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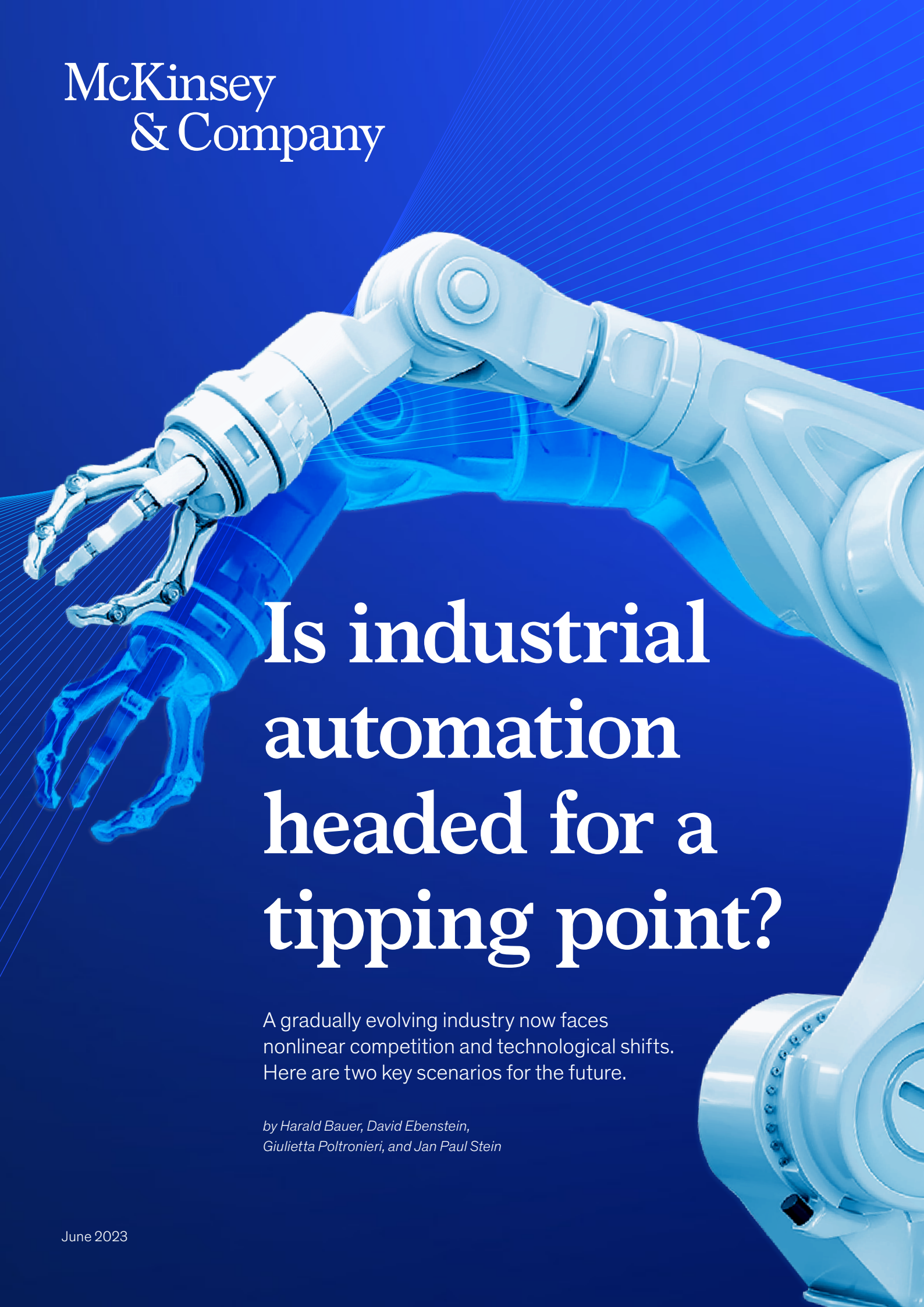

Is industrial automation headed for a tipping point?

A gradually evolving industry now faces nonlinear competition and technological shifts. Here are two key scenarios for the future.

by Harald Bauer, David Ebenstein, Giulietta Poltronieri, and Jan Paul Stein

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Executive summary

Over the past few decades, industrial automation has evolved gradually, with few changes in market structure. But the pace of change is accelerating thanks to technology disruptions and macrotrends such as reshoring, a global skilled-labor shortage, and environmental, social, and governance (ESG) efforts.

Innovations in digitalization and connectivity as well as advances in processing power and design regularly disrupt markets. In the smartphone market, the iPhone and the iTunes ecosystem redefined what consumers wanted and how they would get it. The idea of software-defined cars that could be updated over the air—sometimes called "smartphones on wheels"—first became reality in the automotive market in 2012.

Is the day likewise coming when software-defined manufacturing will turn shop floors into "smartphones with robotic arms"? A scenario analysis by McKinsey suggests that the answer is yes.

According to our analysis, many of today's most advanced trends in manufacturing technologies—such as digital twins, robots capable of teaching themselves, and devices that can do their own programming—will become commonplace in the future. These trends will enable a "software-defined" paradigm for industrial automation.

It is harder to predict when this future will arrive. It may come in 15 years, but it also may come in five years, depending on the speed of technological advances and their adoption in different industrial sectors. Which time frame turns out to be correct has important implications for companies' near-term strategies. Providers and end users can form their own sense of this time frame by tracking inflection points in the development of ten key automation technologies.

To get a better sense of industrial automation's current and future state, McKinsey conducted a survey of 188 industrial automation users and vendors. Insights also came from interviews with more than 20 experts in the field (see sidebar, "The basis for this report").

This report goes into detail on the following points:

— *Automation users' perceptions.* Ninety-four percent of the users participating in our survey said digital solutions will be important to their automation efforts in the future. Users' focus in the past few years has shifted away from self-developed digital solutions that often did not go beyond learning exercises. Fifty-four percent of manufacturing companies now use OEM partnerships in a bid to develop standardized industrial IoT platforms. That's close to an eightfold increase since 2019.

— *Changes in the supplier landscape.* The report identifies four vendor archetypes—hyperscalers; automation players, including machinery equipment manufacturers; software players; and specialized players—and shows how each of their strategies are evolving. Of the four archetypes, hyperscalers, or cloud-service providers that have already disrupted other industries, are changing industrial automation the most. Hyperscalers are moving into the embedded software and hardware part of the automation stack and are starting to grab a larger share of industrial automation spending. At an estimated 18 percent, the market for connectivity and industrial IoT (IIoT) will grow faster than any other part of the industrial automation market. This is the key source of revenues for hyperscalers within industrial automation.

— *Game-changing technologies.* Soft programmable logic controllers (PLCs), digital twins, and teach-less robotics are among the ten key technologies that are ushering in the future of automation. This report describes how the key technologies will revolutionize factory

operations. It also identifies the inflection points that may cause the technologies to take off. For instance, advances in connectivity and data exchange protocols would likely spur the growth of soft PLCs; rising labor costs would drive more development and interest in teach-less robotics; and AI is a strong enabler of almost all of the ten key technologies.

— *Two potential scenarios.* There are two scenarios for the future of industrial automation that basically differ by the speed at which technology will be adopted. The first, more likely scenario is one of gradual market development. However, a second scenario—involving a much faster transition—is also possible and would necessitate dramatic changes for both suppliers and manufacturing plants by 2030.

— *Potential courses of action for those in industrial automation.* Different players in industrial automation can do quite a few things today to prepare for the future. Hyperscalers might expand their domain know-how and set up partnerships with established automation players and system integrators. Automation players might consider moving up the technology stack, strengthening their positions in software and in cloud or IoT platforms. And automation users—the manufacturing plants themselves—may want to take steps to expand their digital capabilities, since they will need these capabilities no matter what comes and when.

