35 percent of GE's first turboprop engine that is 3D-printed reduces what was formerly 855 parts to 12,²⁷ enabling GE's entry into that engine market. Meanwhile, Invisalign built on another benefit of the technology—customization—to produce dental braces, making it the first \$1 billion additive-enabled company. Medical device manufacturers, including Zimmer Biomet, Stryker, and others, are following suit by investing heavily in metal spine, hip, knee, and other implants. Meanwhile, SpaceX expects that its ratio of additively manufactured components to traditionally tooled parts soon will be 2:1.²⁸

Each of these applications brings benefits that traditional tools, still often an order of magnitude cheaper than AM, cannot provide. Whether through customization, light-weighting, part-count reduction, or pure processing capability, these AM-produced parts are paying their own way. While doing so, each bears witness to an evolution in AM materials, processes, or machines that is reducing cost and improving performance to the point where other industries and use

cases seem plausible. Already, major manufacturers and users, from Caterpillar to Deutsche Bahn, are exploring AM for spare parts. Automotive original equipment manufacturers (OEMs) also are embracing the technology; Renault recently presented its first fully 3D-printed engine block.²⁹

There is much more to do—despite the market entry of BASF, Dow, and others, the range of materials (900+ at last count) remains low and poorly characterized compared to traditional tools. And while the size of 3D printers has improved—most notably, by using standardized robotic arms as Stratasys or Viridis machines do—it still takes 24+ hours to produce a typical titanium print.

Solutions are in the works, however. Lawrence Livermore Lab published a paper on multi-array diode laser printing;³⁰ the new technology improves metal printing cost and speed 10–100x. It is now being commercialized, as is culturing and “printing” biological materials. Software is aiding the additive process too: Increasing deployment of generative design tools and AM-focused simulation packages helps engineers make the most of the evolving technology and prevent build failure. Connecting AM tools to machines and everyday Internet of Things (IoT) sources is the next step in creating a fully digital idea-to-part value chain, one in which designs are created automatically based on the data that surrounds us, and processes are seamlessly executed in the most efficient way possible. By doing this, AM is demonstrating the applied use of Industry 4.0 approaches to other manufacturing sectors, which may end up being its most impactful contribution.

Mr. Wegner's participation in this article is solely for educational purposes based on his knowledge of the subject, and the views expressed by him are solely his own. This article should not be deemed or construed

to be for the purpose of soliciting business for Authentise, nor does Deloitte advocate or endorse the services or products provided by Authentise.

Advanced analytics

Description:³¹ Advanced analytics involves statistical examination and analysis of data that goes beyond generic data intelligence gathering to unearth deep, actionable insights and make predictions on an autonomous or semi-autonomous basis. It includes a range of statistical methods or procedures, including but not limited to: pattern recognition, text analytics, cluster analysis, factor analysis, multivariate modeling, multiple regression, forecasting, machine learning, simulation, and neural networks.

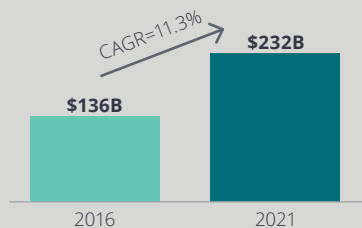
Market size and growth³²

During the forecast period (2016-2021):

Largest segments: Services (IT + business) and software (end-user query, reporting, and analysis tools and data warehouse management).

Largest industries: Discrete manufacturing, banking, and process manufacturing.

Highest-spending regions: United States and Western Europe.



Potential issues/challenges³³

1. Advanced analytics needs to be packaged so it is more menu-driven, user-friendly, and transparent.
2. The lag between data collection and processing has to be addressed.
3. The important managerial issues of ownership, governance, and standards have to be considered.
4. Data in certain industries is rarely standardized, often fragmented, or generated in legacy IT systems with incompatible formats.

Current applications³⁴



Predicting consumer behavior and purchasing patterns; demand planning and fulfillment; smoother supply chain operations.



Predicting the failures of circuit boards at early stages in the manufacturing process; forecasting energy demand in hyperlocal regions to predict the overload situations of energy grids.



Monitoring real-time aircraft health; identifying system/component failures in advance; making intelligent scheduling and forecasting models.

Potential future applications³⁵



Making automated recommendations; enabling self-learning supply chains with minimal human intervention.



Matching electricity supply (from renewable sources like solar) to localized demand—which unlocks higher efficiency in electricity generation.



Doing large-scale digitization of plane maintenance data and schedules; creating synergies across business and functional areas by enabling the “connected plane.”



Did you know? Advanced analytics can now predict the probability of aircrafts being delayed or canceled in the future.³⁶



My take | Advanced analytics

William Sobel

Chief Strategy Officer, VIMANA

Chair, Technical Steering Committee, MTConnect Institute

Advanced industrial analytics: Engine of the industrial IoT

It is often said that data is the fuel of the industrial Internet of Things (IoT), and if data is the fuel, then analytics are the engine. For many years, industrial applications languished as other industries evolved into new areas of advanced analytics, using machine learning and artificial intelligence (AI) to dig through the peta- (and then exa-) bytes of data being generated on the web and add real business value. Industrial applications, meanwhile, stayed firmly rooted in the same PLC and CNC technology that had been used since the 1980s.

It wasn't until 2011 that the ideas of using industrial data and modern analytical approaches were promulgated by large companies such as Cisco³⁷ and picked up by the market analysts. Initial estimates of market size were in the hundreds of billions and soon grew to over one trillion dollars.³⁸ The core tenant was: "If we could collect all the data from all the industrial equipment in the world, it would significantly exceed the number of connected people. The possibility for value-generation would be much greater as well, since the benefits would directly impact the creation of new goods and services."

The Industrial Internet Consortium (IIC) was created in March 2014 to address industrial internet issues and the creation of systems that exhibited the correct architectural concerns to meet the requirements of industrial applications; namely safety, security, and deterministic behavior. As part of its charter, the IIC has developed a document that provides a detailed analysis of the requirements and concerns for advanced industrial analytics.³⁹

Machine learning and AI, terms that are often conflated, are the primary tools being hyped as the solution for advanced analytics. Machine learning is a subset of AI, the latter being the umbrella concept

for all technologies that enable software to behave in a manner that is considered "smart." Machine learning is a set of technologies that automates the software engineering process by using data-driven statistical approaches to find patterns and automate the creation of classification and feature detection in large data sets. These data sets are used to train the software; the resulting models can then be deployed to handle deterministic data-in-motion concerns.

The latest focus in the AI domain is deep learning, which uses multilayer neural networks to reduce the need for feature extraction. Deep learning provides a much more automated approach to creating models but also increases the complexity of the algorithms. Deep learning techniques have been around for a long time but have only been made practical recently by GPU and CPU performance advances and the availability of large-scale, low-cost, abundant storage required for creating the models.

Learning models and AI are not a panacea. These methods can solve a certain class of problems but are not always an optimal solution. The most prevalent use case is predictive health and maintenance, which has great potential value but works only with simple devices with a limited number of operational states. There are many statistical methods and real-time event process techniques, like Complex Event Processing (CEP), that have much faster time-to-value. In the future traditional techniques will likely be coupled with machine learning and AI as they gain the ability to make systems more prescriptive. The key architectural guidance is to make the systems location-independent so they can best be deployed to meet an industrial system's requirements and their function within that system.

The true benefit of these technologies will likely be seen when we move toward

self-aware industrial systems that are self-managing and that provide real-time access to their state and capabilities so the advanced analytics can reason on solutions for optimal productivity and performance. Ultimately, AI analytics will likely be the foundation of the industrial system's ability to autonomously collaborate and optimize decision-making processes.

Mr. Sobel's participation in this article is solely for educational purposes based on his knowledge of the subject, and the views expressed by him are solely his own. This article should not be deemed or construed to be for the purpose of soliciting business for VIMANA, nor does Deloitte advocate or endorse the services or products provided by VIMANA.

Advanced materials

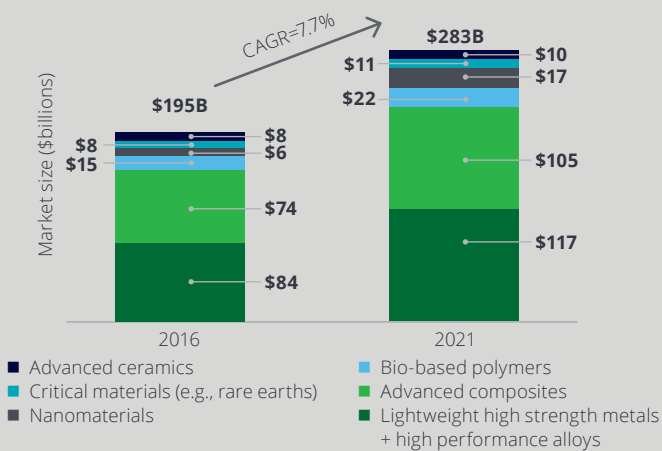
Description:⁴⁰ “Advanced materials” includes a whole gamut of chemicals and materials like lightweight, high-strength metals and high performance alloys, advanced ceramics and composites, critical materials, bio-based polymers, and nanomaterials.

These materials can be designed and/or optimized to have excellent thermal, magnetic, optical, catalytic, structural, luminescent, and electrical properties and to display high dimensional stability, temperature and chemical resistance, flexible performance, and relatively easy processing, enabling them to be used for lighter components and/or to help address other functional design and manufacturing challenges to unlock a new set of possibilities for manufacturers.

In the future, digital and exponential technologies will likely be used to combine, iterate, produce, and engineer functionality from these different advanced materials to make new types of materials, not occurring naturally.

Market size and growth⁴¹

During the forecast period (2016-2021):



Potential issues/challenges⁴²

1. For metals and alloys, process challenges like batch-to-batch inconsistency and tools wearing out quickly exist; machining cost for ceramics is usually high and contributes to 80 percent of overall expenses.
2. Energy efficiency and the environmental footprint of the manufacturing process of advanced materials like carbon-fiber composites are top concerns.
3. For critical materials, separating these elements from each other is costly and time consuming.
4. For bio-based polymers, further reduction of the production costs and scalability issues are top concerns.
5. Developing predictive models for estimating the potential impact of nano-materials on the environment and human health is a challenge.

Current applications⁴³



Reducing weight of aircraft and automobile components; used in permanent magnets in electric vehicle (EV) motors; used in automotive catalytic converters to filter toxic pollutants.



Manufacturing sporting goods such as golf club shafts and bicycle rods; used in light emitting diodes (LEDs) for solid-state lighting, permanent magnets in wind turbine generators, and advanced battery components.



Making anti-corrosion barrier coatings, UV protection gels, new fire-retardant materials, and superior-strength fibers and films.

Potential future applications⁴⁴



Manufacturing future airframes and vehicle bodies using higher proportion of aluminum alloys and composite materials while manufacturing aeroengines and gas turbines using more of high performance alloys.



Increasing use of natural fiber composites in thermoplastic decking, building materials, furniture, and automotive components.



Using carbon nanotubes in new class of display as emission device for the next generation of monitor and television; using printed organic electronics in OLED displays, lighting, thin film photovoltaics, and flexible sensors.



Did you know? A nanoscale biological structure is now capable of producing hydrogen from water using light.⁴⁵



My take | Advanced materials

Jim Phillips

Chairman of the Board and CEO, NanoMech®

Nanomanufacturing: Small is the new big

“Less is more” and “small is the new big” in the dynamic, transformative fields of nanotechnology and nanomanufacturing. The constant search for flexible, adaptive materials and higher performance at a lower cost are making nanotechnology one of the fastest-growing technological and commercial innovations of the 21st century. Lux Research projected the value of manufacturing goods using nanotechnology to rise from \$147 billion in 2007 to \$3.1 trillion in 2015.⁴⁶

Nanomanufacturers are using nanoscale (one billionth of a meter) materials to produce next-generation products that are stronger, lighter-weight, safer, more durable, and more reliable. Nanomanufacturing also represents the best of sustainable practices because it finds ways to exponentialize materials, reduce waste, reuse elements, and recycle materials—always considering how to make less...more!

My company, NanoMech, uses platform nanomanufacturing technologies to produce a broad range of **lubricants**, **specialty chemicals**, and **coatings** for companies, industries, and governments worldwide. Application areas include automotive, transportation, and trucking; retail; energy manufacturing, exploration, and service; truck and marine manufacturing; Indy and NASCAR racing; agriculture and construction equipment manufacturers; refining and formulating lubrication manufacturers; aerospace manufacturing; and advanced military applications. NanoMech is doing some fascinating work in adaptive chemistries for advanced textile coatings. We're currently developing next-generation US Army uniforms. The requirements are rigorous: The uniform fabric must be able to withstand 55 washings a day; be microbial, odor-proof, and fireproof; be embedded with sensors that can detect the different smell of the enemy; be light, breathable, and soft; and use no harmful chemicals. It's a multifaceted challenge

that illustrates how nanomanufacturing is ushering in a new era of product design with more flexibility than ever before.

United States needs to think and act big to get small

Nanoengineering and nanomanufacturing will dramatically accelerate the development of new materials and spawn a huge range of nanoscale applications and performance specifications. But, somewhat ironically, the United States is going to have to think and act big to reap the benefits of getting small.

The United States can justifiably claim a proud history of technology innovation, but we're becoming a mature country, getting settled in our ways, and falling behind China, India, and other ambitious nations which already have captured 80 percent to 85 percent of the materials market. Several things are holding us back from competing fully in the new nano-ecosystem. A big one is funding priorities: US venture capital is focused on the software side, and most growth in capital and new companies is in software applications. Meanwhile, other countries have been pouring money into non-software exponential technologies. The challenge of obtaining capital for deep science and manufacturing innovation could make the United States noncompetitive in the long run. Take, for example, public-private partnerships (PPPs): They're an out-of-favor business model in the United States (at least in the recent/near term), but we are competing against countries with state-run systems that are pouring funding into their innovation infrastructure. We need to revamp and reinvigorate PPP funding to help smaller companies, in particular, innovate if we expect to be competitive.

In addition, our process for cultivating STEM-ready employees has broken down. I trace its decline back 30 years, when the US education system killed-off shop classes: You had people with aptitude in

manufacturing, who used their hands and loved it, but they no longer had an outlet for their interests. The same thing happened when home economics classes were axed; women who liked biology and chemistry (and who might have gone on to major in the sciences in college) no longer had real-life opportunities to apply scientific concepts. As a result, our STEM talent pool has shrunk dramatically. We need to reinvigorate our talent development processes immediately, and this includes reactivating these core courses so the United States can once again supercharge the interest of those with the aptitude and desire to engage in STEM fields.

Most importantly, federal and state policy makers can improve the United States' competitive footing by focusing better on technology transfer commercialization, moving quicker from ideation to innovation to commercialization, and preventing America's innovation from becoming stranded.

Mr. Phillips' participation in this article is solely for educational purposes based on his knowledge of the subject, and the views expressed by him are solely his own. This article should not be deemed or construed to be for the purpose of soliciting business for NanoMech, nor does Deloitte advocate or endorse the services or products provided by NanoMech.

Advanced robotics and cognitive automation

Description:⁴⁷ Advanced robotics are machines or systems capable of accepting high-level mission-oriented commands—for example, navigating to a workplace—and performing complex tasks in a semi-structured environment with minimal human intervention. Includes autonomously or remotely guided commercial drone systems technologies, whether on land, sea, or air. Automation using robotics and cognitive technologies leads to greater efficiency by replicating human action and judgment. Combined with advances in data and analytics, this spectrum of solutions has the potential to reshape the marketplace.

Market size and growth⁴⁸

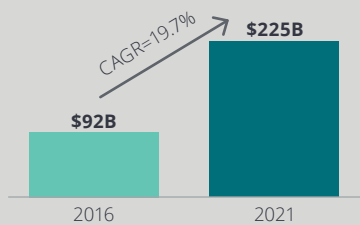
During the forecast period (2016-2021):

Largest segments: Manufacturing, resource industries, consumer, and health care.

Fastest-growing segments: Consumer, health care, and retail.

Largest technology segments: Hardware and services.

Highest-spending regions: Asia-Pacific (incl. Japan), Europe, and Americas.



Potential issues/challenges⁴⁹

1. Growing gap in the skill sets of workers in the manufacturing industry who are required to work alongside robots.
2. Acquiring robots can be very expensive, especially for small-to-medium manufacturing enterprises.
3. There are safety concerns when it comes to robots working with humans.
4. Significant advances in robotics may mostly come from AI/machine learning advances rather than further improvement in hardware.

Current applications⁵⁰



Widespread applications in assembly, welding and painting, and mixing as part of discrete and process manufacturing industries; using drones in intelligence gathering; chemical detection; inspecting wind turbine blades; and monitoring cellphone towers, construction activity, and mining extraction.



Collaborative robots used in manufacturing environments for tasks such as metal fabrication, packaging, testing and inspection, parts assembly, and loading and unloading.



