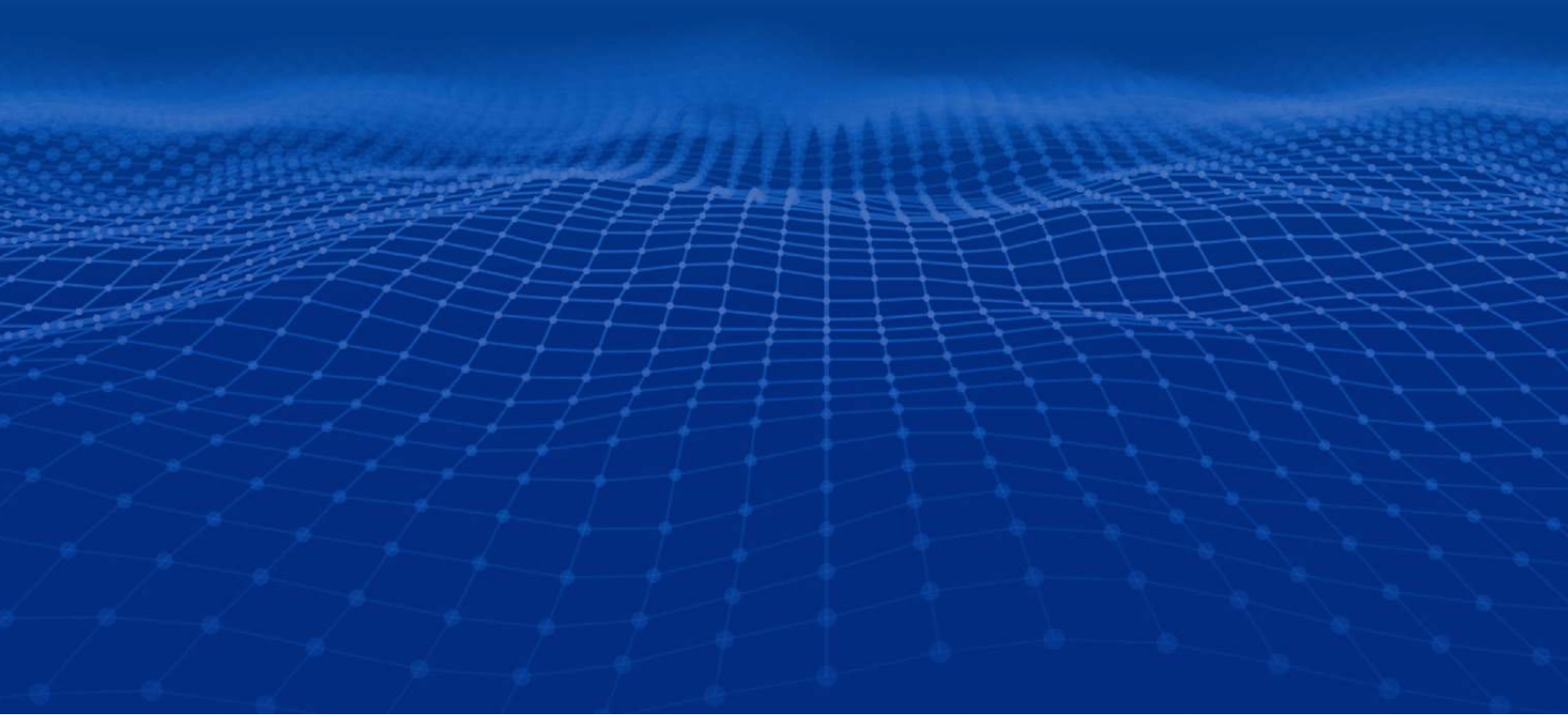
Manufacturing Leadership Council

WHITE PAPER

THE NEXT PHASE OF DIGITAL EVOLUTION

MANUFACTURING IN 2030 PROJECT



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Introduction

In the spring of 2021, the Manufacturing Leadership Council, a division of the National Association of Manufacturers, launched its Manufacturing in 2030 Project. The project's main goal is to enable manufacturers to envision what manufacturing might look like by the year 2030.

Realizing this goal entails thinking broadly about the context in which manufacturing will operate in the decade ahead, including the population, demographic, and economic trends that will shape the industry. In addition, it entails understanding the direction and velocity of technological trends associated with Manufacturing 4.0, the industry's transition to the digital model of manufacturing. Perhaps most importantly, it entails identifying and understanding the challenges that all will face as the industry moves to the next stage of Manufacturing 4.0.

Armed with these understandings, manufacturers can better plan their longer term future and find ways to enhance their value, competitiveness, and contribution to society.

This research paper is therefore part of the Manufacturing in 2030 Project. The paper consists of three major parts – an examination of Megatrends affecting the industry; Industry Trends and Themes, including major technologies such as artificial intelligence; and Decision Points on the Road Ahead, including key questions that the industry needs to address in the future.

The MLC team wishes to thank its M2030 Project partners – EY, Infor, NTT DATA, and West Monroe – for their support of the Project and for their invaluable feedback on the white paper. In addition, the MLC thanks members of its Board of Governors for their review and feedback on the paper.

Executive Summary

Looking back over the last decade, it is undisputedly evident that the manufacturing industry has been through one of the most significant periods of radical change in its 300-year-old history.

Many of today's factories are almost unrecognizable compared to just 10 years ago. Today they are extensively automated, pervasively networked, constantly monitored and analyzed, flooded with data, and staffed by a workforce increasingly empowered by new digital tools. The manufacturing enterprises that manage those production facilities have also changed, with front line and management decisions more data driven, product lines smarter and invisibly connected, traditional corporate silos broken down and replaced with flatter, more collaborative organizational structures, and one-time hierarchical, monolithic entities being replaced by more federalized, distributed, and agile value-chain ecosystems.

Imagine then, what changes may still be ahead for the industry as it approaches 2030.

Many key trends are already underway that are set to shift almost every manufacturing company's market and operational focus in the immediate years ahead, influencing a host of decisions as they seek to grow, from where to make factory and plant investments, to what kinds of products to make, who to sell to, how to organize supply chains, and who they hire.