The basis for this report

This report is based partly on an external survey of 188 industrial automation users and vendors. We also gathered insights from more than 20 McKinsey and external experts with deep experience in industrial automation. Finally, we gathered information from public and proprietary sources to analyze the strategies of different automation players. Those information sources included the ARC Advisory Group, International Data Corporation (IDC), and IHS Markit.

Today's landscape and what could disrupt it

The potential of industrial automation is most obvious in the tiny percentage of manufacturing sites known as "digital lighthouse factories." These plants are leading the way in automation. Digital analytics and IoT solutions aren't just in the plants producing the end products; they're in these manufacturers' whole value chains. A survey by the World Economic Forum found that 93 percent of lighthouse factories had gotten a growth benefit from their embrace of automation.[1] Most of the growth benefit came from the ability to increase their output, with automation leading to new revenue streams for a handful of factories.

The vast majority of the world's factories have nowhere near the level of automation and digitalization of lighthouse factories. This is because factories set up 20, 30, 40, or even more years ago were not designed with the benefits and needs of modern automation technologies in mind. The automation at these brownfield plants tends to be piecemeal—for a specific machine or process. Factories built later can have full-plant automation based on a single standardized architecture in an environment in which information technology (IT) and operational technology (OT) converge. Besides the age of a factory, industrial sector and geography are also factors that influence how much automation a plant has. In particular, the wages, subsidies, and number of skilled workers available in a certain geography can drive more or less automation of factories there.

With plants automating and digitalizing brownfield projects at different speeds—and improving processes specific to their own needs—automation vendors have been conservative in developing their strategies. Those strategies have tended to assume incremental, rather than disruptive, market changes.

But three developments may make it risky for providers to stay with a conservative strategy for industrial automation. The three developments that are threatening the status quo are the following:

— *Hyperscalers' growing interest in industrial automation.* Hyperscalers—which allow companies to outsource large amounts of their data processing—are looking to do more business with manufacturing clients. Although their starting points are clearly their cloud platforms and data analytics capabilities, hyperscalers have made rapid progress in their industrial automation business. They've also used M&A to position themselves as solution providers in other areas of automation more directly tied to factory operations.

— *The emergence of new technologies.* It wasn't so long ago that digital twins and teach-less robots seemed far off. The same was true of 5G and Wi-Fi 6—two forms of wireless connectivity that offer a quantum leap in bandwidth and in the number of connected devices. These technologies are starting to mature, and users' interest in them is increasing.

— *A sense that automation can address new boardroom imperatives.* The initial appeal of automation was in the cost reduction and productivity improvements it could provide, at a high level of reliability. Today, many industries that embraced automation early have largely captured these benefits. In addition, the global economy is facing the megatrends of ESG, a skilled-labor shortage, and supply chain disruptions. Together, these factors are shifting attention to other potential benefits of automation—namely, resilience, flexibility, and sustainability. This will create opportunities for automation vendors that can deliver these benefits.

In different ways, these changes could all imperil the fortunes of today's industrial automation providers. These providers need to have a clear picture of how the automation market is developing and of how they will respond under different scenarios.

[1] The Global Lighthouse Network, an initiative of the World Economic Forum, conducted the survey in 2020.

Overview of the current market

Industrial automation products in the following three categories will represent an approximately $115 billion global market in 2025, according to McKinsey's estimates, representing compound annual growth of about 3.5 percent since 2019.

The distribution of manufacturers' investments will vary by industry as companies look to improve their efficiency and mitigate their risks. The risks for manufacturers include supply chain disruptions such as the global semiconductor shortage, soaring raw-material prices, and energy prices, which are an especially big problem in the European Union. By automating processes and using data to optimize operations, manufacturers may be able to reduce the impact of these supply chain problems.

A good way to get a sense of the industrial automation market and to understand how it's growing is to break it down by segment.

— *Classical automation equipment*[2] *for process manufacturing industries.* Process industries spend the most on industrial automation products. These industries use mixing, boiling, blending, and other processes to join ingredients based on formulas and recipes. The process takes place in batches, leading to finished products whose ingredients, once combined, can no longer be separated. Process industries have been spending the most by far to automate their traditional equipment because their control systems are usually larger and are purchased for considerably longer durations. In total, they will spend about $76 billion in 2025, up from $64 billion in 2019, according to our forecast—a CAGR of about 2.8 percent. Oil and gas is the biggest automation buyer among the process industries, slightly ahead of chemicals, though it is growing at the slowest pace.

— *Classical automation equipment for discrete manufacturing industries.* Discrete manufacturing industries make goods from individual parts according to a job order record. The production work usually takes place in different areas and is done independently or sequentially. Automation spending is considerably lower in this manufacturing category ($26 billion in 2019) but is growing faster (at a CAGR of about 3.9 percent), with high variation between sectors. The semiconductor and electronics and electrical sectors are increasing their automation spending the fastest.

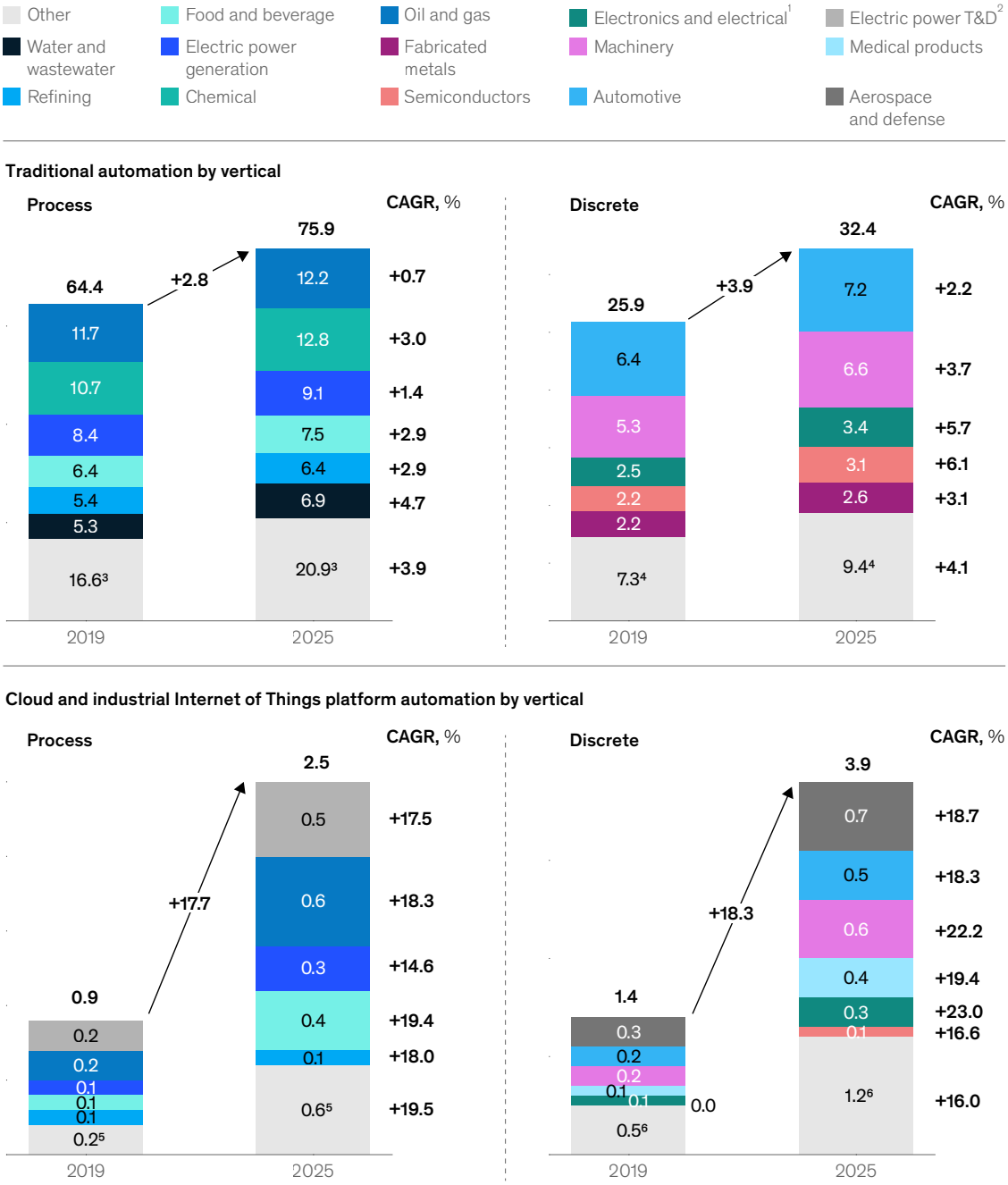
— *Industrial IoT and cloud services for process and discrete manufacturing.* This last segment includes all the solutions that connect industrial equipment within a factory and that enable the use of data analytics and the creation of data-driven supply chains. It is the smallest automation product segment but, at 18 percent, the fastest growing. From a vendor perspective, IIoT and cloud services is also the most concentrated product segment (Exhibit 1).