Using robotics in aircraft manufacturing allows for more efficient production, with fewer errors and quality issues.

Potential future applications⁵¹



Adaptable, multitasking industrial robots that leverage AI to learn, don't require expensive and time-consuming reprogramming, emulate human senses, and are equipped with an array of sensors for vision recognition, sound, movement detection, and collision avoidance, and even tactile and force resistance sensing.



Human and robot “workers” that could interact and collaborate in a factory, driven by an AI “reasoner” that allocates a discrete task or tasks to each “worker” according to capabilities and to achieve greater efficiencies.



Did you know? Blurring boundaries between smart materials, artificial intelligence, biology, and robotics will likely create more sophisticated robots that may not only mimic humans but also perform tasks better, faster, and cheaper.⁵²



My take | Advanced robotics and cognitive automation

Samuel Bouchard

CEO and Co-Founder, Robotiq

Author of *Lean Robotics: A Guide to Making Robots Work in Your Factory*

Collaborative robots can help close the manufacturing skills gap

Broadcast and social media outlets regularly ring alarm bells about cold-hearted robots stealing people's jobs. But a visit to a typical factory floor often tells a different story: Many manufacturers' overriding challenge is not preventing robot robbery; it's finding enough people willing and able to perform the jobs that keep their factories running.

A study from Deloitte and the Manufacturing Institute states that "over the next decade nearly three and a half million manufacturing jobs likely need to be filled [in the United States] and the skills gap is expected to result in 2 million of those jobs going unfilled."⁵³ Can collaborative robot technology be part of the solution to close the manufacturing skills gap?

Unlike traditional industrial robots, which often require complex systems integration, collaborative robots can be easily programmed and installed on existing production lines, without guarding in most cases. Collaborative robot vendors are establishing ecosystems of plug-and-play components so end users can build robotic cells on their own. This enables a bottom-up, robot-as-a-tool way of deploying robots that provides quick payback and favors a manufacturer's autonomy.

Innovative manufacturers of all sizes and in various industries are aggressively adopting collaborative robots. Typical use cases are stand-alone manual, repetitive processes such as packaging, machine feeding, or simple assembly. Increasing numbers of Fortune 500 companies are leveraging collaborative robotics to impact their bottom line. One example is Procter & Gamble, which has deployed well over 80 such robots in the past 18 months.⁵⁴ P&G is expanding

its use globally to boost productivity, reduce costs, and improve quality and safety. At the other end of the spectrum, collaborative robots' ease of use and flexibility are allowing a new generation of manufacturing start-ups to robotize processes right from the start. One example is Lowercase, a New York City-based, high-end eyewear manufacturer. Lowercase's operation totals three people, one collaborative robot, and one machining center.

Collaborative robot technology is ripe for mass adoption by manufacturing companies, but its implementation may necessitate an executive balancing act: Companies need to concurrently invest in and manage employees assigned to transformative robotics projects and those handling the important daily activities that keep a factory floor humming.

Think it's difficult to hire and retain qualified manual workers today? Have you started recruiting people with robotics skills? If you haven't, you'll quickly realize it can be even more difficult, especially if your manufacturing facility is in a remote area. Whereas before you may have been competing for employees with the factory down the street, now you're going up against companies of all types and sizes—including tech giants like Google, Uber, and Amazon—all of which are hiring robotics graduates. And the demand for robotics skills will only increase as robots are adopted more broadly.

The longer you wait to build your own in-house robotics staff and expertise, the harder it gets—and the further behind you'll lag in productivity relative to competitors. Now is the time to "employ" collaborative robots to help close the manufacturing skills gap.

Mr. Bouchard's participation in this article is solely for educational purposes based on his knowledge of the subject, and the views expressed by him are solely his own. This article should not be deemed or construed to be for the purpose of soliciting business for Robotiq, nor does Deloitte advocate or endorse the services or products provided by Robotiq.

Artificial intelligence

Description:⁵⁵ Artificial intelligence (AI) is the theory and development of computer systems able to perform tasks that normally require human intelligence. Technologies that emanate from AI, called cognitive technologies, include: machine learning; computer vision; natural language processing; speech recognition; robotics; optimization; rules-based systems; and planning & scheduling. Specifically, machine learning refers to the ability of computer systems to improve their performance by exposure to data, without the need to follow explicitly programmed instructions.

Market size and growth⁵⁶
During the forecast period (2016-2021):

Largest use cases: Automated customer service agents, quality management investigation and recommendation systems, diagnosis and treatment systems, and fraud analysis and investigation.




Largest industries: Banking, retail, health care, and discrete manufacturing.

Largest segments: Cognitive applications, cognitive software platforms, and cognitive/AI-related services.




Year	Market Size (\$B)
2016	\$8B
2021	\$72B


- Potential issues/challenges**⁵⁷
1. There are legal and ethical issues regarding use of AI; at the same time, consumer acceptance of AI is low.
 2. Presence of inaccurate industrial data; industrial AI systems cannot be run in the cloud, but on the “edge”/on location, which limits their big-data applications and use cases.
 3. Complex models made using AI must be interpretable, which sometimes is a challenge.
 4. Predictive algorithms can be costly to develop.

Current applications⁵⁸

-  Enabling computer vision in autonomous/ semi-autonomous vehicles.
-  Applying AI to robotics, automatic programming of tasks and processes in industrial settings, and enabling predictive maintenance.
-  AI to transform ticketing process into a hassle-free experience and make in-flight experience personalized.

Potential future applications⁵⁹

-  Leveraging AI and computer vision technologies to augment advanced safety features in vehicles and aircrafts.
-  Amalgamating advanced AI into other exponential technologies like robotics, drones, etc.
-  Creating full replacement for human copilots in new, autonomous aircrafts.

 **Did you know?** By 2019, AI platform services could cannibalize revenues of 30 percent of market-leading companies.⁶⁰



Case study | Artificial intelligence: Machine learning

While efforts toward general artificial intelligence (AI)—systems capable of a comprehensive range of cognitive tasks similar to those of people—progress, an increasing number of companies have begun to implement narrow applications of AI to improve business processes, and even customer service and experience. Think consumer-facing virtual assistants deployed to man call centers to reduce costs, or digital assistants—like Siri and Alexa—designed to make voice-enabled search, information retrieval, and even shopping, more convenient. In both instances, these applications are enabled by cognitive technologies from the field of AI: natural language processing (NLP) and speech recognition.

In manufacturing environments, computer vision—another technology within the domain of AI—has long been used on factory floors for automated inspection and quality purposes. More recently, many automotive OEMs have been equipping vehicles with computer vision to enhance safety systems and satisfy consumers.⁶¹ Other promising applications of artificial intelligence technologies are being considered and adopted by manufacturers—case in point: machine learning.

Reducing downtime of critical assets in manufacturing: Machine learning for predictive, intelligent maintenance

Unscheduled downtime in industrial manufacturing operations is a killer of efficiencies and can reduce a plant's productive output, sometimes by up to 20 percent. These disruptions also carry significant increased costs—including labor, delayed delivery, unfilled orders, and restoring production lines—with an annual estimated cost to manufacturers upwards of \$50 billion, according to Deloitte research.⁶²

At the core of the problem are typically reactive approaches to maintenance, with more than three-fourths (76 percent) of downtime occurring before

remediation.⁶³ Despite offering some benefits, scheduled maintenance can be time-consuming, expensive, and largely ineffective in detecting incipient failures that can result in operational downtime: Some studies suggest that 85 percent of asset failures may happen despite it.⁶⁴

Ensuring the uptime of critical assets compels manufacturers to develop more proactive, and even predictive, data-driven approaches to maintenance to identify and preemptively address equipment issues to avoid failure and plant shutdowns.⁶⁵ Given the ubiquitous connected nature of modern manufacturing operations, the massive amounts of information continuously streaming from industrial assets seem ripe to mine and analyze for information about the equipment status and health. Taking this unstructured data—and deriving insights, and enabling them to detect anomalies and be predictive of asset failures—requires machine learning.

Machine learning and its promise for predictive maintenance applications

A cognitive technology emanating from the field of artificial intelligence, machine learning—to paraphrase Deloitte's David Schatsky—refers to the ability of computer systems to access data and use it to learn and improve without explicit programming, and automatically discover patterns in data and iteratively become more accurate in predicting outcomes.⁶⁶ In industrial manufacturing settings, machine learning systems can learn from patterns that preceded downtime events culled from data in maintenance history. The systems can track live data to recognize those patterns, or anything anomalous that could cause fresh failures, and can inform operators when a machine requires attention and even be prescriptive of required actions.⁶⁷

Case example: Leading global manufacturer of industrial pumps, seals, and valves and service provider of comprehensive flow control systems

Challenge: With thousands of customers in over 50 countries, the company's existing threshold monitoring systems were only able to identify pump failures for customers a few hour in advance, providing them insufficient time to respond and fix problems to avoid failure and downtime. As well, each pump type required custom engineered algorithms for predictive capability, proving too intensive.⁶⁸

Solution: The company partnered with an AI-solutions vendor to develop an advisory application for predictive maintenance, underpinned by machine learning and augmented by natural language processing. The application proved capable of processing machine data, drawing conclusions, and codifying learnings, while enabling the rapid development of algorithms adaptable to different pump types, and scalable across plants.⁶⁹

Benefits: The company was able to provide customers a powerful predictive maintenance tool, which:

- Lowered the maintenance costs and improved asset availability for users by up to 10 percent
- Detected events or predicted failures 5-6 days in advance—instead of, as previously, hours—a 20x improvement⁷⁰

To conclude...

The use of machine learning in manufacturing environments could proliferate, and help address thorny issues in manufacturing operations. From identifying which operating speeds could be most cost effective—and thereby optimizing production plans and schedules—to understanding and proactively addressing employee absenteeism, or assessing and correcting customer delivery issues, future applications of machine learning could prove beneficial.⁷¹

Biotechnology/Biomanufacturing

Description:⁷² Biotechnology, broadly defined, involves any technological application that uses biological systems, living organisms, or derivatives thereof to make or modify products or processes for specific use. Inclusive of any technologies used to investigate, manipulate, or synthesize living organisms.

Biomanufacturing is a type of manufacturing or biotechnology that utilizes biological systems to produce commercially important biomaterials and biomolecules for use in medicines, food and beverage processing, and industrial applications. Includes manufacturing life *de novo* or with substantially different form or function from those found in nature.

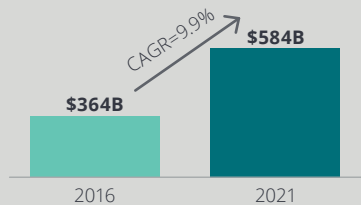
Market size and growth⁷³

During the forecast period (2016-2021):

Largest segments: Tissue engineering and regeneration, fermentation, PCR, nanobiotechnology, chromatography, DNA sequencing, and cell-based assays.

Largest industries: Medical/Health care, food & agriculture, and environmental & industrial.

Highest spending regions: North America (primarily United States), Europe, and Asia-Pacific.



Potential issues/challenges⁷⁴

1. Unintended or malicious genetic modifications or changes could impact entire species and have catastrophic consequences.
2. Public concern about potential risks could result in excessive regulation, and stymie innovation and development of new products.
3. Regulatory and legal standards lacking in synthetic biology. Regulation is also lagging for biotech/biomanufacturing involving gene editing, particularly for agriculture and health.
4. Ensuring IP protection, and that technical standards are deployed, when products are transitioned to commercial status.

Current applications⁷⁵



Renewable oils from plant sugar used in automotive applications, including prototype car tires.



Synthetic flavorings for food and beverage products as well as synthetically derived fragrances.



Production of apparel, including neckties and jackets made from yeast-derived spider's silk.

Potential future applications⁷⁶



Synthetic biological cars could be designed to adapt and repair themselves.



"Green" bioplastics that decay naturally are on the horizon and expected to help reduce environmental waste.



Use of synthetic biology to support astronaut health during space exploration by making it safer to store food for extended periods, and development of hydratable, single-use packets for human consumption.



Did you know? In the first half of 2017, 22 synthetic bio start-ups raised more than \$500 million in VC, public funding, and grants.⁷⁷



My take | Biotechnology/Biomanufacturing

Dr. Tiffany Vora

Vice-Chair, Medicine and Digital Biology, Singularity University

Giving life to biomanufacturing

At Singularity University, we frame the future of life sciences-based technologies as *digital biology*; essentially viewing life as information. Through this data-driven paradigm, many of the trends we see in other manufacturing realms are being translated to biological manufacturing—including the manufacturing of bioactive products such as drug treatments, the manufacturing of consumables based on biomaterials, and even the manufacturing of life itself. Rapid prototyping, computer-aided design, crowdsourcing, short and dynamic supply chains, customization, real-time data analytics to achieve actionable insights, and even platform “experiences” are beginning to transform biological manufacturing.

The democratization of technologies have led to exciting developments in the animal-free, plant-free manufacturing of many biological materials that we’ve come to rely on. Cellular agriculture is on the verge of becoming economically viable at scale, thanks to the efforts of pioneers such as Modern Meadow (leather), Memphis Meats (meat), Finless Foods (seafood), and Perfect Day (dairy). Organovo is bioprinting live human tissue, with an eye on research and, ultimately, therapy. More controversially, companies such as Pembient and Ceratotech are biomanufacturing synthetic rhino horn; are these efforts supporting or undercutting conservation initiatives and anti-poaching laws around the world? These are just a few examples of manufacturing capabilities that would have seemed like science fiction just a few years ago.

Within the next decade, I believe that we will witness an explosion of opportunity in biomanufacturing. Imagine automated delivery of customized food products that are tailored to the medical history, microbiome, and schedule of each of your customers. Imagine predictive analytics that tell your manufacturing plants which customers will need

which of your vaccines when—in time to maximize the efficiency of your supply chain. Imagine using CRISPR genome editing to construct animal or cell models that perfectly capture the genetic landscape of a disease, including all the variations in specific patients, to identify the ideal combinations of your drugs for personalized medicine. Imagine designing, from scratch, a bacterium whose genome includes plug-and-play modules for health monitoring, or drug production, or another tailored function.

Like tremors underfoot, the plummeting cost of foundational technologies such as DNA sequencing—the price performance of which is beating Moore’s Law—as well as accelerating advances in biotechnologies hint at profound societal and cultural changes on the horizon. By embracing an exponential mind-set now, tomorrow’s world may be one of abundance—abundant information, abundant resources, abundant health—for everyone. The future of health care, wellness, pharmaceuticals, agriculture, biological manufacturing, and so many other life sciences-based economies is right here, right now. Let’s manufacture that future.

Dr. Vora’s participation in this article is solely for educational purposes based on her knowledge of the subject, and the views expressed by her are solely her own.

Blockchain

Description:⁷⁸ Blockchain is a distributed ledger technology that provides a way for information to be recorded and shared by a community. It is a way to structure and distribute data without the need for a centralized authority. The data recorded and transmitted through the blockchain technology is believed to be immutable, safe, secure, and tamper-proof.

Simply put, blockchain technology is used to “create and manage a distributed database and maintain records for digital transactions of all types,” in a variety of industries.

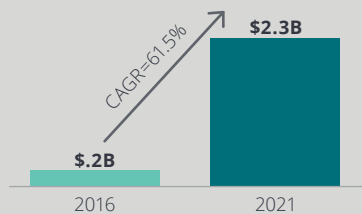
Market size and growth⁷⁹

During the forecast period (2016-2021):

Largest segments: Business and financial services and technology, media and telecom.

Largest protocols: Bitcoin, Ethereum, and Ripple.

Highest-spending regions: North America and Europe.



Potential issues/challenges⁸⁰

1. Issues with respect to integration of software/product life cycle management (PLM) platforms exist.
2. Challenges with respect to recording of events that occur during the manufacturing process, which may render a blockchain solution ineffective.
3. Both public and private blockchain networks need interoperability, which will require agreement on common standards.
4. Different laws and regulations and rights of ownership exist across shipping routes, supply chains, and multiple jurisdictions.
5. Significant collaboration and infrastructure development required to make blockchain solutions scalable.

Current applications⁸¹



Securely transferring an owner’s personal mobility profile, including preferences, between multiple vehicles and even third-party partners, such as car sharing or multimodal transport providers.



Enabling greater transparency of accurate information between different parties; improving just-in-time logistics; reducing erroneous orders; improving inventory turnover.



Used as digital currency and for reducing fraud, reducing counterfeit goods, and enabling B2B payments.

Potential future applications⁸²



Tracking and verifying automotive parts; monitoring and distributing information about vehicle safety.



Integrating blockchain with other exponential technologies—like 3D printing and IoT—to realize greater manufacturing efficiencies.



Improving tracking in supply chains and procurement by using a shared database with suppliers and partners; enabling validation of supplier performance and reputation; and time-stamping product-related records to reduce fraud and improve supply chain security.