Future population growth in many industrialized countries, for example, manufacturing's traditional markets, is forecast to continue slowing down in coming years. Middle class populations with purchasing power in the U.S., Eurozone, and Japan are only expected to expand at around 0.5 percent by 2030, compared to a substantial expansion of six percent or more in China and India. By then, those two countries will also represent two thirds of the world's population and 59% of middle-class consumption. Predicted growth rates for Africa are even higher, producing half of global population growth by 2050 and 88% of the next billion entrants into the global middle class.

While this suggests new global markets will open up for manufacturers and their products by 2030, it doesn't necessarily mean that manufacturing power centers will shift correspondingly. Investment trends in advanced skill development, innovation, and digital infrastructure will also play an important role in determining where those centers reside.

Certainly, predicted developments in some of the key technologies underpinning the accelerating industrial digitization trend offer vast opportunities for both existing and new manufacturers to achieve greater efficiency, productivity, and increase global competitive differentiation over the coming decade. With a predicted trillion transistors on semiconductor chips by 2030, data volumes exploding between 200-500% in the next few years, quantum and nano-computing vastly increasing processing speeds, upcoming 6G networks supporting data rates of a terabyte a second, and increasingly advanced AI systems turning all that data into meaningful analytical insights in ever-more engaging visual ways, manufacturing's potential to use these increasingly

powerful digital tools to improve business outcomes is enormous.

The importance of doing so in ever more sustainable ways will also become a fundamental driver that will determine competitive success over the decade ahead. A significant majority of senior manufacturing executives already recognize that the industry has a special responsibility to become more sustainable in the future and needs to transition swiftly to a more circular economy where materials, production processes, energy usage, and product lifecycles all adhere to more sustainable codes of conduct. Again, the power of digital technologies will be instrumental in their ability to achieve this future state and help them enhance their corporate reputations, meet rising customer, employee, and investor expectations, and comply with the increasing number of global regulations the next few years will bring.

The impact on the future manufacturing workforce of these combined future trends, of course, is likely to be profound. New skills and roles will be needed to apply, operate, manage, and benefit from these new tools. New approaches to redefining human machine relationships will be needed for employees at all levels to best leverage advanced technologies for both personal and company improvement. And leadership teams will need to develop more digital acumen as they strive to master the vast amounts of data that will be available and harness the exponentially increasing digital power at their fingertips to create fruitful new business models and engaging customer experiences.

Manufacturers have already learned many valuable lessons over the last decade to help them successfully digitally transform their businesses in the years ahead – focus on the value case not the technology, connect everything and collaborate with everyone, reduce complexity, empower the workforce, prioritize innovation and agility at scale, and build a broad, rapidly responsive, inclusive, and unified ecosystem. These lessons will need to be applied with ever greater vigor in the years to 2030.

There will be many significant challenges along the way, however. Unpredictable disruptions, whether caused by global economic and political factors, weather events, cyber criminals, pandemics, or many other factors, will be inevitable, so the lessons learned from recent events over the last few years must now be used to help manufacturing companies better prepare for future disruptions with ever higher levels of agility and resiliency.

This future journey to 2030 will also raise some broader, more fundamental decision points for the industry to address as it approaches 2030 - from understanding more about how humans and machines will work together effectively, to the best ways of mastering the vast tsunami of data the next few years will release, to what to fully automate and what not, to the ethical rules that may be needed to govern advanced intelligent systems like AI, to reconciling national needs and globalization in an ever changing world.

“Many key trends are already underway that are set to shift almost every manufacturing company’s market and operational focus in the immediate years ahead.”

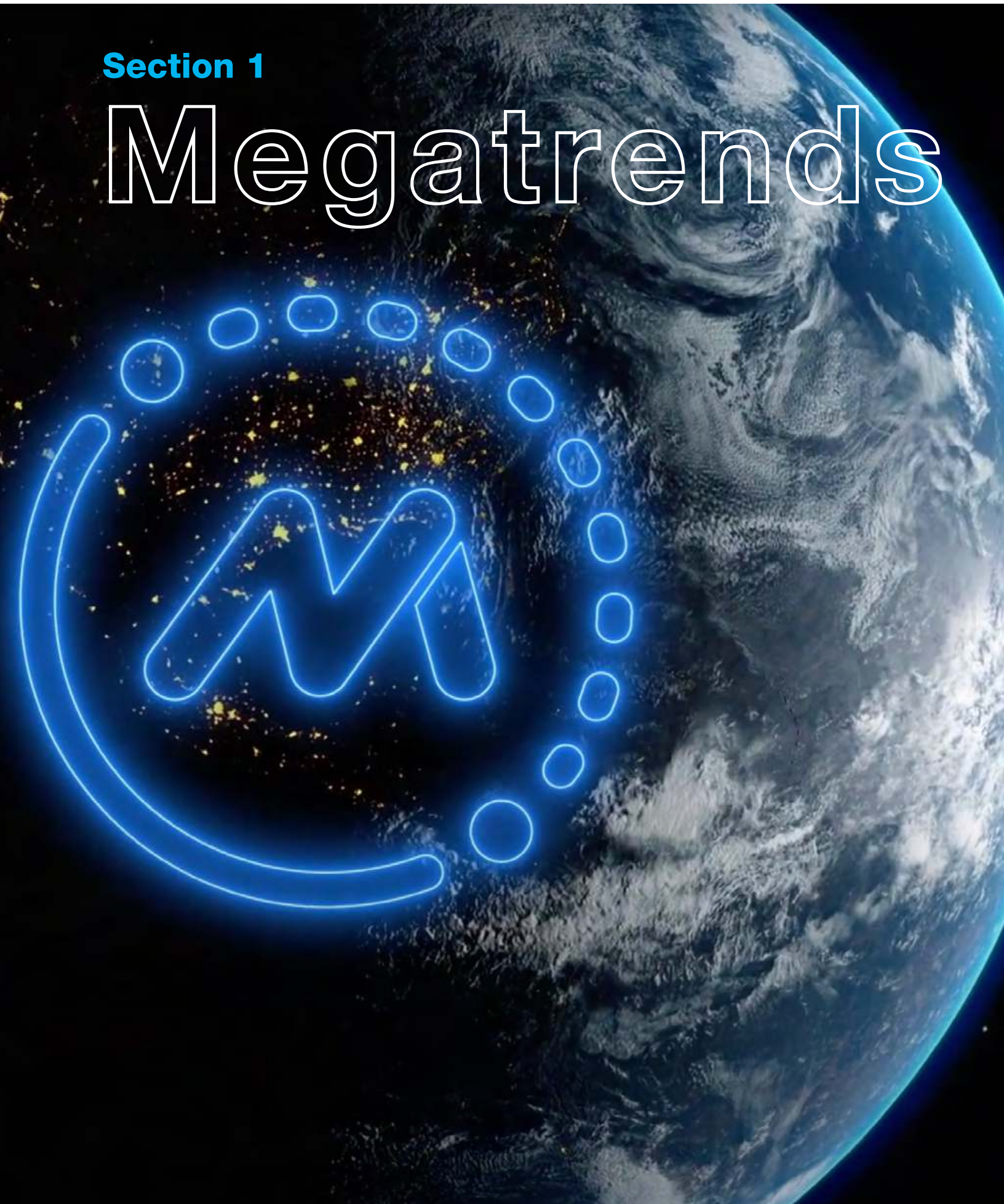
One thing of which we can all be certain. Manufacturing in 2030 will be different. It will be more efficient, more innovative, and more responsive to customers’ needs. It will produce better products, for more people, in more sustainable ways. And it will be more rewarding for employees, for leadership teams, and for stakeholders of all kinds.