[2] Classic automation equipment, as classified under the ISA-95 standard, generally refers to the hardware and software components that are involved in controlling and monitoring industrial processes.

Exhibit 1

Size and rates of growth vary in different segments of industrial automation.

Total market size, $ billion: 92.6 (2019), 114.7 (2025)



Note: Figures may not sum, because of rounding.
[1]This is defined based on the North American Industry Classification System (NAICS) Standard Industrial Code 36 (except 3674): Electronic and Other Electrical Equipment and Components, Except Computer Equipment.
[2]Trasmission and distribution.
[3]Includes cement and glass, electric power transmission and distribution, metals, mining, pharmaceutical and biotech, pulp and paper, and textiles.
[4]Includes aerospace and defense, buildings, furniture and wood products, medical products, plastics and rubber, and printing and publishing.
[5]Includes metals, mining, and pharmaceutical and biotech.
[6]Includes transportation and logistics and wholesale and distribution.
Source: ARC Advisory Group; McKinsey analysis

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What's changing and what people say: Our survey

Digital solutions are seen as an increasingly important part of companies' factory automation efforts. That came through in our survey of automation users and vendors. Sixty-nine percent of respondents said digital solutions are already an important part of their automation efforts. Even more—94 percent—said such solutions would be important to their automation efforts in the future (see sidebar, "Who we surveyed").

The drumbeat of technological advances seems to be pushing industrial automation toward mature, functional solutions. This is evident in the growing number of partnerships and codevelopment efforts.

A critical question in the survey addressed how users today create their IIoT platforms. This is the infrastructure in manufacturing environments—built on a common architecture and standardized communication protocols—that helps industrial users monitor, manage, and control connected devices. IIoT platforms allow manufacturers to get value out of the vast amounts of data generated at their factories for data analytics and optimization.

Fifty-four percent of respondents say their mechanism for creating an IIoT platform today is through a partnership with an OEM, versus the 7 percent who say they are using a self-developed IoT platform. In our 2019 automation survey, these percentages were inverted, with more than half of respondents saying they were using a self-developed IIoT platform.

The next most common mechanism for deploying an IIoT platform today, cited by 30 percent of respondents, is to work with an existing offering from a large provider. Further down the list, 10 percent of respondents said they are implementing a single lighthouse project—a sort of proof of concept—with a partner.

An IIoT platform's ease of integration with existing traditional software solution platforms—such as enterprise resource planning, manufacturing execution systems (MES), product life cycle management, and customer relationship management—is the most important selection factor, according to survey respondents.

Next most important is the level of service provided by the IIoT vendor. Ready-to-use apps are also on the list, though they are rated as less important by end-user respondents than they are by provider respondents. The opposite is true of an IIoT platform's use of open standards: end users see open standards as more important than vendors do. Overall, both factors get the attention of about 13 percent of total respondents (Exhibit 2).

The story that comes through clearly—certainly on the user end—is of a preference for partnering and standardized integration. These attitudes will shape user and manufacturer initiatives over the next few years, as we discuss later in this report.

The manufacturing performance dimensions that are improved by automation

To date, a lot of the efforts in automation have been aimed at making factories more productive and cost-efficient. While some industries—textiles, for example—some parts