Did you know? Banks have reportedly saved \$8–\$12 billion annually by employing blockchain technology.⁸³



My take | Blockchain

Nathana O'Brien Sharma

Program Director for Faculty Affairs and Faculty, Law, Policy, Ethics and Blockchain, Singularity University
Partner, Crypto Lotus, LLC

Beyond bitcoin: Blockchain grows up

Blockchain is growing up. While most people are familiar with bitcoin, the first and still biggest use of this exponential technology, blockchain is maturing beyond its origin as the public ledger for digital cryptocurrency transactions, and entrepreneurs are beginning to apply its unique capabilities to transform entertainment, health care, manufacturing, and other segments of the economy.

Want to license and distribute a song you wrote but avoid third-party legal and management costs? Blockchain might be music to your ears. Want to tap industry cohorts for information about a potential supplier's performance without compromising competitiveness? Blockchain participants could share insights honestly and anonymously. Need to increase your company's in-transit supply chain visibility? Blockchain may keep parts moving more smoothly and securely.

Blockchain creates unique opportunities to reduce complexity, enable collaboration, improve efficiency, and lower costs. A shared, immutable record of linked, peer-to-peer transactions stored in a digital ledger, blockchain technology allows each participant in an open or closed network to interact (e.g., store, exchange, and view information) without mediation by a central authority. Interactions with the blockchain are visible to all participants and require verification by the network before information is added or changed.

Blockchain has countless potential applications. Three, in particular, hold promise for the manufacturing industry:

Creative ownership and licensing—In 2015, musician Imogen Heap worked with start-up UjoMusic to distribute her song "Tiny Human" on the Ethereum blockchain. Fans could use Ether, the blockchain's digital currency,⁸⁴ to buy a license to download, stream, remix, and sync the song; their payments were

automatically directed to and shared among Heap and her collaborators,⁸⁵ bypassing the traditional centralized intermediation of a major music label. In April 2017, music streaming giant Spotify acquired blockchain start-up Mediachain Labs; the two will develop enhanced technology for connecting artists and other rights holders with the tracks hosted on Spotify.⁸⁶ By verifying which artists and people on a chain have creative ownership and licensing rights, blockchain can reduce copyright, distribution, and payment costs. By extension, blockchain could verify when and how a manufacturer uses other companies' parts and patents in one of its products and make sure that the suppliers are paid accordingly.

Identity and reputation management—ConsenSys is an Ethereum-focused start-up that builds decentralized applications and various developer and end-user tools for blockchain ecosystems.⁸⁷ Among the core components used in its digital applications (dApps), platforms, and other solutions is uPort, a decentralized digital identity platform that gives users complete control of their identity, personal information, and digital assets.⁸⁸ ConsenSys currently is using uPort to pilot a blockchain identity application for Brazil's Ministry of Planning, Budget and Management to verify the legitimacy of personal documents.⁸⁹ Another ConsenSys core component, RepSys, is a multitiered reputation system that enables people, organizations, and objects to attest to the conduct of their counterparties in different types of transactions, including buying/selling, lending/borrowing/repaying, collaborating on projects, and data quality and reliability.⁹⁰ Manufacturers seeking information on what it's like to work with a particular supplier (and vice versa) could anonymously request and share performance reviews with participants on an industry-focused blockchain.

Supply chain management—Radio-frequency identification (RFID) is widely used by manufacturers in life sciences, consumer products, and other industries to track the flow of assets along the supply chain. Adding blockchain's tagging and time-stamped recording capabilities can increase supply chain efficiency and reduce instances of fraud and human error by providing visibility into the provenance of a product and its sourced supplies at every stage of production. As we build additional sensors to increase in-transit supply chain visibility and eventually move toward Internet of Things (IoT) and ubiquitous sensors, blockchain potentially serves as the data or transaction layer for all of that information moving within and between organizations in an encrypted fashion.

Like other exponential technologies, blockchain is maturing at a speed that makes it difficult for manufacturing companies to stay abreast of the latest developments; collaborating with organizations that really understand the technology and its myriad potential applications can help. Suggestions include the ConSensys Academy, which describes itself as "the educational core of the Ethereum movement."⁹¹ Also, don't think about blockchain technology in isolation. The convergence of blockchain and artificial intelligence (AI), for example, has a promising future in further optimizing supply chain operations. The 21st century is all about the knowledge economy. Devoting some measure of headspace and headcount to integrating blockchain and other new and maturing technologies can help companies become and remain vibrant members of that economy.

Ms. Sharma's participation in this article is solely for educational purposes based on her knowledge of the subject, and the views expressed by her are solely her own. This article should not be deemed or construed to be for the purpose of soliciting business for Crypto Lotus, nor does Deloitte advocate or endorse the services or products provided by Crypto Lotus.

Cybersecurity

Description:⁹² Though typically not considered a discrete exponential technology in itself, cybersecurity technologies, processes, and practices serve as hygiene factors and are essential in ensuring that the full potential of exponential technologies is realized. The role of cybersecurity becomes even more essential today as significant operational risks for connected, smart manufacturing, digital supply networks, and entire manufacturing ecosystems emerge—risks that lie at the intersection of cyber and physical infrastructure. The combination of a variety of secure and sophisticated tools powered by AI/machine learning enables real-time responses to cybersecurity threats. This greatly helps in empowering a secure, vigilant, and resilient approach to Industry 4.0-enabled devices, digital networks, and more broadly, manufacturing environments.

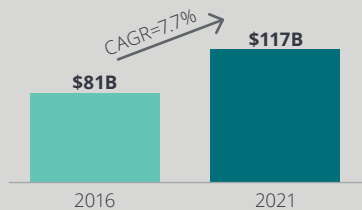
Market size and growth⁹³

During the forecast period (2016-2021):

Largest segments: Security services: IT outsourcing and consulting, firewall equipment, and infrastructure protection: security software.

Fastest-growing segments: Security testing, security services: IT outsourcing, and identity access management.

Highest-spending regions: North America, Europe, and Mature Asia (excl. China).



Potential issues/challenges⁹⁴

1. Need for executive- and board-level engagement and adequate funding.
2. Vulnerability of legacy assets and systems, industrial control systems, and connected products in manufacturing environments. Machine and materials costs.
3. Theft of intellectual property.
4. Talent: Employees as weakest link to cyber-threats; dearth of skilled cybersecurity workers; many companies in industry lack dedicated Chief Information Security Officer.
5. Connected products: Connectivity security, data ownership and management, and consumer/customer privacy.

Current applications⁹⁵



Hiring of a Chief Information Security Officer and dedicated security team; performing penetration testing and war-gaming scenarios within IT and OT groups; in industrial environments, inventory and security testing of all assets and continuous monitoring for potential security events, unauthorized access, or changes; implementing ICS Security programs to remediate any weaknesses.



Comprehensive and layered security solutions for connected cars that protect privacy, ensure safety, and thwart unauthorized access.



Designing, developing, and implementing Product Security Programs™ to secure connected products both at an enterprise level (e.g., security incident response) and product level (e.g., technical security testing).

Potential future applications⁹⁶



Within digital supply networks, addressing cyber imperatives around data sharing, proprietary data security, and assuring trust in vendor processing.



Implementing intrusion detection systems to detect malware in 3D printing instructions or encoded in the structure of items being scanned to produce objects.



Supply chain partner security validation and audits within manufacturing value chains and secure product procurement from vendors to assist with identification of cybersecurity and privacy risks with the products, subcomponents, or services being procured.



Did you know? There could be 3.5 million cybersecurity jobs unfilled, globally, by 2021.⁹⁷



Building resiliency in the age of escalating cyberattacks

Cyber threats can come from any direction and have cascading consequences. Manufacturers may not be the direct target of a specific cyberattack, yet they can easily become collateral damage and suffer major business disruptions. For example, the recent “NOTPETYA” computer virus epidemic was a “wiper” style malware that disrupted older operating systems within the global manufacturing infrastructure: Automotive companies, a cocoa manufacturer, and a major pharmaceutical company, among others, had their operations temporarily shuttered. The “patient zero” target was a small tax accounting software vendor in Ukraine, but the situation quickly spread to the manufacturing industry. Unfortunately, the affected companies either did not have the required cybersecurity resources in place to monitor for such potential threats or they were unable to patch out-of-date operating systems used on production line computers in time to prevent the damages from this particular attack.

Cybersecurity should be a major strategic focus for manufacturers in every industry and region, and control and management should extend beyond information technology (IT) to operating technology (OT) and manufacturing technology assets—especially if they are running on old, legacy operating systems. In many industries, there is an underlying misperception that these systems are air-gapped—in other words, safe from cyber threats because they are not connected to the worldwide web, or to other unsecure computers or networks. But the reality is, even such systems today are more vulnerable to targeted or tangential attacks than previously thought. Cyber adversaries have proven they can hack into such environments through self-propagating computer viruses (also called worms) that will spread between systems using internal shared networks or even thumb drives shared between devices. For more modernized manufacturers,

researchers doing a proof-of-concept demonstration hack last year on industrial robots were able to conduct remote attacks on the computers that control the robots on the production lines.⁹⁸ Individual manufacturing companies aren’t necessarily at fault when a cyber breach occurs. Compromised third-party software can render an organization’s technology assets vulnerable, which points to a wider, collective manufacturing ecosystem issue. Fortunately, companies are beginning to recognize that in a connected, IoT, modern manufacturing world they may be more vulnerable to a cyberattack than before and that the potential consequences are greater.

Manufacturing companies that are ahead of the cybersecurity curve typically concentrate on three things:

1. Talent and know-how. Forward-thinking manufacturers invest in cyber tech and cyber talent. As seen in industrial controls, energy, and a few other industries, these companies typically have a Chief Information Security Officer (CISO) who reports to the Chief Information Officer (CIO) or directly to the Chief Executive Officer (CEO) or company board. The CISO heads a department of security experts who protect all of the organization’s cyber and physical assets. These leading companies also have internal research teams that employ a hacker mind-set to test existing systems (sometimes called “red team testing”) and recommend protective (and proactive) actions.

2. Digital twin technology. A number of large companies are looking at digital twin technology, a way to model the closed-loop product development and manufacturing process to identify which “crown jewels” in a manufacturing facility are at risk of a cyberattack and to simulate what a protective software upgrade would look like. Ideally, the

time to introduce security features is up-front during design; the process becomes exponentially more costly and complicated when it is introduced as an afterthought.

3. Technology ingredients lists or “bill of materials” (BOM). Manufacturing supply chains are increasing in size and complexity. An ingredients list improves tracking and accountability and provides clear pointers to who makes what component and where it comes from. A BOM can assist by identifying all open-source and third-party software components, allowing the organization to respond to any possible security vulnerabilities or breaches. Ingredients lists are already in use by certain medical device manufacturers and have applicability in other industries that are highly dependent on critical supply chain security.

The concept of creating supply chain accountability and transparency speaks to the importance of taking an ecosystem approach to manufacturing cybersecurity. It also points to the need for collaboration. I can see opportunities for collaborative cybersecurity frameworks popping up among companies with good experiences in tackling complex security challenges and in countries that have dealt with cyberattacks.

Ms. Elazari’s participation in this article is solely for educational purposes based on her knowledge of the subject, and the views expressed by her are solely her own.

Digital design, simulation, and integration

Description:⁹⁹ Digital design, simulation, and integration (DDSI) is the conceptualization and digital construction of a virtual prototype or a process achieved through computer simulation of a physical product or a process. Simulation models are developed through logic and symbolic relationships between entities to study the behavior of a system that evolves over time. DDSI is inclusive of digital thread, digital factory design.

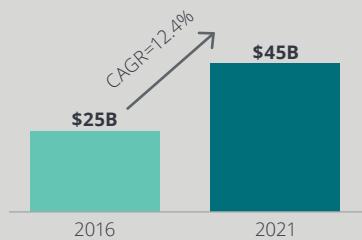
Market size and growth¹⁰⁰

During the forecast period (2016-2021):

Largest segments: Computer-Aided Design (CAD) software.

Fastest-growing segments: Design automation, plant design, product design & testing, and drafting & 3D modeling.

Highest-spending regions: United States.



Potential issues/challenges¹⁰¹

1. High cost to either purchase or license engineering and design software.
2. Conversely, increase in open-source engineering and design software impacting engineering and design software market.
3. Talent pool shortage and/or learning curve/lack of technical expertise in advanced design software (i.e., 3D CAD/CAM).
4. Ensuring intellectual property protection and safety of design content in cloud and/or open-source environments.

Current applications¹⁰²



Fostering design collaboration and providing an environment to share best practices in digital manufacturing.



3D CAD modeling used to design, and test and validate designs, prior to tool manufacturing.



Use of CAD permits auto manufacturers to design sophisticated parts and components by using advanced tools to detail the designs.

Potential future applications¹⁰³



Enabling digital integration and access to digital data across the manufacturing life cycle in the future factory, and enabling greater supply chain visibility.



Advanced technologies from IoT to additive manufacturing to advanced analytics could speed and improve the design cycle, reduce time to market, and link design to smarter products.



Simulation could enable the virtual testing of plant production systems at planning phase to prevent any potential faults, even before any components have been installed.



Did you know? Automakers switching from 2D to 3D CAD have realized 20 percent reduction in design time.¹⁰⁴



My take | Digital design, simulation, and integration

Michael Vergalla

Founder and Lead Researcher, Free Flight Research Lab
Faculty, Robotics, Space and Digital Manufacturing, Singularity University

One foot in the future can maximize today's technology investments

Manufacturing is well-known for its leading-edge use of technology advancements including machine vision and robotics. As the rest of the world catches up, new solutions are being created that will need to be refolded into manufacturing. Stanford Research Institute, for example, developed two novel mechanical transmissions in 2017—a 98 percent-efficient transmission and an infinitely variable transmission.¹⁰⁵ Stanford designed these transmissions for lightweight humanoid robotics, but they will likely have direct impact on the key manufacturing areas of power generation, power consumption, and machine capability.

Other new processes and technologies are expected to benefit manufacturing: Combined-cycle additive and subtractive processes can merge into one machine utilizing low-cost, accessible robotics. Additive manufacturing can enable customized tooling design and fabrication. Machines can incorporate sensors and analytics to minimize downtime and increase machine-to-machine awareness, and provide the ability to optimize work flow based on as-built configurations. Inflatable structures emerging from cloud-based simulation capability gains can unlock fluid structure interaction capabilities. The convergence of this digital simulation capability tracking with maturing material technology—specifically, practical applications for graphene/carbon and micro-lattice—can enable minimal material solutions that are structurally robust and rapidly deployable. Multi-species robotic assembly and manufacturing can transform construction and disaster management. Robotics will no longer be viewed as a computer-controlled single machine capable of complex tasks but as multiple connected, distributed machines carrying out complex series of tasks with onboard insights programmable by

various types of computers (quantum, biologic, photonic). Software tools such as generative design can enable design curation in collaboration with software and create thousands of possible solution spaces.

Manufacturing companies that invest in these and other new, digital technologies can benefit via process improvements, operating efficiencies, cost savings, and improved employee satisfaction. But the prospect of these gains doesn't always translate into immediate uptake: Technology adoption faces cultural, regulatory, and financial challenges. Many manufacturers are aware of emerging technologies, but unless they deliver a near-term, direct, quantifiable benefit, it can be difficult for management to rationalize major shifts away from the way business is currently conducted. Investing in a new technology at the wrong time could result in a large expenditure that does not produce anticipated gains. Companies looking to maximize today's investments should have one foot in the future but be mindful of the present. A suggested approach is to allocate a small group to drive technology innovation, harvest successes, and integrate them into the larger organization. And, sometimes, moving forward means looking back at a technology that didn't make sense 10 years ago but has matured enough that it offers great promise for tomorrow.

Mr. Vergalla's participation in this article is solely for educational purposes based on his knowledge of the subject, and the views expressed by him are solely his own. This article should not be deemed or construed to be for the purpose of soliciting business for Free Flight Research Lab, nor does Deloitte advocate or endorse the services or products provided by Free Flight Research Lab.

Energy storage

Description:¹⁰⁶ Energy storage technologies enable higher, more efficient, mobile/nonmobile storage and capture of energy for use-on-demand applications. These technologies enable a more resilient energy distribution infrastructure and bring more cost savings to utilities and consumers. Energy storage mainly includes: solid-state batteries, flow batteries, flywheels, compressed air energy storage, thermal, and pumped hydro-power.

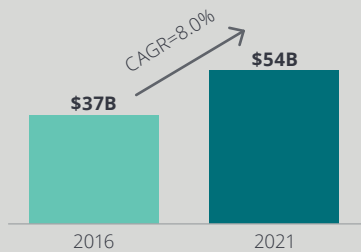
Market size and growth¹⁰⁷

During the forecast period (2016-2021):

Largest use cases: Electric vehicles, smartphones/tablets, and residential.

Largest industries: Consumer electronics, transportation, and stationary.

Highest spending regions: United States, China, and Europe.