But it will take informed visions, open minds, enlightened leadership, and dedicated execution to get us there.

To put a positive spin on a reputedly old Chinese proverb: May you live in interesting times.

Section 1

Megatrends



CHAPTER ONE

FOLLOW THE BABIES

In the next 10 years and beyond, population trends – which regions and countries will experience the greatest growth and which will not – will be a major influence on a host of decisions manufacturers will make as they seek to grow, including where to make factory and plant investments, what kinds of products to make, who to sell to, how to organize supply chains, and who they hire.

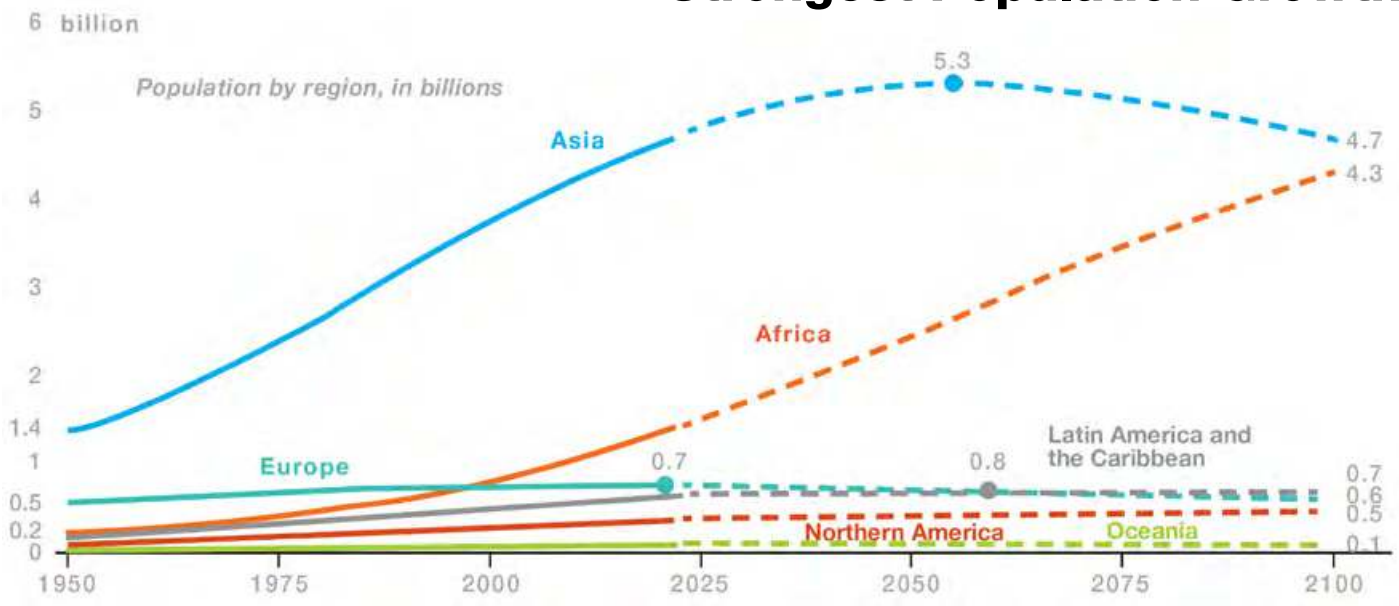
Absent another global pandemic or some other global disruption in the years ahead, total world population is expected to reach 8.6 billion in 2030, compared with 7.7 billion today, and is expected to grow to 9.7 billion in 2050 and 11.2 billion by 2100. Based on the current population total, 61% of the world's people live in Asia, 17% live in Africa, 10% are in Europe, eight percent are in Latin America and the Caribbean, and the remaining five percent are in North America and Oceania.

China and India are the two most populous countries, with 1.44 billion and 1.39 billion people, respectively. By 2027, India is projected to overtake China as the world's most populous country.

More than half of global population growth between now and 2050 is expected to occur in Africa. The populations of 55 countries, including many in Europe, are expected to decrease by 2050. Fertility

FIGURE 1

Africa, Asia Will Have Strongest Population Growth



Note: Data labels show projected peak population for each region: Europe (2021), Asia (2055) and Latin America and the Caribbean (2058).
Regions follow United Nations definitions and may differ from other Pew Research Center reports.
Source: United Nations Department of Economic and Social Affairs, Population Devision, "World Population Prospects 2019."