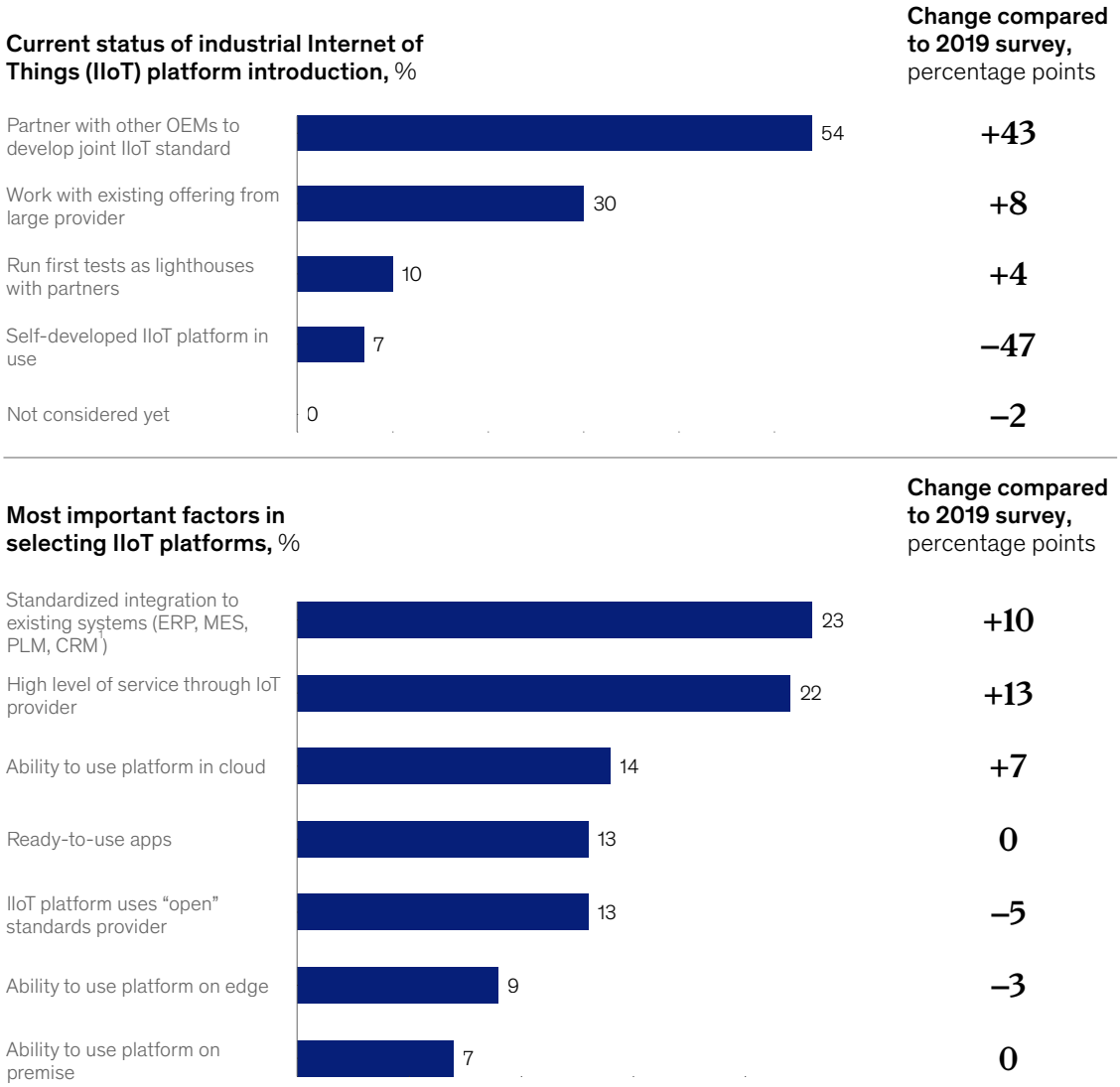
Who we surveyed

McKinsey's survey was conducted online in June 2022. The survey had 188 participants, with the largest proportions (49 percent and 39 percent, respectively) in North America and Europe. Twelve percent of the respondents were in Asia.

Two-thirds of the survey participants were end users at either discrete manufacturing companies (including in the automotive, machinery, and electronics sectors) or process manufacturing companies (for instance, in oil and gas or in chemicals). The other third consisted of automation providers. The majority of respondents (more than 85 percent) are leaders in operations (supply chain, manufacturing, or procurement), with a smaller proportion being strategy leaders.

Exhibit 2

Interest in OEM partnerships and in standardized integration is growing.



[1]ERP = enterprise resource planning; MES = manufacturing execution systems; PLM = product life cycle management; CRM = customer relationship management.
Source: McKinsey Future of Automation Survey, 2022; McKinsey Shifting Value Pools in Machinery & Industrial Automation Survey, 2019

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of the value chain are earlier in their automation efforts and haven't yet fully reaped these financial benefits, many other manufacturing sectors have already optimized their benefits from automation. Besides automation's financial benefits, some of these other sectors have also been able to use automation to cut down on hazardous or repetitive tasks, thereby improving employee safety and well-being.

In these more advanced manufacturing sectors, automation is starting to be seen as something that can increase resilience, flexibility, and sustainability. Additive manufacturing is a technology that can increase factories' resilience because of its potential to produce spare parts locally, thereby reducing a company's exposure to supply chain disruptions. Digital twins can also provide a kind of resilience by allowing manufacturers to simulate the impact of a disruption on a piece of equipment or an entire factory and to quickly draw up countermeasures. Two automation-boosting technologies, 5G and Wi-Fi 6, can make

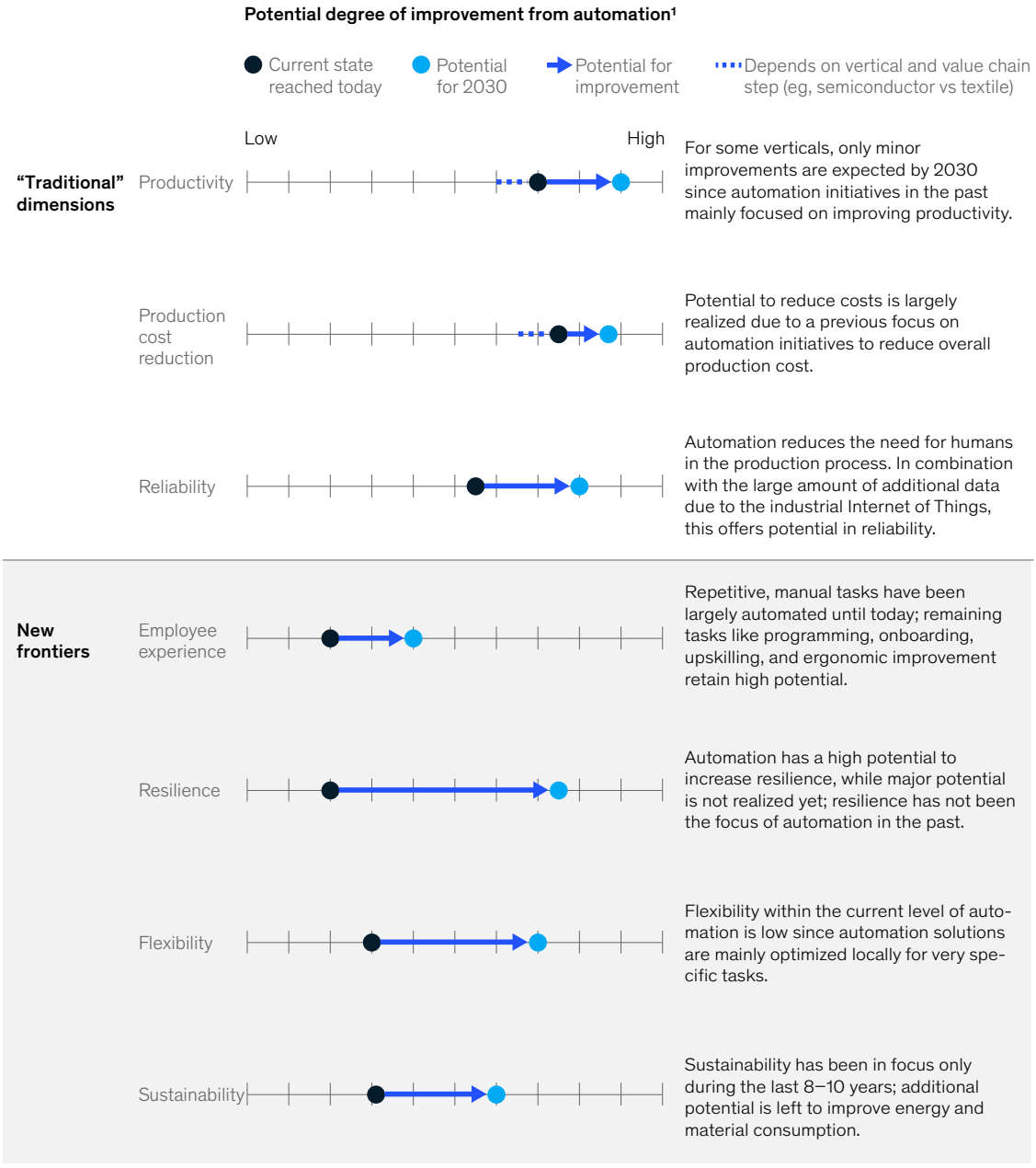
manufacturers' logistics and supply chains more resilient by tracking a much larger number of devices while reducing latency challenges.

We also expect automation to contribute to manufacturers' flexibility between now and 2030. For instance, automation can support a factory's ability to quickly switch its production lines to new products. Automation could be especially valuable to manufacturers looking to move away from traditional assembly lines and adopt matrix approaches.

Finally, there is also the potential for automation to improve companies' sustainability. This, too, could happen through additive manufacturing, which can significantly reduce energy and water consumption as well as waste and the quantity of scrap produced (Exhibit 3).

Exhibit 3

There will be a shift from industrial automation's traditional benefits in productivity and cost to new dimensions.



[1]Relative scale.

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Archetypes of players in the market

A good way to understand how the automation market is changing is to start with the digital technology stack and position the four industrial automation–player archetypes along the stack (Exhibit 4). Such an exercise also gives a sense of each archetype's strengths, opportunities, and challenges.