Potential issues/challenges¹⁰⁸

1. High up-front cost of developing and commercializing energy storage systems is a large barrier to ready adoption.
2. Lack of familiarity with storage technology among utilities, regulators, and financiers.
3. Need for highly skilled and experienced technicians to maintain and operate energy storage systems correctly.
4. Regulations exist that prevent storage from competing in energy, ancillary service, or capacity markets.

Current applications¹⁰⁹



Using electricity storage for electric vehicle charging; lowering fuel consumption.



Reducing facility electricity costs by charging batteries at night when electricity costs are low, and using that energy during the day to avoid expensive peak-hour electricity prices and demand surcharges.



Developing and using lithium-based batteries, proton exchange membrane (PEM) fuel cells for aerospace applications that require higher energy density and storage requirements.

Potential future applications¹¹⁰



Integrating IoT with energy storage technologies can increase its effectiveness and efficiency.



Increasing use of distributed energy storage systems in residential, commercial applications where solar and other renewable energy integration is happening at a rapid pace.



Creating higher-density solid-state batteries and reducing cost of energy storage systems will enable these technologies to be used in a variety of industries.



Did you know? The US energy storage market is set to “explode”—from 6 gigawatts (GW) in 2017 to over 40 GW by 2022.¹¹¹



My take | Energy storage

Ramez Naam

Co-chair, Energy & Environmental Systems, Singularity University

Manufacturing powers up clean energy storage

When it comes to energy production and consumption, the long-held truism that “you can have it cheap or you can have it clean” soon may be replaced by “you can have it cheap and you can have it clean.”

Organizations and individuals understandably want to purchase the least expensive energy available; historically, that has been energy generated from fossil fuels. But the picture is changing: In certain parts of world, solar energy is becoming the cheapest unsubsidized energy you can buy; in others, it’s wind power—and countries, companies, and consumers are taking advantage of the trend.

Factors powering clean energy’s rise include improving and less costly production and storage technology; companies’ growing commitment to manufacturing their products using clean energy; and nations’ increasing investments in solar and wind energy to reduce pollution from fossil fuels. Saudi Arabia, for example, plans to develop 30 solar and wind projects over the next 10 years as part of a \$50 billion program to boost power generation.¹¹² The world’s biggest photovoltaic solar plant—at 1.2 gigawatts—is scheduled to begin operating in Abu Dhabi, United Arab Emirates, by April 2019.¹¹³ Government-owned Abu Dhabi Water & Electricity Authority received a then record-low bid of 2.42 cents a kilowatt-hour (kwh) for power from the planned facility.¹¹⁴ In November 2017, Mexico saw even lower bids of 1.9 cents a kwh for new solar power plants. India has now seen solar bids as low as 3.8 cents a kwh, 20 percent cheaper than the price of new coal.

Among options for companies looking to tap into clean energy savings are building manufacturing facilities in countries that generate ample (read: inexpensive) solar or wind power; installing solar panels on existing buildings’ roofs and generating some of their own energy; or investing in an energy storage system in which

on-site batteries stockpile electricity from rooftop solar panels or the grid overnight to use during peak cost times.

While it’s early days in manufacturing’s use of on-site energy storage (in which batteries and operational software typically are provided by a vendor and paid for as a service), the approach is worth considering for a couple of reasons. First, it provides protection in case of a grid blackout. Second, it can save money on energy consumption. Many commercial buyers pay a higher price and additional surcharges for electricity during daylight hours when demand is greatest. If a manufacturer can store excess energy (from rooftop solar or the cheap, off-peak grid electricity), it can use that electricity instead of the much more expensive grid power during peak cost times in midday and afternoon.

There are some operational issues to work out before clean energy production and storage can go mainstream in manufacturing. A big one: variability and availability. Companies can access electricity from the grid at any time, but there is no solar power when the sun doesn’t shine. How can solar customers save energy during a string of rainy days? Also, the availability of energy varies by time of day—no solar at night, right? Can manufacturers align their most energy-intensive processes with the time of day energy will be the most available and least expensive?

Manufacturers interested in exploring the benefits of clean energy production and storage should talk to their customers about how important it is that their products be produced by clean energy; investigate the feasibility and cost of installing on-site energy collection and storage devices, and discuss options with alternative energy providers and energy storage vendors.

Mr. Naam’s participation in this article is solely for educational purposes based on his knowledge of the subject, and the views expressed by him are solely his own.

High performance Computing/Next-gen computing

Description:¹¹⁵ High performance Computing (HPC) refers to the practice of aggregating computing power in a way that delivers much higher performance, i.e., systems that typically function above a teraflop or 10^{12} floating-point operations per second, in order to solve large highly complex problems in science, engineering, or business.

Next-generation computing includes: cognitive computing, quantum computing, neuro-synaptic computing, and DNA computing as emerging concepts and computing architectures.

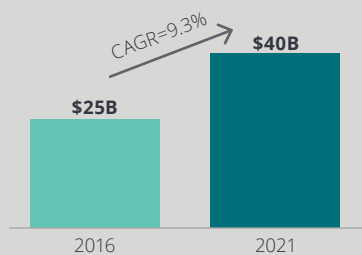
Market size and growth¹¹⁶

During the forecast period (2016-2021):

Largest segments: Servers and storage.

Fastest growing segments: Quantum computing and high performance data analytics.

Highest spending regions: North America and Europe.



Potential issues/challenges¹¹⁷

1. Paucity of memory capacity and bandwidth required for optimal functioning of advanced supercomputers.
2. Lack of tolerance for some degree of hardware failure without inhibiting workload execution.
3. Outside interferences include heat, internal defects, magnetic noise, and vibrations that disrupt quantum computing.
4. Scalable quantum computing with error correction has not yet been proven in practice.
5. Managing energy use and efficiency for exaflop computing systems

Current applications¹¹⁸



Designing and analyzing internal combustion engines using simulation models on supercomputers; performing virtual crash testing for automobiles; analyzing the deformation profile of plastics and metals; simulating wear and tear of moving parts.



Modeling components and testing assembled systems without the need to create physical prototypes; shortening the time to discovery in many manufacturing industries while accelerating the product development process.



Performing and modeling blood flow analysis for medical devices; genome processing and sequencing; drug design; molecular modeling; and biology simulation.

Potential future applications¹¹⁹



Inspecting infrastructure; enabling intelligent supply chain; predicting the properties of futuristic/exotic materials; modeling and simulating real manufacturing processes to fix errors.



Using quantum computation to uncover new, high-density designs that could considerably increase the capacity of batteries for electric vehicles.



Analyzing inventory; optimizing logistics and supply chain; marketing offers to varied consumers.



Did you know? Japan's K supercomputer has conducted huge simulations of how earthquakes can play out in cities like Tokyo.¹²⁰



My take | High performance computing/Next-gen computing

Dr. Davide Venturelli

Quantum Computing Team Lead and Science Operations Manager, USRA Quantum AI Laboratory at NASA Ames
Adjunct Faculty, Quantum Computing, Singularity University

Kick-starting the industrial age of quantum computing

After nearly 20 years of theorizing and experimenting, major computer hardware companies, venture capital (VC) firms, and governments (led by the European Union and Canada) have finally begun investing heavily (more than a billion dollars combined¹²¹) to kick-start the industrial age of quantum computing.

Quantum computing (QC) is a spectacular manifestation of the attention of the tech world to paradigm-shattering new approaches to computation. It needs to be contextualized within the many different hardware approaches (e.g., Annealers, Optical Coherent Machines, Neuromorphic, DNA-Computing, Spintronics) that have been proposed to circumvent the computational bottlenecks produced by scaling the quality of solutions for problems arising in machine learning, big data, and optimization.

A combination of two factors is driving industrial interest in quantum computing:

- Realization that these computer science problems could benefit from special-purpose, hardware-optimized devices designed specifically to accelerate the solution and reduce the energy consumption of particular classes of problems
- Fear of missing out (FOMO) on being an early mover in what could be a key competitive advantage in the next decade

Another factor increases QC's future appeal—it has the potential to offer some known, algorithmic-level advantages which, at a large scale, would be mathematically unbeatable by any non-quantum information processing technology. The caveat is that these known advantages would not be practical for more than a decade at quantum computers' current and projected growth of power. Even when the known algorithms become runnable, their impact on industrial optimization and artificial intelligence (AI) is not likely to be a game-changer.

Notwithstanding QC's known advantages, forward-looking enterprises and investors are mostly fascinated by the unknown: It may be possible to invent quantum algorithms that could be practically deployable within a decade and could deliver *exponential* speed-up. But we don't yet know enough about quantum information processing to determine this, and we won't likely learn much more about this elusive field of applied science unless (and until) we have a quantum computer to play with—a classic chicken-and-egg problem.

There is no clear “big win” in sight, but QC as a research field has grown exponentially in the last five years. Today, the community at large encompasses nearly 10,000 researchers, not including the numerics practitioners in finance, optimization, and AI, who are approaching the field from the perspective of end users. This, I believe, is the perspective that is appropriate for the manufacturing industry. Innovation departments in charge of automation, operations research, planning and scheduling of robotic operations, value-chain optimization, and machine learning should: (1) evaluate which of the current computational approaches could be ported to benefit from quantum cloud computing in five to seven years; (2) design new, high-end computation systems in a modular way so they could be effectively hybridized with quantum and unconventional dedicated processors; and (3) identify which among the current numerical challenges in their business is presenting a significant bottleneck in terms of intrinsic exponential difficulty that could be potentially addressed by disruptive, unconventional methods.

To facilitate this computational evolution, IBM and Google (along with start-up companies such as Rigetti Computing and IonQ) are creating an experimentation ecosystem by providing free cloud access to their processor prototypes to any qualified researcher.¹²² Another

groundbreaker is D-Wave Systems, the first QC company with a commercially viable product—a quantum annealer (i.e., a computer) that can be used as a “black box” to solve discrete optimization problems. D-Wave is selling computing time on the cloud to enterprise customers.¹²³ In addition, several government institutions and innovation programs have created collaborative opportunities to test the machine for free; for example, the USRA Research Opportunity Program,¹²⁴ which makes available the computer installed at NASA Ames Research Center.

Technology providers recognize that there is still a long way to go before making quantum computing “plug-and-play” and that success likely will come via a hybridized, quantum-classical system dedicated to solve specific problems that are collaboratively identified with the end-user community.

Mr. Venturelli's participation in this article is solely for educational purposes based on his knowledge of the subject, and the views expressed by him are solely his own.

Interface of Things




Description:¹²⁵ Interface of Things includes: virtual reality (VR), which creates a fully immersive digital environment that replaces the user's real-world environment; augmented reality (AR), which overlays digitally-created content into the user's real-world environment; mixed reality (MR), a subset of AR, which seamlessly blends the user's real-world environment and digitally created content, where both environments can coexist and interact with each other; wearables that enable users to take real-world actions by providing relevant, contextual information precisely at the point of decision making; gesture recognition technology that enables humans to communicate and interact with a machine, naturally, and without any mechanical devices.

Market size and growth¹²⁶
During the forecast period (2016-2021):
Largest segments: Mixed reality and wearables.
Largest industries: Retail, discrete manufacturing, and process manufacturing.
Largest use cases: Retail showcasing, product development, and industrial maintenance.
Highest-spending regions: United States, Asia-Pacific (excl. Japan), and Western Europe.





Year	Market Size
2016	\$38B
2021	\$163B


- Potential issues/challenges**¹²⁷
1. VR/AR devices' need for: greater computational power, battery life, better field of view, new eye-tracking techniques, lower price point, better bandwidth, as well as security and privacy considerations.
 2. Brands may be unclear on how to create a customer experience using AR/VR, as consumers may be unsure of usefulness.
 3. Wearables have experienced product recalls, litigation risks, patent breaches, and medical liability risks.
 4. Safety and regulatory compliance implications, especially in critical infrastructure environments.

Current applications¹²⁸

-  Head-mounted displays used for hands-free instruction or training in simulated environments, and for remote expert assistance and collaboration.
-  Replacing assembly manuals with smart glasses displays is enabling aerospace companies to realize substantial reductions in wiring production time.
-  Wearables for quality checks and assurance at automotive assembly plants.
-  Gesture control of interactive visual display systems for marketing or promotional purposes in retail environments.

Potential future applications¹²⁹

-  Use of virtual reality to optimize and design factories.
-  Simulation of an entire factory or warehouse to enable workers to train to use equipment more safely and efficiently.
-  An AR solution that would allow a technician within a factory to view and respond to environmental data about a piece of machinery.
-  Auto retailers in showroom can provide 3D car configurators to enable customers to explore and interact with a 3D virtual car.

 **Did you know?** BVR/AR headset shipments could reach 100 million units by 2021.¹³⁰



My take | Interface of Things

Aaron Frank

Principal Faculty, AR/VR, Singularity University

Game on: Mixed-reality technologies on the factory floor

Earlier this year, Protectwise, Inc., a cybersecurity startup in Denver, Colorado, released a new visual interface technology—one that allows security analysts to navigate through data from a company's IT systems in a 3D video game city.¹³¹ The tool works by representing each machine on an IT network as a building. The height, width, and color of each building provide an analyst with information about what's happening with the machine, and whether a data breach might be taking place.

It seems fitting that Protectwise's mixed-reality tool was developed by a Hollywood visual designer who worked on films including *Tron: Legacy*. As futuristic as this IT city scenario appears, fairly soon large companies may have war rooms of Oculus Rift-wearing security professionals patrolling their company's digital infrastructure inside video game worlds like these. In fact, the future of work for numerous business professionals and technicians may appear ripped straight from the script of a big-screen science fiction blockbuster.

While immersive computing and mixed-reality technologies like augmented and virtual reality are only recently emerging as relevant business tools, expect them to fundamentally reshape the relationship between workers and their business processes. For manufacturing companies that rely on industrial equipment, for example, augmented reality glasses or other head displays will provide real-time instruction to equipment service professionals by overlaying visual guides on the machines they're troubleshooting—or enable far-away experts to guide local technicians through the repair process. This guided approach

has the potential to lower skill barriers, increase operational efficiencies, improve worker satisfaction, and create an experience closer to that of playing a real-life video game.

Taking a step further into the future, businesses may routinely create entire simulations of their factories or warehouse floors so that employees can train to operate equipment more safely and effectively. StriVR, a Menlo Park, California-based start-up spun out of Stanford University, is already working with several large companies to develop relevant training scenarios for its employees using interactive footage filmed with 360-degree cameras¹³²—employees may not be allowed on the factory floor until they can demonstrate proficiency in beating what is effectively a real-world training game.

Companies hoping to dive right in and adopt mixed-reality tools should expect to take an experimentation-based approach in the short term. As these exponential technologies continue their development, the AR/VR ecosystem will need to develop more uniform hardware and software specifications, and a more robust set of tools for developers to build out relevant applications. In the long run, however, mixed-reality platforms will create a workforce that's far more engaged, capable, and productive. As my colleague Jody Medich, Director of Design at Singularity University, says, "Our brains have evolved powerful ways of processing information that depend on dimensionality." Humans are 3D thinkers—and tools like these will give technicians a way of working with their equipment that's far more intuitive and efficient.

Mr. Frank's participation in this article is solely for educational purposes based on his knowledge of the subject, and the views expressed by him are solely his own.

Internet of Things (IoT)

Description:¹³³ Internet of Things (IoT) refers to an amalgamation of advanced software, cost-effective sensors, and network connectivity that allow objects to interact digitally. The IoT concept involves connecting machines, facilities, fleets, networks, and even people to sensors and controls; feeding sensor data into advanced analytics applications and predictive algorithms; automating and improving the maintenance and operation of machines and entire systems; and even enhancing human health.

Market size and growth¹³⁴

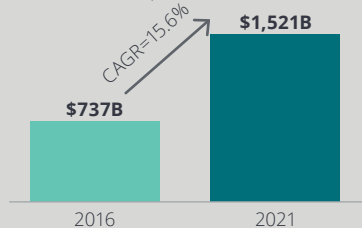
During the forecast period (2016-2021):

Largest segments: Manufacturing, transportation, consumer, and utilities.

Fastest-growing segments: Insurance, consumer, health care, and retail.

Largest technology segments: Hardware, services, and software.

Highest-spending regions: Asia-Pacific (excl. Japan), United States, and Western Europe.



Potential issues/challenges¹³⁵

1. Thwarting threat actors from hacking industrial control systems at nuclear power plants or in connected cars is vital for safeguarding critical assets and human life.
2. Determining use cases, developing a business case, justifying initial investment, and proving ROI are common challenges for manufacturers considering implementing IoT projects.
3. Existing IoT-enabled products that don't offer enough tangible benefits relative to cost of investment could stymie further customer adoption.
4. In the manufacturing ecosystem, establishing who owns the data generated by IoT applications—the manufacturer or its suppliers, vendors, or customers—can be a thorny issue.

Current applications¹³⁶



Services related to vehicle, driver, and passenger safety, such as automatic crash notification that alerts emergency responders when an accident has occurred; enabling communication of the vehicle with other vehicles and its surroundings (V2V and V2I).