Source: Pew Research Center

in all European countries is below the level required for full replacement of the population in the long run.

In the United States, the population is expected to rise to 355.1 million by 2030, compared with 332.6 million in 2020. U.S. population grew a scant 0.1% in 2021, a rate slower than in any year since the founding of the country. The fertility rate that year was 1.8 per woman.

The U.S. Census Bureau says that the year 2030 will mark "a demographic turning point" for the country when all baby boomers will be older than 65. By 2034, the Bureau projects that older adults will outnumber children for the first time in U.S. history. And by 2030, because of population ageing, immigration is expected to overtake natural increase (the excess of births over deaths) as the primary driver of population growth in the U.S.

"By 2030, it is projected that the global middle class will number 5.3 billion people, compared to 1.7 billion in 2020."

For manufacturers, the sweet spot in the population and demographic trends will be where middle classes, the working population and their purchasing power, will grow most significantly.

By 2030, it is projected that the global middle class, which is generally defined as adults whose assets amount to between $10,000 to $100,000, will number 5.3 billion people, compared to 1.7 billion in 2020, with 88% of the next billion entrants into the middle class coming from Africa. By contrast, the middle-class market in the U.S., the Eurozone, and Japan is expected to grow at only 0.5% per year, compared with annual growth of six percent or more in China and India.

› CHAPTER TWO

FOLLOW THE MONEY

The world appears to be on an economic growth trajectory that will provide significant opportunities for manufacturers that are positioned to take advantage of them.

Research conducted before the rise of current inflationary pressures indicates that global GDP in 2022 is expected for the first time to pass $100 trillion. By 2035, in the space of only 13 years, that number could double. By comparison, global growth doubled between 1970 and 2016, when measured in GDP per capita. The five largest economies at present are the U.S., with an estimated GDP of $24 trillion at the end of 2021; China with $18.4 trillion; Japan with $5.3 trillion; Germany with $4.5 trillion; and the United Kingdom with $3.4 trillion.

But by 2030, a seismic shift is predicted to occur. That year, China is expected to become the world's largest economy, overtaking the U.S., whose own GDP will grow to $32 trillion but not at a rate that will prevent China, which passed the U.S. as the world's largest manufacturer in 2010, from taking the top economic slot.

Translating these numbers into middle-class spending, the years ahead will see a significant increase in the purchasing power of this group. This will represent a large jump in the number of potential consumers for manufactured goods, presenting a sizable opportunity for manufacturers in the U.S. even as global competition escalates.

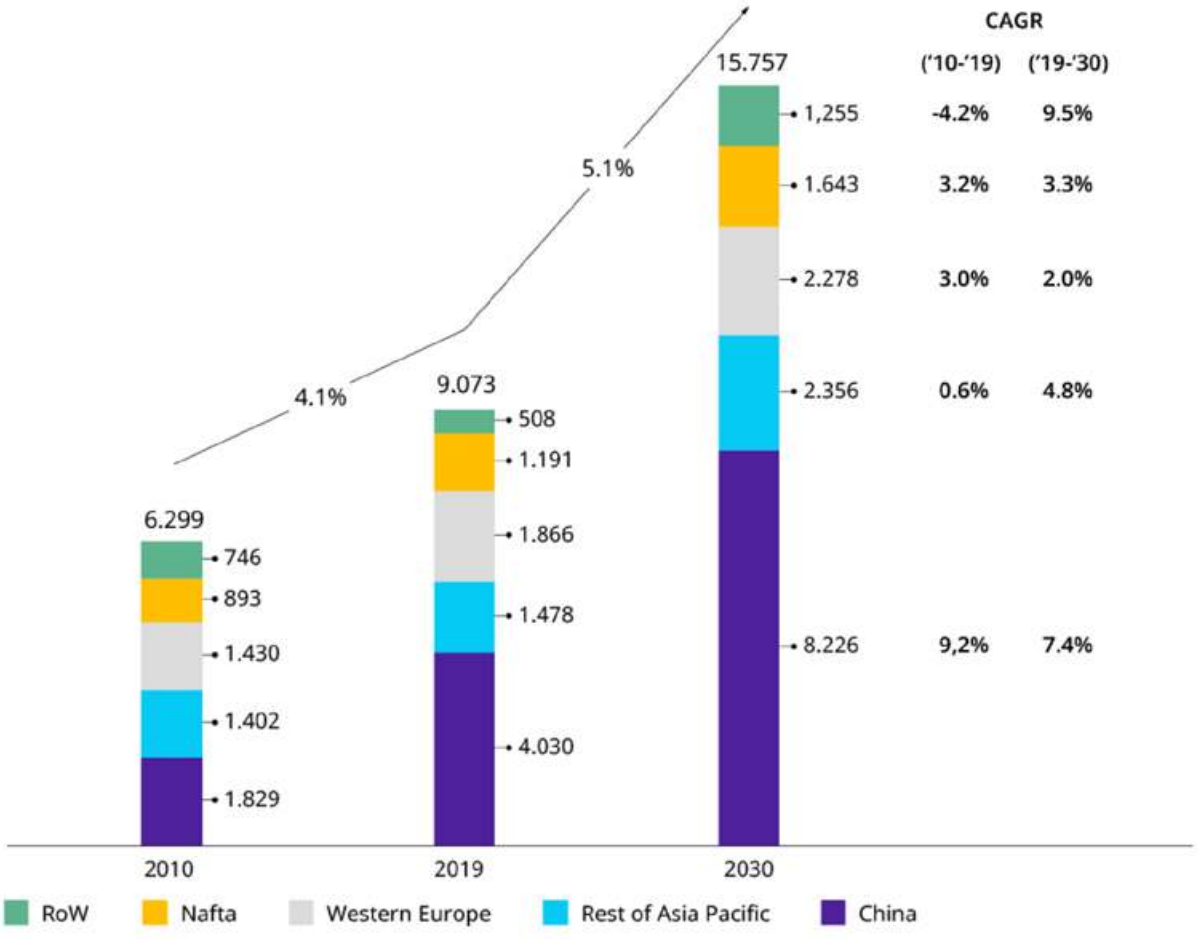
The global middle class is already spending an estimated $35 trillion annually. An additional $29 trillion is projected to be spent by 2030, which would represent roughly one-third of projected GDP growth over that period.