Hyperscalers—companies that operate large-scale data centers to provide cloud computing infrastructure and that provide advanced data-analytics services—have strong offerings in the top part of the stack, including in areas related to the user interface. Hyperscalers' strength is that their applications are horizontal in nature: capable of helping with every digital asset a plant has.

Automation players, which traditionally provide hardware-based automation solutions like robotics and controls to manufacturing users, try to offer a complete automation solution. This includes hardware products, such as robots, automation equipment, and smart sensors. It also includes software applications and analytical tools that can be integrated into manufacturing execution systems or warehouse management systems.

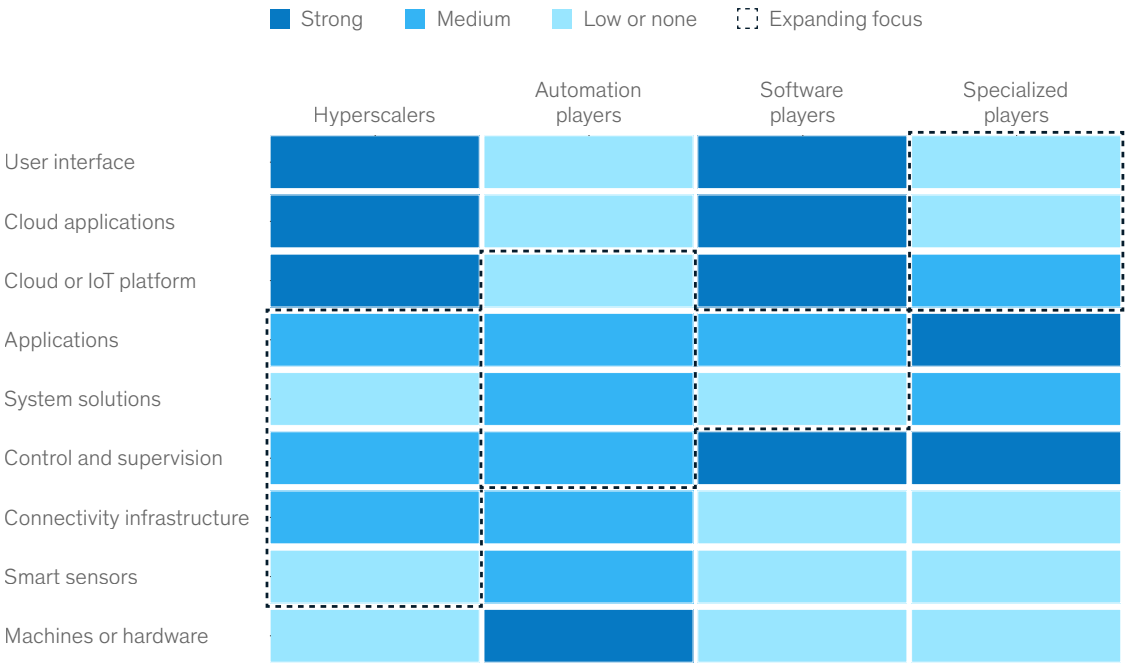
Software players focus mainly on software and technology solutions. They offer business applications that can be used in cloud, analytics, mobile, and IT solutions; in IIoT and cloud platforms; and for control and supervision.

The final archetype, specialized players, includes system integrators and companies that offer advanced IoT applications such as virtual reality and augmented reality platforms.

The domains of the different archetypes aren't static. Exhibit 4 shows how companies within each archetype are starting to expand their offerings.

Exhibit 4

Current strengths and expansion plans for automation's four archetypes vary.



Note: To create this exhibit, data was gathered from the websites of hyperscalers, automation players, software players, and specialized players and then mapped along the digital technology stack. Interviews with experts in the field were conducted to validate the results.

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Automation players are starting to move up the technology stack, including into software and cloud applications, which are also the fastest-growing portions in the tech stack (16 to 20 percent CAGR from 2019 to 2025). These players' large installed bases—and their familiarity with many end-user vertical markets—is what has allowed them to make these expansion moves. Software companies and specialized players are beginning to shift their focus both up and down the technology stack.

A lot of the attention, however, is on hyperscalers because of their market power and financial resources. Already strong in cloud applications and user interface features, hyperscalers have turned to M&A in recent years to deepen their capabilities in areas ranging from cybersecurity to self-driving vehicles to AI and analytics software.

A close look at the hyperscalers' acquisitions suggests that the deals are meant to entice end users into the higher parts of the industrial automation stack, in which hyperscalers already have their biggest advantage; at the same time, deals are meant to help hyperscalers move "down" the automation stack closer toward hardware. Indeed, despite machine control hardware and software having relatively slow growth (2 to 5 percent on a compound annual basis between 2019 and 2025), these product areas represent about 60 percent of the overall market and are a key control point to providing end-to-end solutions for automation users.

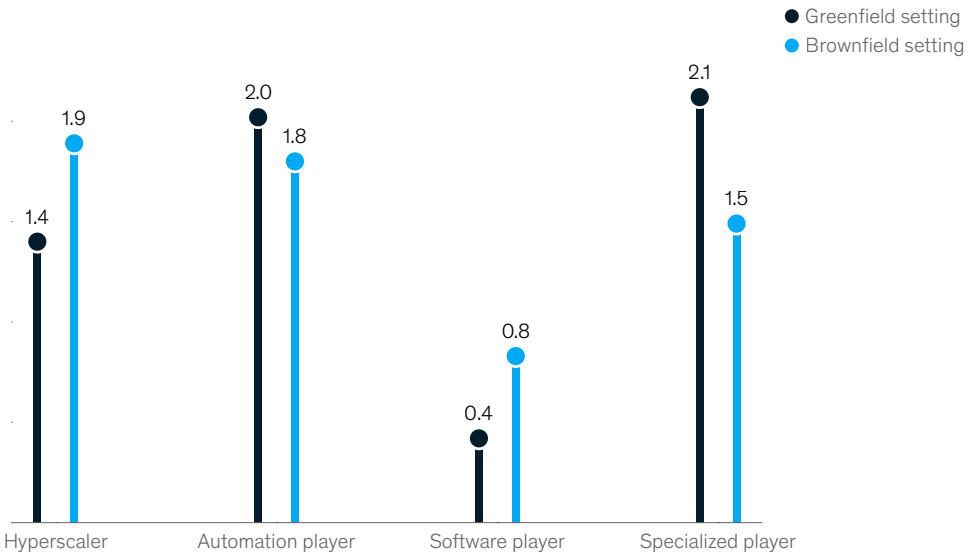
Hyperscalers are certainly on the radar of industrial automation users. When asked who they would approach first if they were looking for digitalization solutions for a brownfield factory, the end users in our survey ranked hyperscalers and automation players equally high. Hyperscalers would be a much lower priority in greenfield settings, users said.

Automation players and specialized players are seen as the most relevant for greenfield settings in which factories are newly built. Software players are the last choice for shop floor digitalization in both brownfield and greenfield settings (Exhibit 5).

Exhibit 5

Hyperscalers are the first choice for digitalization in brownfield settings.

Priority of archetypes,[1] average score



[1]Question: "Which of the following company archetypes would you approach first for shop floor digitalization needs when operating in a greenfield/brownfield setting? Rank in order of priority." Respondents ranked the four archetypes from highest (3 points) to lowest (0 points) priority. The scores were then averaged.
Source: McKinsey Future of Automation Survey, 2022

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Another indication of the hyperscalers' strong position came in response to a question about future share of wallet. Looking ahead to 2030, end users said they expect to spend about 27 percent of their automation dollars with hyperscalers by then—virtually the same as they expect to spend with automation players and specialized players.