Developing smarter products and services; adding visibility on the shop floor; reducing the time-to-market of products and solutions.



Monitoring aircraft engine health and optimizing engine performance based on data collected from sensors.

Potential future applications¹³⁷



Collecting and relaying car-related data back to auto OEMs and insurers that could enable them to make better informed business decisions.



Managing material costs, product price, and demand fluctuations by analyzing big data, enabling integrated smart connected assets and operations and, eventually, an autonomous production environment.



Improving airport operations using sensor data to proactively manage ground operations based on insights gathered from across the entire airport.



Did you know? The number of connected IoT devices, sensors, and actuators could reach over 46 billion by 2021.¹³⁸



My take | Internet of Things (IoT)

Dr. Kevin A. Shaw

Chief Technology Officer and Co-Founder, Algorithmic Intuition Inc.
Faculty, Networks and Computing, Internet of Things and Sensors, Singularity University

Getting a sense of sensors' promise

Smartphones, tablets, the Internet of Things (IoT), connected homes, wearables, and other emerging devices are proliferating in popularity because they give us sense of the world around us. It's like extending our nervous systems around the globe. Couple these myriad devices with fast internet activity and we become part of a continuous, pulsing creation wrapping the world in sensors—a system so large many view it as the largest single system yet made by man.

Sensors' capabilities are expanding even as their size is shrinking. Wikipedia already lists 200-300 sensor types¹³⁹ and many of these are becoming "transistorized"—tinier and more powerful because they are made of silicon. This means that, in the near future, we will see more and more sensors on objects, collecting more and more information from those sensors, and sharing that information with more people—provided those sensors are connected.

The variety of things that can be sensed is also expanding. Even the most mundane items—lightbulbs, trash cans, doorknobs—can become sensors when connected to the Internet of Things. In addition, every IoT device is, in essence, another place for a sensor. To get a sense of how today's sensor applications promise tomorrow's innovations, consider these examples:

- **Phones.** Remember when a phone was just a box with a wire (connected to the wall) for talking to people? Who knew they needed cameras, GPS, and 20+ other sensors.
- **Garbage cans.** By putting sensors on plastic or metal trash receptacles, cities like Barcelona, Spain, and Baltimore, Maryland, have cut trash pickup costs by millions of dollars.¹⁴⁰ The cities use the sensors and wireless networks to measure the trash in a given can,

determine when it's full, and pick it up only when it's needed. Skipping empty or partially filled cans reduces employee time, gas usage, truck wear and tear, and the city's carbon footprint.

- **Doorknobs.** Many office buildings have automated doorknobs with keypads that respond to a badge swipe, and hotels have had electronic keys for years. Now house doorknobs are incorporating Bluetooth sensors that know when homeowners arrive, unlock the door, and welcome them in the process.
- **Farms.** They used to be just fields with dirt, plants, and a little rain. Now they are huge wireless sensor arrays, measuring nutrients, water, and salinity at two-, four-, and six-foot depths, and insects, sun, wind, and dust overhead. Farms are big business, and now they are becoming leaders in high-tech.
- **Lightbulbs.** Recently, manufacturers began replacing old inefficient incandescent bulbs with LED fixtures and, since they use low voltage, they are running power to these fixtures with Ethernet cables. With this, buildings can control on-off settings and ambient lighting as a person walks through the halls. However, Ethernet works both ways, and manufacturers realized that they could run data through the same Ethernet, turning every lightbulb into a sensor endpoint that is connected to a computer. Lightbulbs are being called the "Trojan horse" of sensors because LiFi—putting data traffic through a lightbulb—likely will be the point of entry for widespread sensor use in buildings.

Despite building excitement around sensors' promise, challenges to innovation exist. One is perception: Most IoT applications take existing products that we barely notice and add intelligence and sensing capabilities. It may be difficult getting people to realize they are now using an object that can be "cognified"—made intelligent—and used in

nontraditional ways. There are technical challenges as well. In a manufacturing setting, for example, most machines are already fitted with sensors that generate important data, but legacy software and network limitations prevent operators from bringing that data together to look for larger patterns. Power is a big issue, too. Many IoT apps want to be wireless. These require batteries, which drain over time. Energy harvesting to extend battery life is not yet where it needs to be, so developers are stuck with reducing the app's power. Fortunately, these and other challenges—coding data handling, for instance—should be overcome within the next five years.

People ask me what the next big sensor-enabled device will be and I honestly don't know. The hardest part is seeing mundane objects we've used since children and imagining how they could be different: How does one see a lightbulb as anything but a lightbulb? Someone somewhere is going to look at an object, thinking, "I wonder..." and then the next game-changer is born.

Dr. Shaw's participation in this article is solely for educational purposes based on his knowledge of the subject, and the views expressed by him are solely his own. This article should not be deemed or construed to be for the purpose of soliciting business for Algorithmic Intuition Inc., nor does Deloitte advocate or endorse the services or products provided by Algorithmic Intuition, Inc.

Call to action

Executives agree the pace of change in manufacturing and the broader ecosystem is getting faster and faster. It's critical, therefore, that manufacturers understand and harness the power of new disruptive technologies and business models to transform into agile and adaptable organizations, and take the exponential leap to achieve exponential results.

The exponential transformation journey

Executives' indicated awareness of exponential technologies does not translate to transformation. Action does. The exponential transformation journey is an iterative process that can be characterized by three phases (figure 21):

1. Observe & imagine

Establish an exponential vision and prioritize opportunities. In this early phase, manufacturers set out to understand the nature of disruptive exponential forces and appreciate the urgency to innovate.

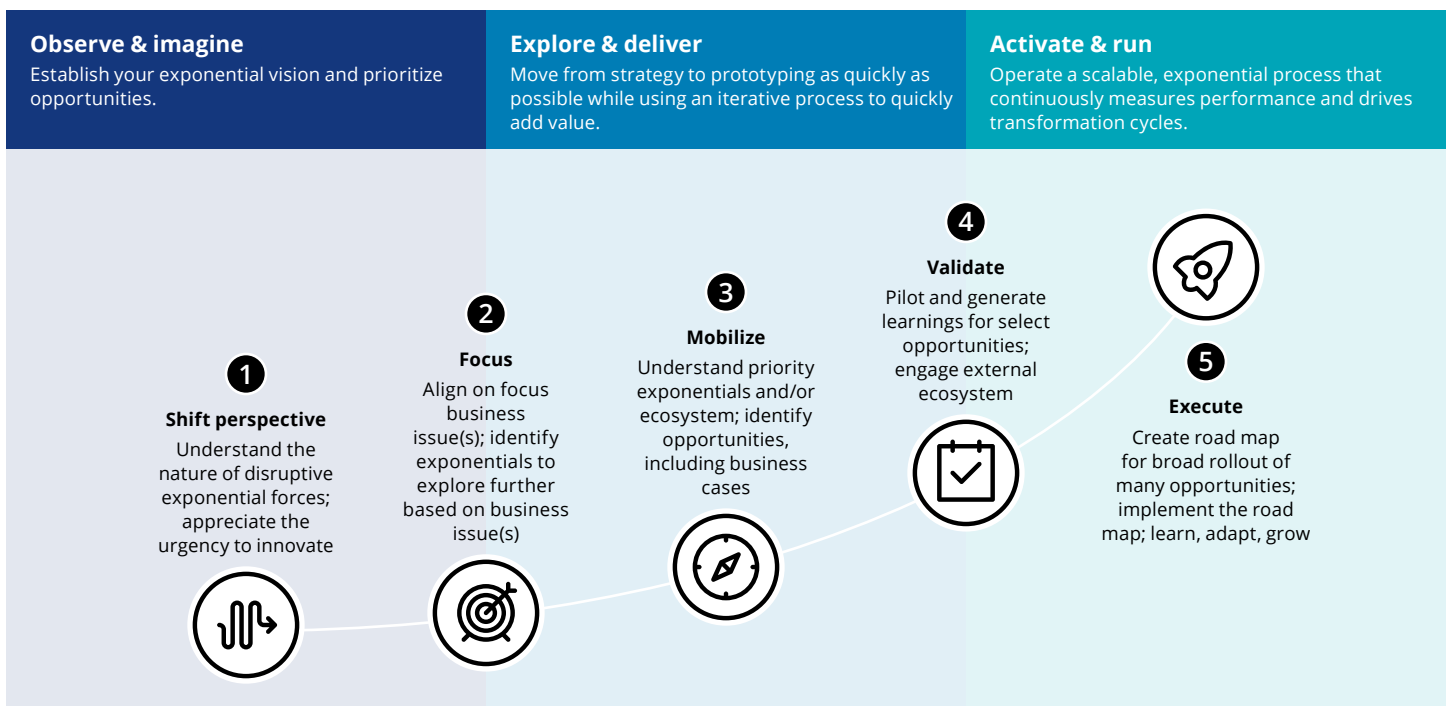
2. Explore & deliver

Move from strategy to prototyping as quickly as possible while using an iterative process to quickly add value. In this middle phase, attain a deep understanding of priority exponentials and/or ecosystem components to focus on, as well as identify discrete and tangible opportunities, including business cases.

3. Activate & run

Operate a scalable exponential process that continuously measures performance and drives transformation cycles to think big, start small, and act fast. In this final phase, create and implement a road map of opportunities to learn, adapt, and grow, all the while refining the road map as it is being executed.

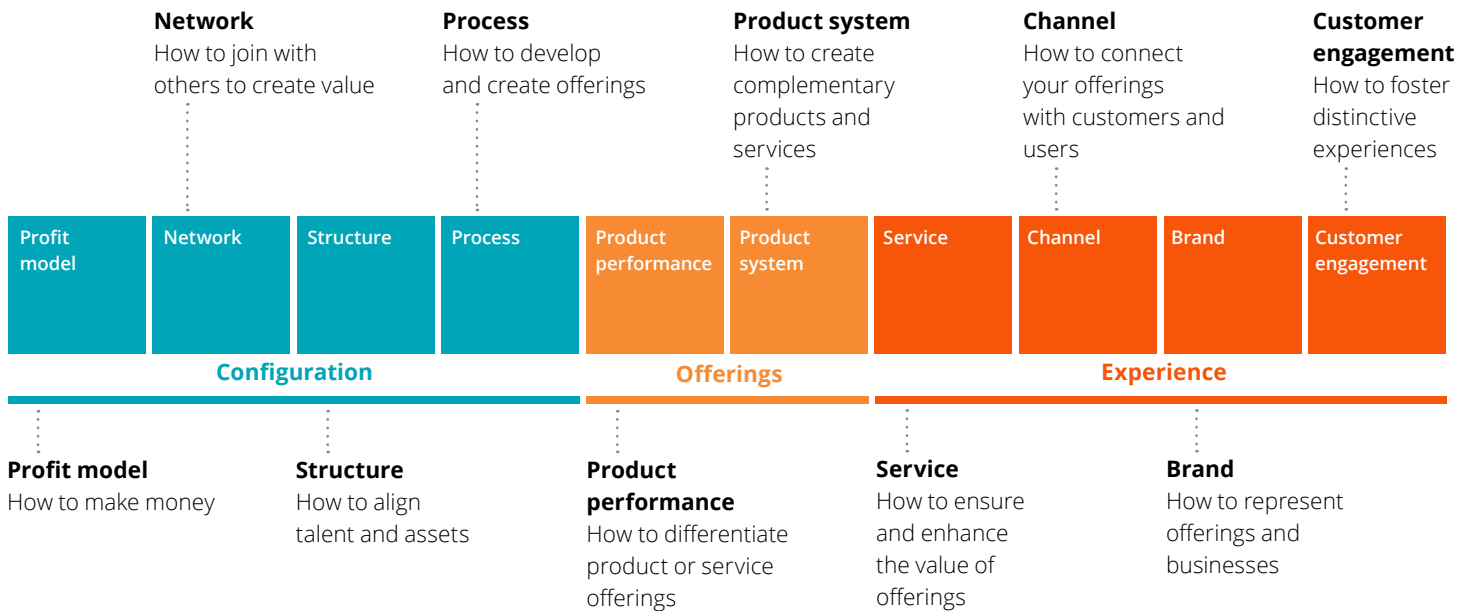
Figure 21. Exponential transformation approach: Use an iterative process that begins by determining strategic vision and needs



Source: Deloitte analysis

Executives also agree that manufacturing companies should view exponential transformation holistically in terms of how it can evolve traditional, product-centric innovation. Manufacturers could benefit by exploring a more expansive innovation framework (figure 22):

Figure 22. Manufacturers can benefit from looking at a more expansive framework for innovation



Source: Keeley et al., *Ten Types of Innovation: The Discipline of Building Breakthroughs*

Companies also should realize that most of innovation's value is realized outside the product—be it in the profit/business model or at the customer-engagement level.¹⁴¹ Therefore, organizations should not restrict the application of exponential technologies (and other resources) to products and processes alone.

As mentioned earlier in the report, exponential technologies can be leveraged in each of three areas: core, adjacent, and transformational (see page 15). Taking a flexible, portfolio approach to allocating resources in each of the three areas may aid future financial performance. (Note that transformational bets tend to be where 90 percent of future revenue could reside in five to ten years.)¹⁴²

Achieving manufacturing transformation and developing an exponential mind-set also require thoughtful, engaged, and brave company leadership—executives with the courage to allocate resources, invest in new technologies, and take risks (albeit ones that are calculated and informed). Such leadership provides the agency for technology development and implementation—as well as calendar time to address barriers large and small—and clearly articulates the enterprise rationale and mandate for adoption to help ensure cultural alignment. And most of all, such leadership can empower employees at all levels to work to their greatest potential.

Executives seeking to develop an exponential mind-set should consider the following recommendations based on findings from our executive interviews:

Know what problem(s) you are trying to solve. Adopt advanced technologies based on an existing and well-considered business

problem and/or imperative coupled with a clear action plan. As needed, start small with pilots that address unmet internal or customer-based needs, accruing wins that prove ROI along the way as larger implementations launch.

Entrust small teams to innovate at the edge. Make organizational structure flexible. Provide teams with the autonomy and means to fail fast, and fail better—until they succeed—while protecting them from corporate rigidity. “The worst they can do is come up with a threat to the core business—better to disrupt yourself, and keep the innovation in your own tent,” advised a technology domain expert.

Operate outside traditional walls. Be open to exploring the broader ecosystem to gain or leverage talent, capabilities, or solutions. For example, work with suppliers and customers to develop a common language for supply chain alignment, or partner with technology domain start-ups to access know-how and talent or universities and/or national labs. Be open to learning and leveraging assets that aren't your own.

Raise the national dialogue on system-level competitiveness and innovation enablers. Public-private partnerships (PPPs) foster and provide forums for industry to collaborate, and to dialogue with academia and government about areas critical for manufacturing competitiveness. These may include IP protection, burdensome regulations, R&D investment and tax credits, STEM education, and the ability to attract and retain needed talent. PPPs may help manufacturers' concerns be heard by policymakers and other members of the ecosystem and build an impetus for change.

Authors and acknowledgments

Authors

Michelle Drew Rodriguez

Manufacturing Leader
Deloitte Center for Industry Insights
Deloitte Services LP

Robert Libbey

Manager
Deloitte Center for Industry Insights
Deloitte Services LP

Sandeepan Mondal

Assistant Manager
Deloitte Center for Industry Insights
Deloitte Services LP

Jeff Carbeck

Specialist Leader, Advanced Materials and
Manufacturing
Deloitte Consulting LLP

Joann Michalik

Managing Director
Strategy and Operations
Deloitte Consulting LLP

Advisory board

Duane Dickson

Vice Chairman, US Chemicals and Specialty
Materials Sector Leader
Deloitte Consulting LLP

Doug Gish

Principal, US Consulting Supply Chain and
Manufacturing Operations Leader
Deloitte Consulting LLP

Trina Huelsman

Partner, Deloitte Risk and Financial Advisory
Deloitte & Touche LLP

Barb Renner

Vice Chairman, US Consumer Products
Leader
Deloitte LLP

Andrew Vaz

Global Managing Partner, Global Chief
Innovation Officer
Deloitte Touche Tohmatsu Limited

Craig Giffi

Vice Chairman, US Automotive Industry
Leader
Deloitte Insights Global Leader
Deloitte LLP

Dan Haynes

Principal, US Consulting Manufacturing
Sector Leader
Deloitte Consulting LLP

Robin Lineberger

Principal, US and Global Aerospace and
Defense Leader
Deloitte Consulting LLP

Geoff Tuff

Principal, Deloitte Digital
Transformation Leader
Deloitte Consulting LLP

Paul Wellener

Vice Chairman, US Industrial Products and
Services Leader
Deloitte LLP

Mark White

Principal, US Innovation Office Chief
Technologist
Deloitte Consulting LLP

Special advisors

Deborah L. Wince-Smith (President and CEO, Council on Competitiveness), **Rob Nail** (CEO, Singularity University), and their teams provided significant guidance in shaping the overall effort.