By 2030, some studies show that more than 70% of China's population could be in the middle class category and would be consuming nearly $10 trillion in goods and services, but India could end up being the largest middle class consumer market, surpassing both China and the U.S. in

FIGURE 2

Past and Future Growth of Industrial Goods Sector

Exhibit 1: Past and future growth of industrial goods sector
Global Industrial Goods Output (Sales)[1] in $US BN



1. Engineering & Metal Goods (NACE: 25, 27, 28): Fabricated metal products, electrical equipment, machinery and equipment n.e.c.

Source: Oxford Economics

Country Ranking by Foreign Direct Investment (FDI)

When companies seek to utilize manufacturing assets as a means of creating shareholder value they typically pursue opportunities to place operations in countries that generate revenue for the business, improve operating margin by reducing structural operating costs, or both. Over the last five years, the countries receiving the most foreign direct investment in the world, both in terms of capital investment dollars and job creation, were China, the US, India, the UK, Mexico, Vietnam and Brazil.

Given these countries have been consistent recipients of significant levels of FDI, it is not expected the leaders in this category of global performance will change. The world ranking of countries on the measures of FDI typically improve or decline by many positions vis-à-vis competing countries. Only in a limited number of occasions do countries make significant gains or falls in the ranking versus their competitors.

Most often a country is able to climb one to four positions in the ranking in any given industry, with only a moderate number of exceptions. When there was an exception to the trend, data suggests it was when a country makes a very concerted effort to invest in a particular industry, there was a global shift in resource needs, or there was either political turbulence or recovery that stimulated a notable change in foreign direct investment behavior.

– By Jones Lang LaSalle Inc.

size.

By 2030, however, China and India will represent roughly two-thirds of the global middle-class population and 59% of middle-class consumption that is expected to amount to $64 trillion that year.

Economic growth and middle-class expansion doesn't necessarily mean, however, that manufacturing power centers will shift correspondingly. Investment trends in advanced skill development, innovation, and digital infrastructure will perhaps play even more important roles in determining where those centers reside.

As a result, advantages that developing countries may have in low-skill, low labor cost production may not persist as routine, low skill tasks are increasingly automated. Because of advanced technologies, the capital intensity of production is rising, presenting opportunities to countries that are actively investing in modern infrastructure and the skills required to manage it.

Right now, the U.S., Europe, and East Asia are making the largest investments in Manufacturing 4.0 technological innovations, including robotics, thereby raising the prospect of further concentration of manufacturing in these regions.

MLC's research in Transformative Technologies offers some hope that these investment inclinations will continue for the foreseeable future. In a study published at the end of 2021, manufacturers in the U.S. indicated strong spending intentions for information, operational, and communications technologies – such as 5G networking, artificial intelligence software, and collaborative robotic systems -- in the years ahead.

What the population, demographic, and economic trends suggest is that even though such growth will benefit developing regions more than established economies, current manufacturing power centers do indeed have the opportunity to continue to lead if they make the right investments in people, operational processes and digital infrastructure, with an innovation mindset that will optimize operations and enable the development of new business models. These are the factors that will define much of the competition in the race to 2030.

› CHAPTER THREE

RIDE THE POWER CURVE

The foundations of manufacturing digitization, which makes data a key asset from unit operations and machine tools to supply chains to manufacturing ecosystems, rests on five technological cornerstones: electronics, computer systems, software, communications technologies, and cyberinfrastructure. Taken together, developments in these technologies over the next decade and beyond will enable advances in human-machine interaction, automation and robotics, and autonomous operation.

These advances will stimulate process and product improvements, new business opportunities, new pathways to environmental sustainability, and new methods of innovation related to how manufacturing is performed. Potential gains for manufacturers stem from the economics of productivity, precision, performance, innovation, and speed extended from the factory floor to supply chains and manufacturing ecosystems – in a few words, creating conditions for greater competitiveness, sustainability, and the creation of technology-enabled jobs.

Predictions on how these technologies will advance in the years ahead and what they may be capable of doing are, to put it simply, awe-inspiring, and have led to predictions of significant market growth for the tools that power digitization. According to Allied Market Research, the global digital manufacturing market is expected to reach $1,370.3 billion by 2030, from $276.5 billion in 2020, registering a CAGR of 16.5% from 2021 to 2030.

Moreover, the pace of implementation may be accomplished in timeframes shorter than previous generations of technologies. For example, the digitization of manufacturing, involving the transformation to digital forms of data and operating systems, has been going on for 40 years. The time between the invention of the internet and its implementation with scaled communications technologies and cyber infrastructure is generally thought to have

“The global digital manufacturing market is expected to reach $1,370.3 billion by 2030, up from $276.5 billion in 2020.”

been about 20 years. In this same 20-year period, there has been a concomitant explosion of pervasive capacity for data management and computation, accelerated by recent events.

In the next 10 years, the technological foundations of digitization will progress, perhaps exponentially. At the electronics level, the performance curve expected for the semiconductors that power so much of industrial operations today is usually discussed within the context of Moore's Law, named for Intel co-founder Gordon Moore, who predicted in 1965 that the number of transistors on a chip would double roughly every two years, with corresponding price improvements.