Impact of new automation technologies

Ten technologies could have an outsize impact on industrial automation's future. All are already in use and will likely grow at double-digit rates through 2030. Certain developments would set the stage for inflection points—for more rapid adoption of the technologies.

One example is the increasing use of AI technology, including generative AI, which has recently come into the spotlight because of ChatGPT. AI will play a significant role in the development of many of the ten technologies and will likely accelerate their adoption, potentially making the fully automated future a reality sooner than people expect.

The following examines the technologies and the developments that would accelerate their use.

Soft PLCs

Programmable logic controllers (PLCs) are ruggedized industrial computers that, due to their reliability and temporal determinism, are used to control manufacturing processes such as the actions of robotic systems and other automated machines. Soft PLC software allows any computer to function as a PLC while preserving an open architecture. Such an architecture makes it possible to provide control instructions in more flexible ways and for the device to perform computing functions beyond machine control. The adoption of soft PLCs is propelling the convergence of IT and OT. The programmers building or updating the control functions don't have to be standing or sitting next to the equipment; they could be in a different building or even in a different country. Soft PLCs allow for faster changes, fixes, and production process optimization.

In the future, AI may provide a lift to soft PLCs, helping with closed-loop optimization, for example. Generative AI might be able to create soft PLC applications automatically.

What might set the stage for more rapid growth. Ethernet-to-the-field technology is one indicator to track. This high-speed networking technology combined with time-sensitive networking would address the reliability and latency challenges that have until now discouraged investments in soft PLCs. Once those issues are addressed, soft PLCs' obvious advantages will likely start to push their usage higher. The share of soft PLCs in the overall PLC market is expected to reach 7 percent in 2025. That would be twice their share in 2019.

Digital twins

These are digital replicas of complex physical systems. A digital twin can use data from the digital and physical worlds to run simulations to benefit a factory's performance. For instance, a digital twin of a factory could be used to simulate manufacturing processes to optimize the plant layout, resulting in planning-time reductions of up to 70 percent. Digital twins can also be used to improve machine and line performance. AI could enable significant increases in the speed at which digital twins perform simulations and detect failures.

What might set the stage for more rapid growth. For all their promise, digital twins have been limited by the fact that the data sources are often isolated in silos. The emergence of standard protocols and data formats as well as low-code programming of digital twins would go a long way toward ending this problem and could lead to faster adoption of the technology. The digital-twin market is expected to grow by 35 to 40 percent on a compound annual basis through 2030.

Teach-less robotics

Robots typically must be "taught," or programmed, in order to contribute to a plant's productivity. Besides time, the ramp-up of robots requires specific programming skills. Teach-less robotics usher in an era of smarter robots and cobots that need little training to perform new tasks. This is another area that will benefit from AI. Manufacturers could see a sharp reduction in programming time and gain the ability to automate more assembly tasks.

What might set the stage for more rapid growth. The labor market for factory workers is already tight. If it were to get tighter, demand for teach-less robots could increase even faster, exceeding current robotics CAGR estimates of more than 15 percent. Also, technology advancements, including in the area of environmental sensing, would accelerate the adoption of these advanced robots.

Edge and cloud computing

This technology trend has to do with having the flexibility to run applications either in the cloud or in the plant—close to the machines generating and processing data at the edge. It reflects the reality that cloud and edge computing have different strengths. The cloud is great for tasks like advanced analytics that use large amounts of historic data. This strength, however, must be weighed against the cloud's latency and connectivity issues, depending on the deployment model. Particularly in the case of control tasks requiring millisecond precision, it can be preferable to gather and analyze data at or near a machine generating the data. Edge computing enables these real-time AI-powered decision-making tasks while offering a high degree of data security.

What might set the stage for more rapid growth. The move to the cloud of MES, supervisory control and data acquisition (SCADA) systems, and other core OT platforms would significantly increase demand for industrial cloud applications. So would the development of partnerships between hyperscalers and automation providers, given the one group's technological capabilities and the other's domain knowledge.

5G and Wi-Fi 6

This is the fast-growing new generation of wireless technologies. They have far less latency and offer a quantum leap in bandwidth and in the potential number of connected devices. This is a significant boon to the IoT and will enable or improve the performance of applications such as factory monitoring systems, augmented reality, automated guided vehicles, and autonomous mobile robots.

What might set the stage for more rapid growth. These technologies could grow faster than expected if there's a rapid rise in software-defined manufacturing use cases that require numerous ultra-low-latency connections, such as autonomous mobile robots or closed-loop digital twins. Current predictions are that more than five billion 5G IoT devices will be sold in 2025.

Simplification and standardization

Harmonization of automation data (allowing for simplified communication between machines) and standards for data exchange (such as the Open Platform Communications Foundation's Unified Architecture [OPC UA]) increase the interoperability and openness of automation systems. These elements reduce development effort and costs and make plant infrastructure more reliable and easier to maintain. Moreover, simplification and standardization are key to enable scaling of digital use cases across the shop floor. Without it, digital use cases will likely get stuck in pilot purgatory.

What might set the stage for more rapid growth. End users' increasing focus on flexibility and matrix production is already pulling them toward technologies that enable "plug and play" operations. The faster users shift in this direction, the faster standardization solutions such as OPC UA will take off. There were more than four million OPC UA network notes in 2022, up from approximately 285,000 five years ago.

Cybersecurity

Manufacturing operations are just as vulnerable to cyberattacks as other parts of companies' businesses, and in many cases, they represent companies' biggest vulnerabilities. Before committing to new automation systems, end users are going to need assurance that the systems they bring in are shielded from attack. The convergence of IT and OT entails the risk that old machines with outdated security systems are connected to global networks—a glaring vulnerability. In our survey, both users and providers cited cybersecurity as one of the top needs. AI technology can automatically detect cyberthreats and can facilitate a safer rollout of systems (such as cloud systems) that increase the number of potential attack vectors.

What might set the stage for more rapid growth. A major inflection point for factory-centric cybersecurity will come when key OT platforms (PLCs, MES, SCADA, and distributed control systems) move to the cloud. New cybersecurity regulations or cybersecurity incidents involving major manufacturers would further raise awareness about OT cybersecurity and accelerate growth in the years leading up to 2030.

Modularization and matrix production

Pioneered by automotive companies, matrix production is an approach in which different parts of manufacturing are done in cells versus in a line of sequential steps. Matrix production adds flexibility to manufacturing, since the cells can be repurposed and material flow can be changed in response to changes in demand; the added flexibility also comes from the lower likelihood of a production breakdown affecting the overall productivity of a plant. We expect AI to facilitate the use of matrix production, including by identifying optimal production layouts or routing.

What might set the stage for more rapid growth. In process industries, modular type package has emerged as a potential standard of modular production. However, it will take more visible proof points from industrial lighthouse applications—and more global acceptance—to create an inflection point for this technology. Matrix production is being piloted in some discrete manufacturing environments, including the production of sports cars.

Simplification and standardization are key to enable scaling of digital use cases across the shop floor. Without it, digital use cases will likely get stuck in pilot purgatory.

Additive manufacturing

Additive manufacturing (AM), also known as 3-D printing, refers to the process of adding materials layer by layer to make objects from 3-D model data. With AM, work can be localized, the number of production steps can be decreased, and the amount of wasted material can be cut, leading to more flexibility and efficiency in manufacturing. Already cost competitive for small and medium lot sizes, AM is on a path to be cost competitive in larger lot sizes, too.