Acknowledgments

The authors would like to acknowledge the guidance and continued support of the following persons: Andre Wegner (CEO, Authentise and Chair, Digital Manufacturing, Singularity University) and Chad Evans (Executive Vice President, Council on Competitiveness) for their involvement throughout the study as well as the following Deloitte leaders and team members: Benjamin Dollar (Principal, Human Capital, Consumer and Industrial Products practice, Deloitte Consulting LLP), Greg Durant (Vice Chairman/Deputy CEO, Deloitte LLP), Doug Alkema (Partner, Audit and Assurance, Deloitte & Touche LLP), Martin Stansbury (Principal, Energy & Resources Practice, Deloitte Consulting LLP), Stavros Stefanis (Principal, Strategy and Operations, Deloitte Consulting LLP), Nick Handrinis (Principal, Strategy and Operations, Deloitte Consulting LLP), John Coykendall (Principal, US and Global Aerospace and Defense Consulting Leader, Deloitte Consulting LLP), and René Stranghoner (Sector Specialist, Industrial Products and Services, Deloitte Services LP).

Endnotes

1. Singularity University, *An Exponential Primer*, <https://su.org/concepts/>.
2. Deloitte and the Council on Competitiveness, *2016 Global Manufacturing Competitiveness Index*, 2016, <https://www2.deloitte.com/us/en/pages/manufacturing/articles/global-manufacturing-competitiveness-index.html>.
3. Deloitte, *Digital Supply Network Study*, January 2018.
4. Deloitte and MIT Sloan Management Review, *Aligning the organization for its digital future*, July 2016, <https://sloanreview.mit.edu/projects/aligning-for-digital-future/>.
5. Ibid.
6. Deloitte, *Introduction: Rewriting the rules for the digital age*, February 2017, <https://www2.deloitte.com/insights/us/en/focus/human-capital-trends/2017/introduction.html>.
7. Manpower Group, *2016-2017 Talent Shortage Survey*, 2017, <http://www.manpowergroup.com/talent-shortage-2016/>; Deloitte, *The skills gap in U.S. manufacturing: 2015 and beyond*, 2015, <https://www2.deloitte.com/us/en/pages/manufacturing/articles/boiling-point-the-skills-gap-in-us-manufacturing.html>.
8. Deloitte, *The skills gap in U.S. manufacturing: 2015 and beyond*, 2015, <https://www2.deloitte.com/us/en/pages/manufacturing/articles/boiling-point-the-skills-gap-in-us-manufacturing.html>.
9. Manpower Group, *2016-2017 Talent Shortage Survey*, 2017, <http://www.manpowergroup.com/talent-shortage-2016>
10. Software Advice, *Manufacturers Are Hiring Again; What Skills Are They Looking For?*, <http://www.softwareadvice.com/resources/manufacturers-skills-in-demand/>.
11. Deloitte, *A look ahead: How modern manufacturers can create positive perceptions with the US public*, 2017, <https://www2.deloitte.com/us/en/pages/manufacturing/articles/public-perception-of-the-manufacturing-industry.html>.
12. Deloitte, *2017 Deloitte Global Human Capital Trends: Rewriting the rules for the digital age*, February 2017, <https://www2.deloitte.com/global/en/pages/human-capital/articles/introduction-human-capital-trends.html>.
13. Indian Express, *How millennials are transforming traditional workplace into a digital one*, June 2016, <http://computer.expressbpd.com/news/how-millennials-are-transforming-traditional-workplace-into-a-digital-one/17836/>; Randstad, *Gen Z and Millennials collide at work*, http://experts.randstadusa.com/hubfs/Randstad_GenZ_Millennials_Collide_Report.pdf.
14. Harvard Business Review, *The New Science of Building Great Teams*, April 2012, <https://hbr.org/2012/04/the-new-science-of-building-great-teams>.
15. Deloitte, *A look ahead: How modern manufacturers can create positive perceptions with the US public*, 2017, <https://www2.deloitte.com/us/en/pages/manufacturing/articles/public-perception-of-the-manufacturing-industry.html>.
16. Figures inside the boxes are "Average R&D spend over 2012–2016" in \$ millions, calculated by S&P Global Market Intelligence.
17. MERICS, *Made in China 2025: The making of a high-tech superpower and consequences for industrial countries*, December 2016, https://www.merics.org/sites/default/files/2017-09/MPOC_No.2_MadeinChina2025.pdf.
18. Ibid.
19. Forbes, *China Hits Record High M&A Investments in Western Firms*, September 2016, <https://www.forbes.com/sites/wadeshepard/2016/09/10/from-made-in-china-to-owned-by-china-chinese-enterprises-buying-up-western-companies-at-record-pace/#68edcf8f5d87>.
20. Deloitte, *Advanced Technologies Initiative: Manufacturing & Innovation*, 2015, <https://www2.deloitte.com/content/dam/Deloitte/us/Documents/manufacturing/us-indprod-deloitte-and-council-on-competitiveness-advanced-tech-report.pdf>.
21. IDC, *Worldwide Spending on 3D Printing Forecast to Grow at a Compound Annual Rate of 22.3% to Nearly \$29 Billion in 2020*, According to IDC's 3D Printing Spending Guide, January 2017, <https://www.idc.com/getdoc.jsp?containerId=prUS42211417>.
22. UBS Research, *How Additive Manufacturing Could Develop and What to Watch for*, July 2016, accessed via Deloitte's subscription to Thomson Research; Imperial College (London), *The current landscape for additive manufacturing research*, 2016; Stratasys, *TREND FORECAST: 3D Printing's Imminent Impact on Manufacturing*, 2015, <http://advancedmanufacturing.org/wp-content/uploads/2016/04/Top-Challenges-to-Widespread-3D-Printing-Adoption.pdf>; Gartner, *Forecast: 3D Printers, Worldwide*, 2016, September 20, 2016, via Deloitte subscription.
23. Deloitte, *Advanced Technologies Initiative: Manufacturing & Innovation*, 2015, <https://www2.deloitte.com/content/dam/Deloitte/us/Documents/manufacturing/us-indprod-deloitte-and-council-on-competitiveness-advanced-tech-report.pdf>; Javelin, *Aerospace*, accessed on August 2017, <http://www.javelin-tech.com/3d-printer/industry/aerospace/>; C&EN, *Printing 3-D Conductive Materials With The Help Of Ionic Liquids*, November 2014, <http://cen.acs.org/articles/92/web/2014/11/Printing-3-D-Conductive-Materials.html>.
24. Deloitte, *3D opportunity in the automotive industry*, 2015, https://dupress.deloitte.com/content/dam/dup-us-en/articles/additive-manufacturing-3d-opportunity-in-automotive/DUP_707-3D-Opportunity-Auto-Industry_MASTER.pdf; TMF, *Smithsonian Magazine*, *What Lies Ahead for 3-D Printing?*, May 2013, <http://www.smithsonianmag.com/science-nature/what-lies-ahead-for-3-d-printing-37498558/?all>; Wired, *The race to build the first 3D-printed building*, March 2017, <http://www.wired.co.uk/article/architecture-and-3d-printing>.
25. Gartner, *Predicts 2017: 3D Printing Accelerates*, November 15, 2016, via Deloitte subscription.
26. Dow Jones Institutional News, *GE Makes Significant Progress with Investments in Additive Equipment Companies*, December 12, 2016; accessed via Factiva (Deloitte subscription).
27. GE.com [GE Reports], *New One-Of-A-Kind Turboprop Engine Delivers Jet-Like Simplicity To Pilots*, November 12, 2017, accessed at: <https://www.ge.com/reports/new-one-kind-turboprop-engine-delivers-jet-like-simplicity-pilots/>.
28. ISSRDC 2015 - *A Conversation with Elon Musk*, *SpaceX's Elon Musk talks about the increasing use of 3D printing in rocket engines*, July 2015 [via YouTube]: <https://youtu.be/ZmEg95wPIVU>.
29. Renault Trucks, *Metal 3D printing: technology of the future for lighter and more compact engines*, January 11, 2017, accessed at: <http://corporate.renault-trucks.com/en/press-releases/2017-01-11-metal-3d-printing-technology-of-the-future-for-lighter-and-more-compact-engines.html>.
30. Lawrence Livermore National Laboratory, *NIF technology could revolutionize 3D printing*, May 25, 2017, <https://www.llnl.gov/news/nif-technology-could-revolutionize-3d-printing>.
31. Gartner, *IT Glossary: Advanced Analytics*, accessed on August 2017, <http://www.gartner.com/it-glossary/advanced-analytics/>.
32. BusinessWire, *Worldwide Big Data and Business Analytics Revenues Forecast to Reach \$187 Billion in 2019, According to IDC*, May 2016, <https://www.businesswire.com/news/home/20160523005153/en/Worldwide-Big-Data-Business-Analytics-Revenues-Forecast>.

33. NCBI, *Big data analytics in healthcare: promise and potential*, February 2014, <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4341817/>.
34. Automotive Logistics, *Advanced analytics: Boiling down the benefits of big data*, January 2017, <https://automotive-logistics.media/intelligence/advanced-analytics-boiling-benefits-big-data>; IBM, *Consumer Goods Analytics*, accessed on August 2017, <https://www.ibm.com/analytics/us/en/industry/consumer-products/index.html>; Harvard Business Review, *Where Predictive Analytics Is Having the Biggest Impact*, May 2016, <https://hbr.org/2016/05/where-predictive-analytics-is-having-the-biggest-impact>; Cyient, *Optimize Aerospace and Defense operations with the help of data analytics*, accessed on August 2017, <http://www.cyient.com/industries/aerospace-defense/data-analytics-in-ad/>; Business Standard, *Big data and analytics can reduce R&D cost in chemical industry*, February 2016, http://www.business-standard.com/content/b2b-chemicals/big-data-and-analytics-can-reduce-r-d-cost-in-chemical-industry-116021800264_1.html.
35. Automotive Logistics, *Advanced analytics: Boiling down the benefits of big data*, January 2017, <https://automotive-logistics.media/intelligence/advanced-analytics-boiling-benefits-big-data>; Forbes, *Big Data, Analytics And The Future Of Marketing And Sales*, July 2013, <https://www.forbes.com/sites/mckinsey/2013/07/22/big-data-analytics-and-the-future-of-marketing-sales/#1420bbc05587>; Harvard Business Review, *Where Predictive Analytics Is Having the Biggest Impact*, May 2016, <https://hbr.org/2016/05/where-predictive-analytics-is-having-the-biggest-impact>; ICIS, *Big data and the chemical industry*, December 2013, <https://www.icis.com/resources/news/2013/12/13/9735874/big-data-and-the-chemical-industry/>; Forbes, *The Data Science Revolution That's Transforming Aviation*, June 2017, <https://www.forbes.com/sites/oliverwyman/2017/06/16/the-data-science-revolution-transforming-aviation/#366096c67f6c>.
36. Harvard Business Review, *Where Predictive Analytics Is Having the Biggest Impact*, May 2016, <https://hbr.org/2016/05/where-predictive-analytics-is-having-the-biggest-impact>.
37. Evens, Dave, *The Internet of Things, How the Next Evolution of the Internet Is Changing Everything*, Cisco, April 2011. https://www.cisco.com/c/dam/en_us/about/ac79/docs/innov/IoT_IBSG_0411FINAL.pdf.
38. IOT Analytics, *IoT Market – Forecasts at a glance*, October 17, 2014, <https://iot-analytics.com/iot-market-forecasts-overview/>.
39. Industrial Internet Consortium, *The Industrial Internet Of Things Industrial Analytics Framework*, <http://www.iiconsortium.org/industrial-analytics.htm>; Industrial Internet Consortium, *Industrial Analytics: The Engine Driving the IIoT Revolution*, March 2017, http://www.iiconsortium.org/pdf/Industrial_Analytics-the_engine_driving_IIoT_revolution_20170321_FINAL.pdf.
40. Deloitte, *Advanced Technologies Initiative: Manufacturing & Innovation*, 2015, <https://www2.deloitte.com/content/dam/Deloitte/us/Documents/manufacturing/us-indprod-deloitte-and-council-on-competitiveness-advanced-tech-report.pdf>.
41. BusinessWire, *Global Lightweight Materials Market - Analysis & Forecast 2017-2023: Focus on Metals, Composites, Plastics, Applications in Automotive, Aerospace & Defense and Wind Energy - Research and Markets*, May 2017, <http://www.businesswire.com/news/home/20170522005534/en/Global-Lightweight-Materials-Market---Analysis-Forecast>; MarketsandMarkets, *High Performance Alloys Market worth 9,698.35 Million USD by 2020*, accessed on August 2017, <http://www.marketsandmarkets.com/PressReleases/high-performance-alloys.asp>; MarketsandMarkets, *Composites Market worth 115.43 Billion USD by 2022*, accessed on August 2017, <http://www.marketsandmarkets.com/PressReleases/composite.asp>; *Bio-based News, Bio-based polymers worldwide: Ongoing growth despite difficult market environment*, February 2017, <http://news.bio-based.eu/bio-based-polymers-worldwide-ongoing-growth-despite-difficult-market-environment/>; Research and Markets, *Nanomaterials Market - Forecasts from 2016 to 2021*, November 2016, <https://www.researchandmarkets.com/research/nsk5tc/nanomaterials>; BCC Research, *BCC Research Publishes A New Report On Critical Materials In Global Nanotechnology Market*, December 2013, [https://www.bccresearch.com/pressroom/avm/global-market-critical-materials-used-nanotechnology-market-grow-nearly-\\$9.4-billion-2018](https://www.bccresearch.com/pressroom/avm/global-market-critical-materials-used-nanotechnology-market-grow-nearly-$9.4-billion-2018) [the market size estimates only look at the applications of critical materials in nanotechnology]; MarketsandMarkets, *Advanced Ceramics Market worth 10.41 Billion USD by 2021*, accessed on August 2017, <http://www.marketsandmarkets.com/PressReleases/advanced-ceramic.asp>.
42. Engineering Research Center for Net Shape Manufacturing (ERC/NSM), *Challenges in Forming Advanced High Strength Steels*, accessed on August 2017, https://ercnsm.osu.edu/sites/ercnsm.osu.edu/files/uploads/S_FormingAHSS/634.pdf; MDPI, *Aluminium Production Process: Challenges and Opportunities*, April 2017; Live Science, *Magnesium: Super Material of the Future*, May 2010, <https://www.livescience.com/6488-magnesium-super-material-future.html>; Energy.gov, *Advanced Composites Materials and their Manufacture: Technology Assessment*, accessed on August 2017, <https://energy.gov/sites/prod/files/2015/02/f19/QTR%20Ch8%20-%20Composite%20Materials%20and%20Manufacture%20Feb-13-2015.pdf>; Critical Materials Institute, *CMI Grand Challenge Problems*, accessed on August 2017, <https://cmi.ameslab.gov/grand-challenges>; Landbauforsch, *Bio-based plastics: status, challenges and trends*, 2013, http://literatur.ti.bund.de/digbib_extern/dn053246.pdf; European Economic and Social Committee, *Challenges and opportunities of nanomaterials: Environment and health issues*, September 2015, <http://www.eesc.europa.eu/news-media/presentations/challenges-and-opportunities-nanomaterials-environment-and-health-issues>.
43. Deloitte, *Advanced Technologies Initiative: Manufacturing & Innovation*, 2015, <https://www2.deloitte.com/content/dam/Deloitte/us/Documents/manufacturing/us-indprod-deloitte-and-council-on-competitiveness-advanced-tech-report.pdf>; UnderstandingNano.com, *Nanomaterials and their Applications*, accessed on August 2017, <http://www.understandingnano.com/nanomaterials.html>; TIFAC, *Nanocomposites – technology trends & application potential*, accessed on August 2017, http://www.tifac.org.in/index.php?option=com_content&id=523.
44. ASM International, *Advanced High-Strength Steels: Science, Technology, and Applications*, 2013, http://www.asminternational.org/documents/10192/3479138/05370G_TOC.pdf/257077c6-8b31-46a2-8a95-75bc88adcee4; McKinsey, *Lightweight heavy impact*, accessed on August 2017, http://www.mckinsey.com/~media/mckinsey/dotcom/client_service/Automotive%20and%20Assembly/PDFs/Lightweight_heavy_impact.ashx; Foresight, *New and advanced materials*, October 2013, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/283886/ep10-new-and-advanced-materials.pdf; Nano World SI Tech, *Nanotechnology Applications*, accessed on August 2017, <http://www.nanocompositetech.com/nanotechnology/nanotechnology-applications.htm>; TIFAC, *Composites: A Vision for the Future*, accessed on August 2017, http://tifac.org.in/index.php?option=com_content&view=article&id=539:composites-a-vision-for-the-future&catid=85:publications&Itemid=952.
45. Nanowerk, *Lipid nanodisks provide a new way of producing hydrogen fuel*, September 2017, <https://www.nanowerk.com/nanotechnology-news/newsid=47944.php>.
46. Lux Research, *Nanomaterials State of the Market Q3 2008: Stealth Success, Broad Impact*, July 2008.
47. Gray, J.O., *Recent developments in advanced robotics and intelligent systems*, Computing and control engineering journal, August 2002, <http://ieeexplore.ieee.org/xpl/login.jsp?reload=true&tp=&number=556826&url=http%3A%2F%2Fieeexplore.ieee.org%2Fiel1%2F218%2F12147%2F00556826.pdf%3Farnumber%3D556826>; Deloitte, *Robotics & Cognitive*, August 2017, <https://global.deloitte.com/ClientsIndustries/hot-topics/Pages/rca.aspx>.
48. IDC, *Worldwide Spending on Robotics Will Reach \$188 Billion in 2020 Fueled by New Use Cases and Expanding Market Acceptance*, According to IDC, January 2017, <https://www.idc.com/getdoc.jsp?containerId=prUS42213817>.
49. Robotiq, *3 Challenges Manufacturers Face When Implementing Robotics*, February 2017, <https://blog.robotiq.com/3-challenges-manufacturers-face-when-implementing-robotics>; GCN, *5 tech challenges holding back robotics*, February 2016, <https://gcn.com/articles/2016/02/25/robotics-challenges.aspx>.