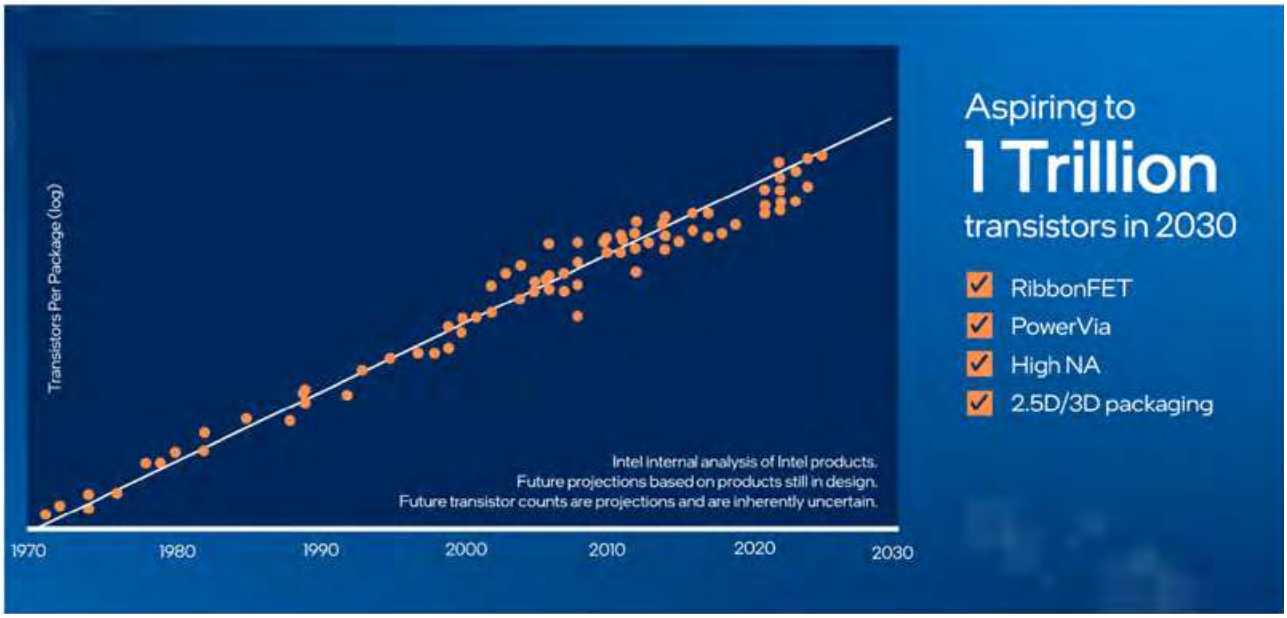
Although some have theorized that Moore's Law will eventually encounter an expiration date, Intel is confident that the price/performance improvements posited by Moore will continue, and is projecting that by the year 2030, it will be able to incorporate one trillion transistors on a single chip.

This kind of power will be necessary to enable computer systems and software to take advantage of and process the exponentially larger data volumes manufacturers expect as they continue to connect and network more and more physical objects such as plant equipment as well as people in their companies and business eco-systems.

MLC research shines a light on the scope of this challenge. In a study by MLC in 2020, manufacturers said they expected their manufacturing data volumes to balloon by 200% to 500% within just a few years. Looking ahead to the rest of de-

FIGURE 3

Intel Foresees 1 Trillion Transistors on a Chip by 2030



Source: Intel

cade, there is every reason to expect that growth in data volumes will only continue and will therefore require increasingly more powerful systems to process and analyze that data.

As the semiconductor industry packs more power into its wares, computer systems builders will continue to progress and innovate as well. Manufacturers should expect a changing computer landscape as biological, physical, and digital systems converge to offer more options. Quantum computing and nano-computing are two developments that manufacturers should watch carefully for their potentially greater computational ability that will allow manufacturers to process more data faster. In the meantime, traditional computers will become lighter, thinner, and more flexible, and non-keyboard interfaces, such as voice recognition, will progress.

In communication technologies, the years ahead will see manufacturers adopt 5G-based networks, which offer higher bandwidth and lower latency than prior generations of cellular technology, at a fairly strong rate. MLC's Transformative Technologies study indicates that almost 27% of manufacturers currently are investing in 5G, with 52% saying they are actively planning investments or are considering investments in the near term. These investments, of course, will have implications, according to other studies. In one, 80% of manufacturing survey respondents said that successful 5G-IoT implementations will require a significant overhaul of their organizations' operating model over the next five years.

As these changes occur, communications technology suppliers are hard at work at the next generation of cellular technology – 6G. Expected to become commercially available in 2030, 6G, which will purportedly support data rates of one terabyte per second, is expected to facilitate improvements in imaging, presence technology, and location awareness. It is also expected that 6G will work in conjunction with AI to determine the best location for computing to occur, including where to store data.

A raft of advances will also take place in the realm of software. Next generation applications, in addition to web and mobile capabilities, will support voice, wearables, touch, and AR/VR to an extent greater than ever before. And those applications will be increasingly AI-driven. To speed innovation, open source, network discoverable software, and data sets will need to become more accepted and widespread.

> **“ Manufacturers expect their manufacturing data volumes to balloon by 200% to 500% within just a few years. ”**

The choice of enterprise software architectures and how cyber infrastructure is used will increasingly become a strategic decision for manufacturers. Cyber infrastructure, which has been in development for the past 20 years, provides the ability to think about computer and

data resources separately from the physical source and use of the data. Cloud is a prominent capability. Architectures that marry on-premise and cloud capabilities with business and technology tools will facilitate the needed data, drive innovation capabilities, determine the economies of research and development, and influence operating models and the ability to grow a company's business.

"Perhaps the most potentially significant technology for manufacturing's future is artificial intelligence."

The Boston Consulting Group predicts that the future of software architectures will be "hyperplexed" as they support many widely distributed software applications, different types of devices, and new user experiences and interfaces.

But perhaps the most potentially significant technology for manufacturing's future is artificial intelligence. AI, considered by MLC to be a pervasive technology, will increasingly be found in many types of applications and systems involved in manufacturing, from software applications used on the factory floor, to robotic systems used to help assemble products as well as move materials, to systems used in design, simulation, customer interactions, supply chain, and logistics, and many others. AI is pervasive in its possibility to find, learn, and predict.