AI has the potential to improve additive manufacturing technology through better 3-D models, including optimized shapes that offer better product performance and simultaneously lower material requirements. And by reducing production steps, AI-enabled 3-D printing will make this option more competitive versus traditional manufacturing technologies.

What might set the stage for more rapid growth. The industrialization of metal binder jetting as AM technology could mark an inflection point for the AM market because it will accelerate the technology's cost competitiveness. In addition, fully automated AM hubs could further improve operational efficiency, improving the AM cost curve and leading to accelerated market growth, with an estimated market size of more than $40 billion in 2025.

Low-code/no-code

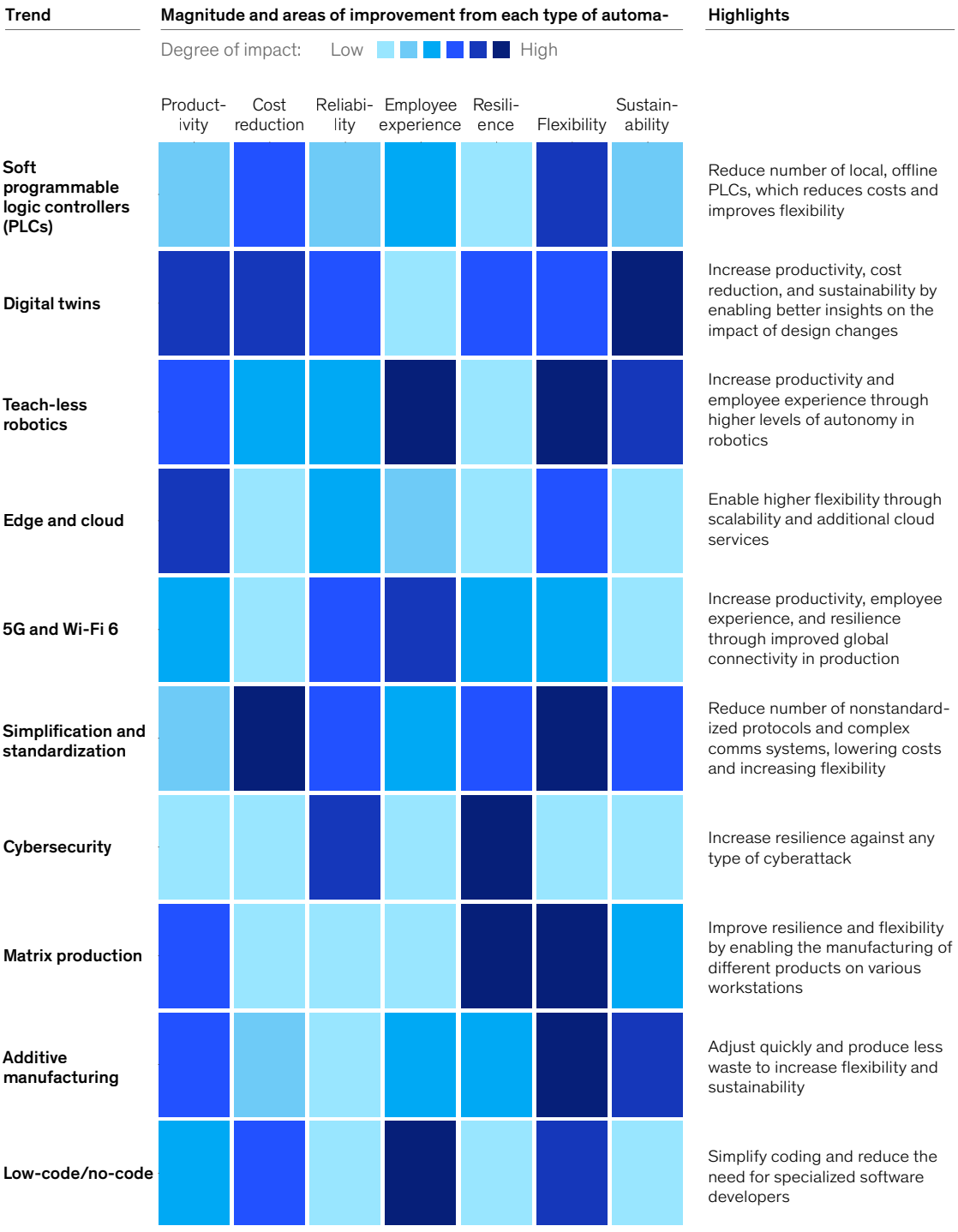
A desire for increased productivity and responsiveness is driving interest in low-code/no-code software. Contributing to the demand is a shortage of skilled labor. There aren't enough software developers and data scientists in the world to meet the demand for industrial software development. Low-code/no-code software allows programming with minimal effort and IT knowledge. Generative AI will further reduce the need for coding and may make it possible for people with no coding experience at all to develop functioning software. This will mean a lower IT workload and the ability to quickly react to changing requirements.

What might set the stage for more rapid growth. When AI technologies are increasingly employed for code generation, it could be an inflection point for low-code/no-code applications, leading to a surge in demand for such software.

Manufacturers will adopt the technologies at different rates, depending not only on the readiness of the ten technologies but also on what's happening in their industries and in the geographies where their plants operate. The overall impact of the technologies, however, will be to push manufacturers into the more automated future of software-defined manufacturing. In that future, factories will have more flexibility, higher throughput levels, orders of magnitude less scrap, and the ability to update instructions for optimization of control on the fly. Moreover, the factories will be more appealing to workers because of their improved ergonomics (Exhibit 6).

Exhibit 6

Ten up-and-coming automation technologies can improve a typical factory's operations.



Source: McKinsey Future of Automation Survey, 2022 (n = 188); McKinsey analysis

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Scenarios for the future of automation

Factories are headed toward extremely high levels of automation and autonomy—toward being software defined or, to put it more colorfully, toward being "smartphones with robotic arms attached." Just as smartphones and cars have evolved to contain a multitude of integrated digital services with a clear hardware–software separation, so will factories, with robots, cameras, and sensors benefiting from human-centered design and seamless integration into the shop floor. Data will track and determine everything that happens in plants, and analytics and AI will allow for vast improvements in forecasting and risk management. Technologies that you'd find in only the most advanced factories today—digital twins, robots capable of teaching themselves, and devices that can handle a lot of their own programming—will be widely adopted. Factory automation will be, in a sense, a commodity: something available to every plant across virtually all process steps.

While this is a desirable target state across industries due to a vast number of benefits, there are certainly questions about when we will get there. And that is where our two scenarios come into play.

Our first scenario doesn't envision the arrival of fully automated manufacturing for at least 15 years—until almost 2040. In this scenario of gradual evolution, the most innovative technologies would be seen only in specific use cases in 2030. Manufacturing processes such as welding and loading would still often be manual—done by human beings at plants. The business case and technical feasibility of each automation technology would still need to be exhaustively vetted before getting a green light, much as is the case at manufacturing plants today. From a talent perspective, there wouldn't be a major disruption in required skill sets; general analytical and digital skills, however, would become increasingly important.

Our second scenario posits a faster transition, with key inflection points materializing in the next five to ten years and full automation and digitalization for many factories by 2035. In this scenario of disruptive change, use of cloud technology for all information processing tasks would be widespread by 2030. A typical manufacturing plant would have automated many of its end-to-end processes. Such a plant would have more of an open-platform ecosystem in place and would use more standardized solutions. More of the products it was using would be priced based on consumption in an as-a-service-model, making it less risky for the plant to try out new types of automation technology. Manufacturers would be recruiting for new, highly specialized digital positions to handle all of their new automation activities (Exhibit 7).