50. Deloitte, *Robots uncaged: How a new generation of sophisticated robots is changing business*, October 18, 2017, <https://dupress.deloitte.com/dup-us-en/focus/signals-for-strategists/next-generation-robots-implications-for-business.html>; Siemens, *Robotics and Automation Solutions in Aerospace & Defense Industries*, June 2017, <https://community.plm.automation.siemens.com/t5/Tecnomatix-News/Robotics-and-Automation-Solutions-in-Aerospace-amp-Defense/ba-p/416843>.
51. Recode, *These industrial robots teach each other new skills while we sleep*, October 14, 2016, <https://www.recode.net/2016/10/14/13274428/artificial-intelligence-ai-robots-auto-production-audi>; Battelle, *Autonomy & Advanced Robotics*, <https://www.battelle.org/government-offerings/national-security/tactical-systems-vehicles/autonomy-advanced-robotics>; Fast Company, *This AI Factory Boss Tells Robots And Humans How To Work Together*, August 7, 2017, <https://www.fastcompany.com/3067414/robo-foremen-could-direct-human-and-robot-factory-workers-alike>.
52. MIT Technology Review, *Robotics, Smart Materials, and their Future Impact for Humans*, April 2017, <https://www.technologyreview.com/s/604097/robotics-smart-materials-and-their-future-impact-for-humans/>.
53. Deloitte Analysis based on data from U.S. Bureau of Labor Statistics and Gallup Survey, cited in *The skills gap in U.S. manufacturing: 2015 and beyond*, <https://www2.deloitte.com/us/en/pages/manufacturing/articles/boiling-point-the-skills-gap-in-us-manufacturing.html>.
54. Cincinnati Business Courier, *P&G relying more on robots to cut costs*, September 30, 2016, <https://www.bizjournals.com/cincinnati/news/2016/09/13/p-g-relying-more-on-robots-to-cut-costs.html>.
55. Deloitte, *Demystifying artificial intelligence*, November 2014, <https://dupress.deloitte.com/dup-us-en/focus/cognitive-technologies/what-is-cognitive-technology.html>.
56. IDC, *Worldwide Cognitive Systems and Artificial Intelligence Revenues Forecast to Surge Past \$47 Billion in 2020*, According to New IDC Spending Guide, October 2016, <https://www.idc.com/getdoc.jsp?containerId=prUS41878616>.
57. UBS, *The Evolution of Artificial Intelligence*, accessed on August 2017, <https://www.ubs.com/microsites/artificial-intelligence/en/new-dawn.html>; Forbes, *4 Unique Challenges Of Industrial Artificial Intelligence*, April 2017, <https://www.forbes.com/sites/mariyayao/2017/04/14/unique-challenges-of-industrial-artificial-intelligence-general-electric/#627fd75c1305>.
58. McCafferty & Company, *Artificial Intelligence Industry Primer*, May 2017, <http://mccaffertyco.com/artificial-intelligence-industry-primer/>; IDC, *Worldwide Cognitive Systems and Artificial Intelligence Revenues Forecast to Surge Past \$47 Billion in 2020*, According to New IDC Spending Guide, October 2016, <https://www.idc.com/getdoc.jsp?containerId=prUS41878616>; Wired, *AI wields the power to make flying safer—and maybe even pleasant*, March 2017, <https://www.wired.com/2017/03/ai-wields-power-make-flying-safer-maybe-even-pleasant/>; IBM, *AI-driven discovery of chemical synthesis*, June 2016, <http://www.ibm.com/blogs/research/2016/06/artificial-intelligence-driven-discovery-chemical-synthesis/>.
59. CrispIdeas Research, *Artificial Intelligence*, August 2016; McCafferty & Co., *Artificial Intelligence Industry Primer*, May 24, 2017; Airfacts, *What The Artificial Intelligence Boom Means For Aviation*, October 2016, <http://airfactsjournal.com/2016/10/artificial-intelligence-boom-means-aviation/>; O'Reilly Media, *AI-assisted computational chemistry: Predicting chemical properties with minimal expert knowledge*, June 2017, <https://conferences.oreilly.com/artificial-intelligence/ai-ny-2017/public/schedule/detail/59072>.
60. Gartner, *Predicts 2017: Artificial Intelligence*, November 2016, <https://www.gartner.com/document/3519744?ref=solrAll&refval=186259905&qid=2910e5363d938f3ee5dbd3cc99946b2e#>.
61. Deloitte Review, *Cognitive technologies: The real opportunities for business*, January 26, 2015, <https://www2.deloitte.com/insights/us/en/deloitte-review/issue-16/cognitive-technologies-business-applications.html>.
62. Deloitte, *Making maintenance smarter: Predictive maintenance and the digital supply network*, May 9, 2017, <https://www2.deloitte.com/insights/us/en/focus/industry-4-0/using-predictive-technologies-for-asset-maintenance.html>.
63. Arc Advisory Group, *Rockwell Automation Unveils Product Announcements at their Automation Fair Event in Houston*, November 13, 2017, <https://www.arcweb.com/blog/rockwell-automation-unveils-product-announcements-their-automation-fair-event-houston>.
64. Arc Advisory Group, *AspenTech Brings a New Dimension to Asset Optimization and Reliability*, November 8, 2016, <https://industrial-iot.com/2016/11/aspentech-brings-a-new-dimension-to-asset-optimization-and-reliability/>.
65. Deloitte, *Making maintenance smarter: Predictive maintenance and the digital supply network*, May 9, 2017, <https://www2.deloitte.com/insights/us/en/focus/industry-4-0/using-predictive-technologies-for-asset-maintenance.html>.
66. Deloitte, *Demystifying artificial intelligence: What business leaders need to know about cognitive technologies*, November 4, 2014, <https://www2.deloitte.com/insights/us/en/focus/cognitive-technologies/what-is-cognitive-technology.html>.
67. Rockwell Automation, *New Predictive and Prescriptive Analytics Capabilities From Rockwell Automation Reduce Downtime*, December 12, 2016, <https://ir.rockwellautomation.com/press-releases/press-releases-details/2016/New-Predictive-and-Prescriptive-Analytics-Capabilities-From-Rockwell-Automation-Reduce-Downtime/default.aspx>.
68. OSIsoft EMEA Users Conference presentation, September 26-29, 2016, <https://cdn.osisoft.com/osi/presentations/2016-users-conference-emea-berlin/2016-users-conference-emea-berlin-d2-Industrial-IT-E060-SparkCognition-Flowserve-Gillen-FlowserveSparkCognition-Industrial-Intelligence--Cognitive-Analytics-in-Action.pdf>.
69. Ibid.
70. Ibid.
71. Control design, *Is machine learning smart enough to help industry?* August 4, 2016, <https://www.controldesign.com/articles/2016/is-machine-learning-smart-enough-to-help-industry/>.
72. Deloitte, *Tech Trends 2017: The kinetic enterprise*, December 2016, https://dupress.deloitte.com/content/dam/dup-us-en/articles/3468_TechTrends2017/DUP_TechTrends2017.pdf; *Convention on Biological Diversity, Text of the convention: Article 2, use of terms*, <https://www.cbd.int/convention/text/>, accessed November 28, 2016; *Input from Dr. Tiffany Vora*, Principal Faculty, Medicine & Digital Biology, Singularity University, September 2017.
73. GMIInsights, *Biotechnology Market [..]*, September 2016, <https://globenewswire.com/news-release/2016/10/05/877191/0/en/Biotechnology-Market-size-to-exceed-USD-775-billion-by-2024-Global-Market-Insights-Inc.html>; Marketline, *Global Biotechnology*, November 2016.
74. Nature, *Time to settle the synthetic controversy*, May 2014, <http://www.nature.com/news/time-to-settle-the-synthetic-controversy-1.15169>; Slate, *Your Cheat Sheet To Synthetic Biology*, April 2017, http://www.slate.com/articles/technology/future_tense/2017/04/a_cheat_sheet_guide_to_synthetic_biology.html; Slate, *The synthetic biology community is divided on intellectual property*, http://www.slate.com/articles/technology/future_tense/2017/04/the_synthetic_biology_community_is_divided_on_intellectual_property.html; Input by Dr. Tiffany Vora, Principal Faculty, Medicine & Digital Biology, Singularity University, September 2017.
75. Amyris, *Industrial*, <https://amyris.com/products/isoprene/>; PBS, *Why Synthetic Biology Is the Field of the Future*, February 2013, <http://www.pbs.org/wgbh/nova/next/tech/why-synthetic-biology-is-the-field-of-the-future/>; bbsrc, *Transforming our future: synthetic biology*, March 2017, <http://blogs.bbsrc.ac.uk/index.php/2017/03/transforming-our-future-synthetic-biology-and-yeast/>.
76. Pskf, *Biological Materials Could Create Cars That Adapt And Repair Themselves*, June 2014, <https://www.pskf.com/2014/06/automotive-biological-materials.html>; *Input from from Dr. Tiffany Vora*, Principal Faculty, Medicine & Digital Biology, Singularity University, September 2017; Explain that Stuff, *Bioplastics and biodegradable plastics*, June 2017, <http://www.explainthatstuff.com/bioplastics.html>; NASA, *Synthetic Biology: Worker Microbes' for Deep Space Missions*, August 2017, <https://www.nasa.gov/content/synthetic-biology>.

77. Synbiobeta, *22 Synthetic Biology Companies Have Raised Half a Billion Dollars in 2017*, July 31, 2017, <https://synbiobeta.com/synthetic-biology-funding-2017/>.
78. Deloitte, *3D opportunity for blockchain*, November 2016, <https://dupress.deloitte.com/dup-us-en/focus/3d-opportunity/3d-printing-blockchain-in-manufacturing.html>; SearchCIO, *Blockchain*, accessed on August 2017, <http://searchcio.techtarget.com/definition/blockchain>.
79. MarketsandMarkets, *Blockchain Market by Provider, Application (Payments, Exchanges, Smart Contracts, Documentation, Digital Identity, Clearing and Settlement), Organization Size, Vertical, and Region - Global Forecast to 2021*, October 2016, <http://www.marketsandmarkets.com/Market-Reports/blockchain-technology-market-90100890.html>; LTP, *Know more about Blockchain: Overview, Technology, Application Areas and Use Cases*, accessed on August 2017, <https://letstalkpayments.com/an-overview-of-blockchain-technology/>.
80. Deloitte, *3D opportunity for blockchain*, November 2016, <https://dupress.deloitte.com/dup-us-en/focus/3d-opportunity/3d-printing-blockchain-in-manufacturing.html>; Harvard Business Review, *Global Supply Chains Are About to Get Better, Thanks to Blockchain*, March 2017, <https://hbr.org/2017/03/global-supply-chains-are-about-to-get-better-thanks-to-blockchain/>; Tractica, *Blockchain for Enterprise Applications*, accessed on August 2017, <https://www.tractica.com/research/blockchain-for-enterprise-applications/>.
81. IBM, *Blockchain for Automotive*, March 2017, <https://www.ibm.com/blogs/internet-of-things/blockchain-for-automotive/>; Forbes, *Blockchain and Retail: Four Opportunities*, August 2017, <https://www.forbes.com/sites/nikkibaird/2017/08/09/blockchain-and-retail-four-opportunities/#46a3dfc572bf>.
82. BigChain, *How Automakers Can Use Blockchain*, June 2017, <https://blog.bigchaindb.com/how-automakers-can-use-blockchain-adab79a6505f>; TechCrunch, *Toyota pushes into blockchain tech to enable the next generation of cars*, May 2017, <https://techcrunch.com/2017/05/22/toyota-pushes-into-blockchain-tech-to-enable-the-next-generation-of-cars/>; Cognizant, *How Blockchain Can Revitalize Manufacturing Value Chains (Part 1)*, January 2017, <https://www.cognizant.com/perspectives/how-blockchain-can-revitalize-manufacturing-value-chains-part1>.
83. DMR, *15 amazing blockchain statistics*, March 2017, <https://expandedramblings.com/index.php/blockchain-statistics/>.
84. Forbes, *How Blockchain Startups Are Disrupting The \$15 Billion Music Industry*, September 16, 2016, <https://www.forbes.com/sites/jonathanchester/2016/09/16/how-blockchain-startups-are-disrupting-the-15-billion-music-industry/#6b95c30a407c>.
85. Ibid.
86. TechCrunch, *Spotify acquires blockchain startup Mediachain to solve music's attribution problem*, April 26, 2017, <https://techcrunch.com/2017/04/26/spotify-acquires-blockchain-startup-mediachain-to-solve-musics-attribution-problem/>.
87. Consensus, *About*, <https://consensus.net/about/>.
88. Consensus, *Ventures: Core Components*, <https://consensus.net/ventures/core-components/>.
89. Coindesk.com, *Brazil's Ministry of Planning Is Testing Blockchain Identity Tech*, August 23, 2017, <https://www.coindesk.com/brazils-ministry-planning-testing-blockchain-identity-tech/>.
90. Consensus, *Ventures: Core Components*, <https://consensus.net/ventures/core-components/>.
91. Consensus, *Academy*, <https://consensus.net/academy/>.
92. Deloitte, *Industry 4.0 and cybersecurity: Managing risk in an age of connected production*, March 21, 2017; List of techs [Deloitte synthesized] definition.
93. Gartner, *Forecast: Information Security, Worldwide, 2015-2021*, 1Q17 Update, May 18, 2017, via Deloitte subscription.
94. Deloitte and MAPI, *Cyber risk in advanced manufacturing*, November 2016, <https://www2.deloitte.com/content/dam/Deloitte/us/Documents/manufacturing/us-manu-cyber-risk-in-advanced-manufacturing.pdf>.
95. Deloitte and MAPI, *Cyber risk in advanced manufacturing: Getting ahead of cyber risk*, 2016, <https://www2.deloitte.com/us/en/pages/manufacturing/articles/cyber-risk-in-advanced-manufacturing.html#>; IndustryWeek, *Cyberthreats Targeting the Factory Floor*, August 18, 2016, <http://www.industryweek.com/information-technology/cyberthreats-targeting-factory-floor>; Axiom, *Delivering Complete, Layered Security for Secure Connected Cars with NXP*, 2016, <http://design.avnet.com/axiom/delivering-complete-layered-security-secure-connected-cars-nxp/>; Philips USA, *How safe is your patient data?*, <https://www.usa.philips.com/healthcare/resources/landing/ultrasound-security>.
96. Deloitte, *Industry 4.0 and cybersecurity: Managing risk in an age of connected production*, March 21, 2017, <https://dupress.deloitte.com/dup-us-en/focus/industry-4-0/cybersecurity-managing-risk-in-age-of-connected-production.html>; Deloitte and MAPI, *Cyber risk in advanced manufacturing*, November 2016, <https://www2.deloitte.com/content/dam/Deloitte/us/Documents/manufacturing/us-manu-cyber-risk-in-advanced-manufacturing.pdf>; Singularity University, *Can You Be Hacked by the World Around You?*, October 13, 2017, <https://singularityhub.com/2017/10/13/can-you-be-hacked-by-the-world-around-you/#sm.00016v397wi0fe69ygu1s1dgm6m67>.
97. Cybersecurity Ventures, *Homepage*, <http://cybersecurityventures.com/>.
98. Quarta, Davide, et al., *An Experimental Security Analysis of an Industrial Robot Controller*, <http://ieeexplore.ieee.org/document/7958582/>.
99. Deloitte, *Advanced Technologies: Manufacturing and innovation*, 2015, <https://www2.deloitte.com/us/en/pages/manufacturing/articles/advanced-manufacturing-technologies-report.html>; Deloitte synthesized definition.
100. Transparency Market Research, *Engineering Software Market - Global Industry Analysis, Size, Share, Growth, Trends and Forecast 2014 - 2022*, <http://www.transparencymarketresearch.com/engineering-software-market.html> [forecasted market size, cited at: <https://www.automation.com/automation-news/industry/engineering-software-market-to-reach-5034-bn-in-2022>].
101. Transparency Market Research, *Engineering Software Market - Global Industry Analysis, Size, Share, Growth, Trends and Forecast 2014 - 2022*, <http://www.transparencymarketresearch.com/engineering-software-market.html> [forecasted market size, cited at: <https://www.automation.com/automation-news/industry/engineering-software-market-to-reach-5034-bn-in-2022>]; Engineering.com, *Is CAD in the Cloud Truly Terrifying?* July 28, 2013, <http://www.engineering.com/DesignSoftware/DesignSoftwareArticles/ArticleID/6026/Is-CAD-in-the-Cloud-Truly-Terrifying.aspx>.
102. ResearchandMarkets, *Global Computer-Aided Design (CAD) Market - Analysis and Forecast 2017-2023 - Focus on Product Type, Operating System, Technology and End-Use Application and Region*, May 2017, <https://www.researchandmarkets.com/research/svtv7f/global>; Walker Tool & Die, *3D CAD modeling*, <http://www.walkertool.com/3d-cad-modeling.html>.
103. UI Labs, *Digital Manufacturing and Design Innovation Institute focus*, <http://www.uilabs.org/innovation-platforms/manufacturing/focus-areas/>; Deloitte, *Industry 4.0 and manufacturing ecosystems*, February 22, 2016, <https://dupress.deloitte.com/dup-us-en/focus/industry-4-0/manufacturing-ecosystems-exploring-world-connected-enterprises.html>; Siemens, *Simulation: Providing a Path to Process Optimization*, May 11, 2016, <https://www.siemens.com/innovation/en/home/pictures-of-the-future/industry-and-automation/digital-factory-simulation-in-the-process-industry.html>.
104. Siemens, *Hyundai Motor Company: Solid models help optimize assembly line design*, <https://www.mayahtt.com/wp-content/uploads/2013/04/Hyundai-Motor-Company-Solid-Edge-Case-Study.pdf>.
105. SRI International, *R&D Projects*, accessed January 5, 2018, <https://www.sri.com/work/projects>.
106. Energy Storage Association, *Energy Storage Technologies*, accessed on August 2017, <http://energystorage.org/energy-storage-1>.