In manufacturing, AI refers to software systems that can recognize, simulate, predict, and optimize situations, operating conditions, and material properties for human and machine action. The power of AI comes from learning from the data that embeds the expertise of an operation. The learning process is a cycle of using the data to build a model, using the model to better run the operation, using better operations to generate more effective data, and using the new data to build an updated model; in other words, a virtuous cycle.

AI experts in academic, industry, and governmental study groups are currently assessing the different roles for AI and what it will take to accelerate industry adoption. Three monetization priorities have been identified with three kinds of AI applications and data sets: (1) asset management on the factory floor, (2) interoperability among assets within factories and supply chains, and (3) intercompany interaction for supply chain resilience.

Factory floor asset management is a monetization progression that addresses supply chain complexities production planning challenges, energy or material consumption costs, preventive and predictive maintenance to reduce equipment downtime and increase operational uptime, and the ability to optimize quality during production execution.

- Asset Management depends on a brokerage of industry data, domain knowledge, and application sharing to build software models for factory unit operations, but most individual manu-

facturers today do not have access to sufficient meaningful data to provide actionable insights.

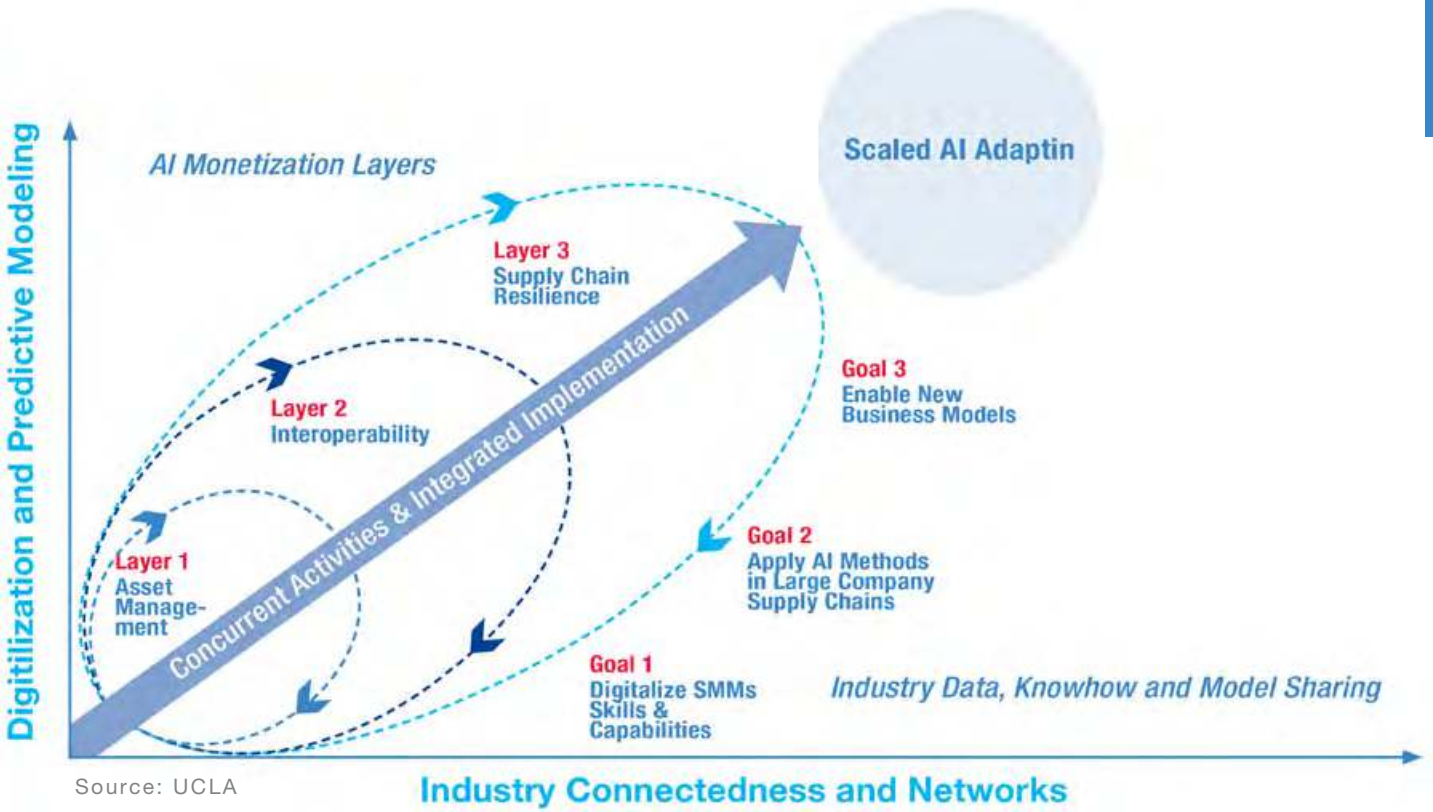
- Interoperability extends asset management by connecting operating assets within factories and across supply chains for greater operational productivity and performance of line operations by monetizing data interconnectedness within existing business models and providing a platform for innovation, through new business models creation, including products-as-service.
- Supply Chain Resilience depends on the visibility and analysis of shared business data that exposes capacity and capability data for greater supply chain responsiveness when faced with disruption.

It is with industry supply chain and ecosystem applications that industry-wide strategies for product safety, environmental sustainability, decarbonization, reductions in GHG emissions, and reductions in energy consumption can be measured, managed, and optimized.

While these layers of monetization build on each other, there is already significant AI work and benefit to be found in each layer across the industry. However, this work is heavily oriented toward those companies that have the resources to build the skills and do the development work. The industry can certainly expect to see signifi-

FIGURE 4

AI Monetization Layers



Source: UCLA

cantly greater AI impact over the next 10 years for those companies that can afford to invest in data and sustain application development. And, of course, the key to successful application development will be whether the right data – meaningful data – can be pulled together to make AI powerful for particular applications that can drive true business benefit.

“If industry can learn to scale data and capability in the years ahead, AI will dramatically increase opportunity within, between, and among companies.”