Exhibit 7

There are two possible scenarios for factory automation in the future.

Scenario 1: Reforms

Gradual evolution

Slow adoption of technology trends, in continuity with past speed of change; standardization at a slow pace; innovation (eg, low-code/no-code and digital twins) being utilized only for specific use cases and industries

Scenario 2: Revolution

Rapid transformation

Disruptive adoption of technology leading to a data analytics–driven and software-driven shop floor with proactive adoption of new business models, widespread use of cloud, and a semiclosed ecosystem with a central and adaptable platform

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What different players should do in each scenario

In our first scenario—gradual evolution—in 2030, industrial automation users will still be creating highly individual solutions in collaboration with their existing vendors. The journey toward fully automated, software-defined factories will be proceeding slowly, with inflection points for many of the ten key technologies not yet reached. Although there will have been advances in soft PLCs, teach-less robotics, 5G and Wi-Fi 6, digital twins, and low-code/no-code technologies, these technologies will not be fully integrated and interconnected with factory ecosystems, resulting in a less efficient and less adaptable manufacturing environment. The adoption of these technologies will likely be phased and selective. Hardware will continue to play a significant role in automation solutions, with software playing a secondary role. Hyperscalers will have a central place in this scenario because of their capabilities in data delivery and in providing data infrastructure. But they certainly won't have been appointed as the new leaders of industrial automation.

In the second scenario, by 2030, automation users will already be well on the way toward building fully automated factories. This scenario assumes that many of the ten key technologies have already gone through inflection points and spiked in growth. There is starting to be a sophisticated use of cloud and edge computing, teach-less robotics, 5G and Wi-Fi 6, digital twins, matrix production, and low-code/no-code technologies, enabling more of a seamless integration of automation systems in the factory ecosystem. As is the case today with smartphone applications, automation solutions will be designed to be intuitive and user-friendly and will take advantage of technologies such as AI and natural-language processing. The emergence of a factory ecosystem with interconnected devices, machines, and systems that can seamlessly share data and automatically make decisions will enable factories to move more quickly and be more flexible. The second scenario would bring the biggest shift in the competitive dynamics of industrial automation, with hyperscalers emerging as a much more visible part of manufacturing's digital transformation.

Market growth would be significantly higher in the second scenario. For instance, we estimate that the CAGR of digital twins would exceed 40 percent through 2030 in the second scenario, versus 30 percent in the first scenario. The industrial 5G and Wi-Fi 6 market would be growing at a CAGR of 40 to 50 percent in the second scenario, at least twice what we see in the first scenario.

The second scenario is obviously the more provocative one. The first, however, is likelier because of the reliability, cost, and ROI concerns that are always top of mind at plants and because of the slow development of industrial automation historically.

Potential courses of action for three cohorts

The critical question, with the uncertainty over how quickly the industrial automation market will develop, is how to prepare. Below, we present our recommendations for three groups: hyperscalers, automation players, and automation users. Our recommendations differ for the two scenarios, but our expectation is that there are certain no-regret moves that different players can make regardless of what they believe about the future.

— *Possible moves for hyperscalers.* In the gradual evolution of the first scenario, one move that hyperscalers might consider would be to continue to expand downward in the automation stack, including into sensors and other hardware areas where they are not currently strong. They might also want to build their domain know-how and set up partnerships with established automation players and system integrators, the odds-on leaders if the slow-development scenario were to materialize.

  In both scenarios, M&A might be a tool for hyperscalers because of their immense financial power. The difficulty that traditional automation players would be having under the second scenario—and the hyperscalers' growing dominance—might make traditional automation providers more receptive to selling some of their automation assets.

In a fast-developing industry in which their influence was rising, the hyperscalers might also look to introduce and rapidly build new standardized solutions.

— *Possible moves for automation players.* If players in this group believe that continuing gradual evolution, as under the first scenario, is most likely, there are four things they might do. First, they could consider vertical expansion of their portfolios, especially into software, through both organic and inorganic means. Second, they could see which strategic control points—including their relationships with regulators and customers, their products' status as de facto standards, and their access to proprietary data—they can use to maintain their advantage. Third, they could build out their digital infrastructures and extend their digital capabilities in a bid to create ecosystems that they can control. Finally, they could collaborate with—and, in some cases, buy—niche players and system integrators to solidify their market positions.

  If the second scenario were to materialize, automation players might want to be bolder. In such a situation, they might focus on data aggregation and analysis to enable new use cases. With hyperscalers holding more power, the automation players might create solutions that would position them as preferred partners of hyperscalers or as the hyperscalers' Tier 1 suppliers. Hardware is basically a commodity in this scenario, which means automation players might want to specialize even more and turn more to software to preserve their profit margins. Finally, just as in the first scenario, automation players might look for ways to create ecosystems around their own infrastructure. This last point may be the most obvious no-regret move since it is basically scenario independent.

— *Possible moves for manufacturing plants and automation users.* In the first scenario, automation users will want to partner with whichever vendor cohort has the expertise—automation players for hardware and hyperscalers for cloud infrastructure. And users might want to push vendors toward standardization and simplification.

  In the second scenario, there would be a chance of becoming overly dependent on individual players. To minimize this risk, users might consider maintaining partnerships with traditional automation players even as their use of hyperscalers' services increases.

  And no matter which scenario emerges, industrial automation users will want to look at expanding their digital capabilities. In the first scenario, the improved capabilities would keep manufacturing plants from becoming too dependent on automation providers and on complex, individualized solutions. In the second scenario, having their own well-developed digital capabilities would allow automation users to leverage hyperscalers in a targeted way versus becoming overreliant on hyperscalers for data-driven, cloud-based solutions.

Specific actions to consider in 2023 and beyond

The coming months might be a good time for hyperscalers and automation players to go beyond the usual stocktaking. The following are bolder steps to consider:

— *Review automation portfolio strategy.* The purpose of this would be to assess the impact of potential automation scenarios on the most important parts of their businesses, including their product portfolios. M&A opportunities should be a part of any strategy discussion.

— *Create new automation businesses.* With the automation market in flux, there is a case for creating a brand-new stand-alone automation business in an intrapreneurial setting resembling a start-up.

— *Boost the commercial strategy.* It may be possible to redefine the commercial strategy and sell more by switching the approach or the channel or by making other changes.

— *Develop new revenue streams.* It might be possible for automation providers to create new products, supported by analytics. The new products could revolve around predictive maintenance, or they could involve a move to an as-a-service business model.

— *Roll out AI technology to support automation.* Automation providers should consider using AI technologies, including generative AI, to develop new automation products in areas such as digital twins and low-code/no-code robots.

In the next year, automation users might want to undertake the following:

— *Launch an automation diagnostic.* This would allow plants to see what unexplored automation opportunities they have.

— *Embark on an end-to-end automation transformation.* This would start by identifying key use cases while keeping scaling in mind from the start. It might also include automation vendor selection and partnerships, manufacturing performance improvement, and the use of automation to fulfill sustainability requirements.

— *Begin a future-of-work transformation.* Building digital capabilities is a no-regret move for automation users, one that will help them no matter which scenario materializes. A future-of-work diagnostic and transformation would allow manufacturers to build a detailed view of the most critical skills of the future and identify the gaps they must fill to get there. Hiring, upskilling, and reskilling would all be part of the equation.

Technical developments and new competitors are altering the shape of the industrial automation market. While no one can say for sure how it will play out, there are definite steps that all automation players can take now to position themselves for the future. It's about making selective bold moves while preserving options. The companies that manage this feat in the coming years will be the ones that lead the way in industrial automation.

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