107. Ibid.
108. IFC, *Energy Storage Trends and Opportunities in Emerging Markets*, 2017, <https://www.ifc.org/wps/wcm/connect/ed6f9f7f-f197-4915-8ab6-56b92d50865d/7151-IFC-EnergyStorage-report.pdf?MOD=AJPERES>.
109. Energy Storage Association, *Applications of Energy Storage Technology*, accessed on August 2017, <http://energystorage.org/energy-storage/applications-energy-storage-technology>; *Current factory applications per email communication by Ramez Naam, Co-Chair*, Energy & Environmental Systems, Singularity University, December 2017; ResearchGate, *Energy Storage for Aerospace Applications*, August 2001, https://www.researchgate.net/publication/24301051_Energy_Storage_for_Aerospace_Applications.
110. The Energy Collective, *Current Trends in the Energy Storage Market*, July 7, 2017, <http://www.theenergycollective.com/willcoenergy/2408164/current-trends-energy-storage-market>; Lux Research, *Energy Storage Market Rises to \$50 Billion in 2020, Amid Dramatic Changes*, accessed on August 2017, <http://www.luxresearchinc.com/news-and-events/press-releases/read/energy-storage-market-rises-50-billion-2020-amid-dramatic>; Forbes, *One Expert's View On The Near-Term Future Of Energy Storage*, June 2016, <https://www.forbes.com/sites/peterdetwiler/2016/06/06/one-experts-view-on-the-near-term-future-of-energy-storage/#167c74d056f6>.
111. Energy Storage Association, *Facts & Figures*, accessed on August 2017, <http://energystorage.org/energy-storage-2>.
112. Bloomberg Technology, *Abu Dhabi's Biggest Solar Project on Track to Start in 2019*, November 5, 2017, <https://www.bloomberg.com/news/articles/2017-11-05/jinko-solar-says-abu-dhabi-project-on-track-to-start-in-2019>.
113. Ibid.
114. Ibid.
115. InsideHPC, *What is high performance computing?*, accessed on October 2017, <https://insidehpc.com/hpc-basic-training/what-is-hpc/>.
116. Top500, *IDC's Latest Forecast for the HPC Market: "2016 is Looking Good"*, November 2016, <https://www.top500.org/news/idcs-latest-forecast-for-the-hpc-market-2016-is-looking-good/>; Homeland Security Research, *Quantum Computing Market & Technologies – 2017-2024*, May 2017, [http://homelandsecurityresearch.com/Quantum+Computing+Market+and+Technologies;Market+Research+Future,+High+Performance+Computing+\(HPC\)+Market+Research+Report+-+Forecast+to+2022,+July+2017,+https://www.marketresearchfuture.com/reports/high-performance-computing-market-2698](http://homelandsecurityresearch.com/Quantum+Computing+Market+and+Technologies;Market+Research+Future,+High+Performance+Computing+(HPC)+Market+Research+Report+-+Forecast+to+2022,+July+2017,+https://www.marketresearchfuture.com/reports/high-performance-computing-market-2698).
117. HPE, *Exascale: A race to the future of HPC*, accessed in October 2017, <https://www.hpe.com/h20195/v2/GetPDF.aspx/4AA6-7771ENW.pdf>; PRnewswire, *Global Quantum Computing Market Growth at a CAGR of 35.12%, 2017-2021 - Latest Challenges, Drivers & Trends*, June 2017, <https://www.prnewswire.com/news-releases/global-quantum-computing-market-growth-at-a-cagr-of-3512-2017-2021---latest-challenges-drivers--trends-300481865.html>; *Issues/Challenges as per: Davide Venturelli*, Science Operations Manager, USRA Quantum AI Laboratory at NASA Ames and Adjunct Faculty, Singularity University, email communication of 1/9/2018.
118. Top500, *The Top 5 Manufacturing Applications*, February 2015, <https://www.top500.org/news/the-top-5-manufacturing-applications/>; IBM, *High Performance Computing & Analytics*, April 2017.
119. IBM, *High Performance Computing & Analytics*, April 2017; Deloitte, *Quantum computing is coming to the marketplace*, April 26, 2017, <https://www2.deloitte.com/insights/us/en/focus/signals-for-strategists/quantum-computing-enterprise-applications.html>.
120. DW, *Predicting the future with supercomputers*, March 2017, <http://www.dw.com/en/predicting-the-future-with-supercomputers/a-38216147>.
121. NASA Ames, *Quantum Computing for Business conference*, December 2018, <http://www.q2b.us>.
122. MIT Technology Review, *A Startup Uses Quantum Computing to Boost Machine Learning*, December 18, 2017, <https://www.technologyreview.com/s/609804/a-startup-uses-quantum-computing-to-boost-machine-learning/>.
123. Computing, *D-Wave bags first commercial customer for D-Wave 2000Q quantum computer*, January 26, 2017, <https://www.computing.co.uk/ctg/news/3003361/d-wave-bags-first-commercial-customer-for-d-wave-2000q-quantum-computer>.
124. USRA, NASA, *Google and USRA establish Quantum Computing Research Collaboration: 20% of Computing Time will be Provided to the University and Industry Research Communities*, accessed on January 2018, <http://www.usra.edu/quantum/>.
125. Deloitte, *Mixed Reality: A user's guide to AR, VR, IoT, and more*, February 2, 2017.
126. [VR/AR/MR] BIS Research, *Global Augmented Reality and Virtual Reality Market - Analysis & Forecast, 2016-2022*, 2016, <https://bisresearch.com/industry-report/global-augmented-virtual-reality-market-report-forecast.html>; [Wearables] CCS Insights, *Global Wearables* [report], February 2016, <http://www.ccsinsight.com/press/company-news/2516-wearables-momentum-continues>; Global Market Insights, *Gesture Recognition and Touchless Sensing Market*, 2016, <https://www.gminsights.com/industry-analysis/gesture-recognition-and-touchless-sensing-market>.
127. Deloitte, *Tech Trends 2017: The Kinetic Enterprise*, 2017, https://dupress.deloitte.com/content/dam/dup-us-en/articles/3468_TechTrends2017/DUP_TechTrends2017.pdf; Deloitte's Global Innovation Sensing, *Line of Sight: 3 Insights to Know*, June 2017; Deloitte, *For more companies, new ways of seeing: Momentum is building for augmented and virtual reality in the enterprise*, April 5, 2017, <https://dupress.deloitte.com/dup-us-en/focus/signals-for-strategists/augmented-and-virtual-reality-enterprise-applications.html#endnote-5>; GrowthEnabler, *Market Pulse Report: AR & VR*, September 2016, <https://growthenabler.com/flipbook/pdf/Market%20Pulse%20Report%20-%20ARVR.pdf>.
128. CIO, *Ford uses 'industry first' wearable for QA at assembly plant*, February 10, 2016, <https://www.cio.com/article/3032177/wearable-technology/ford-uses-industry-first-wearable-for-qa-at-assembly-plant.html>; GestureTek, *Market Uses: Retail Marketing Solutions*, http://www.gesturetek.com/marketuses/retail_malls_windows.php; Deloitte University Press, *Signals for Strategists: For more companies, new ways of seeing*, April 2017, https://www2.deloitte.com/content/dam/insights/us/articles/3768_Signals-for-Strategists_Apr2017/DUP_Signals-for-Strategists_Apr-2017.pdf.
129. Deloitte Digital, *Introducing ... Digital Reality*, February 2017; TNW, *Mixed Reality will be most important tech of 2017*, January 7, 2017, https://thenextweb.com/insider/2017/01/07/mixed-reality-will-be-most-important-tech-of-2017/#.tnw_eVYj3Mby; Deloitte interview with Singularity University subject matter expert; The Washington Post, *Virtual Reality showrooms will change how we shop for cars*, July 2017, https://www.washingtonpost.com/cars/virtual-reality-showrooms-will-change-how-we-shop-for-cars/2017/07/24/3456170e-7097-11e7-8c17-533c52b2f014_story.html?utm_term=.00cd70d65487.
130. IDC, *International Data Corporation (IDC) Worldwide Quarterly Augmented and Virtual Reality Headset Tracker*, June 2017, figure via: BusinessWire press release at: <http://www.businesswire.com/news/home/20170619005183/en/Worldwide-Shipment-Augmented-Reality-Virtual-Reality-Headsets>.
131. Inc., *This Startup Recruited a Hollywood Designer to Create the Coolest Cybersecurity Software You've Ever Seen*, June 12, 2017, <https://www.inc.com/kevin-j-ryan/protectwise-futuristic-cybersecurity-startup.html>.
132. MIT Technology Review, *Finally, a Useful Application for VR: Training Employees*, November 22, 2017, <https://www.technologyreview.com/s/609473/finally-a-useful-application-for-vr-training-employees/>.
133. Deloitte, *The Internet of Things*, September 2013, <https://dupress.deloitte.com/dup-us-en/focus/signals-for-strategists/the-internet-of-things.html>.

134. IDC, *Internet of Things Spending Forecast to Grow 17.9% in 2016 Led by Manufacturing, Transportation, and Utilities Investments, According to New IDC Spending Guide*, January 2017, <https://www.idc.com/getdoc.jsp?containerId=prUS42209117>.
135. Deloitte, *Safeguarding the Internet of Things*, 2015, https://dupress.deloitte.com/content/dam/dup-us-en/articles/internet-of-things-data-security-and-privacy/DUP1158_DR17_SafeguardingtheInternetofThings.pdf; IDC, *Connected Products and Operations: Reshaping the Manufacturing and Operations Landscape*, May 2015, https://www.thingworx.com/wp-content/uploads/WP_idc_infobrief-connected-products-and-operations_EN.pdf; Deloitte, *Industry 4.0 and manufacturing ecosystems*, February 22, 2016, <https://dupress.deloitte.com/dup-us-en/focus/industry-4-0/manufacturing-ecosystems-exploring-world-connected-enterprises.html>.
136. Deloitte, *Who owns the road? The IoT-connected car of today—and tomorrow*, 2016, <https://www2.deloitte.com/content/dam/Deloitte/tr/Documents/technology-media-telecommunications/iot-whoownstheroad.pdf>; Techcrunch, *How Connected Cars Have Established A New Ecosystem Powered By IoT*, January 31, 2015, <https://techcrunch.com/2015/01/31/how-connected-cars-have-established-a-new-ecosystem-powered-by-iot/>; Deloitte, *IoT & analytics in manufacturing*, 2016, <https://www2.deloitte.com/us/en/pages/deloitte-analytics/articles/iot-analytics-in-manufacturing.html#>; Aviation Week, *Internet Of Aircraft Things: An Industry Set To Be Transformed*, January 2016, <http://aviationweek.com/connected-aerospace/internet-aircraft-things-industry-set-be-transformed>.
137. Deloitte, *IoT & analytics in manufacturing*, accessed on August 2017, <https://www2.deloitte.com/us/en/pages/deloitte-analytics/articles/iot-analytics-in-manufacturing.html>; Deloitte, *No appointment necessary: How the IoT and patient-generated data can unlock health care value*, 2015, <https://www2.deloitte.com/content/dam/Deloitte/tr/Documents/life-sciences-health-care/patientgenerateddata.pdf>; Forbes, *Internet Of Things Will Revolutionize Retail*, March 2017, <https://www.forbes.com/sites/louiscolombus/2017/03/19/internet-of-things-will-revolutionize-retail/#59943ae25e58>; Rockwell Automation, *Smart Connected Operations*, 2015, https://www.rockwellautomation.com/resources/downloads/rockwellautomation/pdf/about-us/LNS_SmartConnectedOperations_RockwellAutomation_eBook.pdf; Kellton Tech, *Transforming Aviation Industry with Internet of Things*, October 4, 2016, <https://www.kelltontech.com/kellton-tech-blog/transforming-aviation-industry-internet-things>.
138. Juniper Research, *Internet of Things' Connected Devices to Triple by 2021, Reaching Over 46 Billion Units*, December 2016, <https://www.juniperresearch.com/press/press-releases/'internet-of-things'-connected-devices-to-triple-b>.
139. Wikipedia, *List of sensors*, accessed on January 11, 2018, https://en.wikipedia.org/wiki/List_of_sensors.
140. Enterprise IoT Insights, *How industrial IoT is revolutionizing waste management*, July 28, 2016, <https://enterpriseiotinsights.com/20160728/internet-of-things/waste-management-industrial-iot-tag31-tag99>.
141. Doblin research based on analysis of 2,000+ innovations.
142. Harvard Business Review, *Managing your innovation portfolio*, May 2012, <https://www2.deloitte.com/us/en/pages/strategy/articles/managing-your-innovation-portfolio.html>.



About Deloitte

As used in this document, "Deloitte" means Deloitte & Touche LLP, a subsidiary of Deloitte LLP. Please see www.deloitte.com/us/about for a detailed description of our legal structure. Certain services may not be available to attest clients under the rules and regulations of public accounting.

About the Council on Competitiveness

Founded in 1986, the Council on Competitiveness is a non-partisan leadership organization of corporate CEOs, university presidents, labor leaders and national laboratory directors committed to advancing U.S. competitiveness in the global economy and a rising standard of living for all Americans. Dedicated to building U.S. prosperity, the Council plays a powerful role in shaping America's future by setting an action agenda to assess U.S. competitiveness, identify emerging forces transforming the economy, catalyze thought leaders who drive change and galvanize stakeholders to act.

About Singularity University

Singularity University (SU) is a global learning and innovation community, hundreds of thousands strong, using exponential technologies to tackle the world's biggest challenges with the goal of building an abundant future for all. SU works with individual executives, C-level teams and high-potential team members to identify threats, opportunities and new approaches. SU's collaborative platform empowers enterprises and individuals across the globe to innovate and create breakthrough solutions using accelerating technologies like artificial intelligence, robotics, and digital biology. A certified benefit corporation headquartered at NASA Research Park in Silicon Valley, SU was founded in 2008 by renowned innovators Ray Kurzweil and Peter H. Diamandis with program funding from leading organizations including Google, Deloitte, and UNICEF. To learn more, visit SU.org, join us on Facebook, follow us on Twitter @SingularityU, and download the SingularityU Hub mobile app.

About this publication

This communication contains general information only, and none of Deloitte Touche Tohmatsu Limited, its member firms, or their related entities (collectively, the "Deloitte Network") is, by means of this communication, rendering professional advice or services. Before making any decision or taking any action that may affect your finances or your business, you should consult a qualified professional adviser. No entity in the Deloitte Network shall be responsible for any loss whatsoever sustained by any person who relies on this communication.