However, the impact could end up blunted unless industry can shift current practices to scale data and AI applications. A key question looking ahead to 2030 is whether AI benefits will accrue for an elite few or whether its opportunities can become industry-wide capabilities for small and medium manufacturers as well as large so that supply chains and ecosystems benefit and sustainability strategies can be managed throughout the industry.

As this question is considered, operational technology and business technology performance tools to preserve privacy and security need to be integrated and constructed simultaneously for each form of data sharing. All of these tools depend on carefully building and managing trust within both business collaborations and people and machine interactions. For each manufacturer, business and operating tools, the forms of business exchange, and building skills through training and education all need to align and integrate at the pace of trust and risk maturity.

If industry can learn to scale data and capability in the years ahead, AI will dramatically increase opportunity within, between, and among companies, potentially enabling participants to improve operations, including supply chain operations, to foster greater resiliency.

Perhaps most significant, however, is the potential for AI to benefit from and create what are called “network effects” – the discovery of new business opportunities by analyzing shared data, assuming that security and privacy needs can be met by business ecosystem partners. This is AI used to discover and facilitate AI applications.

What is shaping up is that AI will unleash many opportunities for manufacturers to create greater efficiencies, collaborations, and potentially new business opportunities in the years ahead – if issues around data sharing, IP protection, and know-how are met.

› CHAPTER FOUR
PROTECT THE PLANET

Compelling research clearly shows that the next few years will be critical to mankind’s ability to reduce, if not reverse, the rate of emissions of greenhouse gasses that are rapidly warming the planet with potentially devastating results.

Global surface temperatures had al-

ready reached 1.1 degrees centigrade higher in the decade between 2011-2020 than in the early industrial era between 1850-1900. The past five years, however, have been the hottest on record and by 2020, the combined heating influence of all human-produced greenhouse gases was 47 percent higher than it was in 1990. That trend will only get worse as humanity continues to emit an estimated 40+ billion additional tons of CO2 every year.

At that rate, warn the projections, global warming will be in danger of reaching two degrees higher by 2030 unless urgent action is taken to curb the trend.

The consequences of such a rapid temperature rise could be disastrous for the future of mankind, initiating irreversible global changes in extreme weather events, rising sea levels, famines, population displacement, economic collapse, and the prospect of increasing conflicts as countries battle to manage the impacts.

It's undoubtably the most important existential threat the modern world has ever faced. As U.N. Secretary General António Guterres warned after the publication of its latest Intergovernmental Panel on Climate Change (IPCC) report in August 2021 prior to the gathering of world leaders at the COP26 climate change summit in the U.K, the report's findings marked a "code red for humanity."

Scientists and world leaders alike now agree that the world must find ways to urgently reduce that trend by limiting global warming as close as possible to 1.5 degrees by 2030, and, at the latest, by 2050.

The world's industrial and manufacturing companies have a pivotal role to play in that global effort. Industrial activity currently accounts for around a quarter of all greenhouse gas emissions worldwide, mostly from energy usage. Those emissions have been growing faster since 2000 than in any other sector, driven by increased basic materials extraction and rising levels of production.

The urgency for sustainable industrial change is now clear and present – and there's a lot at stake. Unless manufacturing leaders adopt demonstrably more sustainable approaches for their companies by 2030, their businesses may be at risk of reputational and commercial damage.

Over the last few years, intense pressure from customers, financiers, employees, regulators, governments, and public opinion for industrial companies to declare Net Zero targets, pursue more circular economy practices, and become more openly environmentally responsible has risen exponentially. For example, a burgeoning number of institutional investors around the world are placing greater emphasis on ESG performance in their decision-making and 74% are now more likely to divest from companies with poor ESG track

"The urgency for sustainable industrial change is now clear and present – and there's a lot at stake."

records.

These pressures will only magnify further in the decade ahead.

There is already clear recognition of the need for more environmentally responsible practices among manufacturing leaders themselves. MLC research in December 2021 showed that 87% of senior level respondents agreed that the manufacturing industry has a "special responsibility" to society to become more sustainable and

"Shifting to a green economy could yield a direct economic gain of $26 trillion through 2030 compared with business-as-usual."

accelerate the transition to a future circular industrial economy.

They also cited improving their company's environmental reputation among customers and investors as their top motivation for adopting more sustainable practices, and almost three quarters believe that sustainability transformation is now either essential, or increasingly important, to the future competitiveness and growth of the companies they work for.

This suggests any industrial leaders who still argue that the costs of change prevent sustainable progress may need to consider what the costs of not doing so will mean for their businesses in the years ahead – from irreversible reputational damage to drastically reduced commercial competitiveness.

Taking urgent action, however, by using materials more efficiently, reusing and recycling products, transitioning to renewable energies, and minimizing waste could have lasting benefits, not only for individual companies but for the global economy as a whole.

The 2021 IPCC report noted that if the world can act fast in the decade ahead to reduce emission by half by 2030, and reach Net Zero by 2050, there is every chance the rise in global temperatures can be halted, possibly even reversed. What's more, shifting to a green economy could yield a direct economic gain of $26 trillion through 2030 compared with business-as-usual, and produce over 65 million new low-carbon jobs.

The manufacturing industry's role in creating a cleaner and healthier planet for the future and helping to generate such significant environmentally driven economic gains along the way now lies in the hands of the enlightened leaders who are prepared to turn today's sustainability promises into direct strategic action in the years ahead. The future of their businesses will depend on it.

› CHAPTER FIVE
RETHINK WORK

Of all the disruptions brought about by the COVID-19 pandemic, the one that has perhaps the longest reach is that of the workplace.

Job losses came at a historic level and affected nearly every industry. According to the Bureau of Labor Statistics, there

were 9.4 million jobs lost in 2020, the largest calendar-year decline it had ever recorded. But as business stabilized, companies then found themselves battling the impact of the 2021 Great Resignation – where 47.8 million U.S. workers voluntarily left their jobs – and facing steep competition for new hires. Manufacturers had nearly one million unfilled openings at the end of 2021, and it has been projected that number could skyrocket to 2.1 million by 2030. However, workforce composition is likely to shift by then due to increased digitization and changing roles.

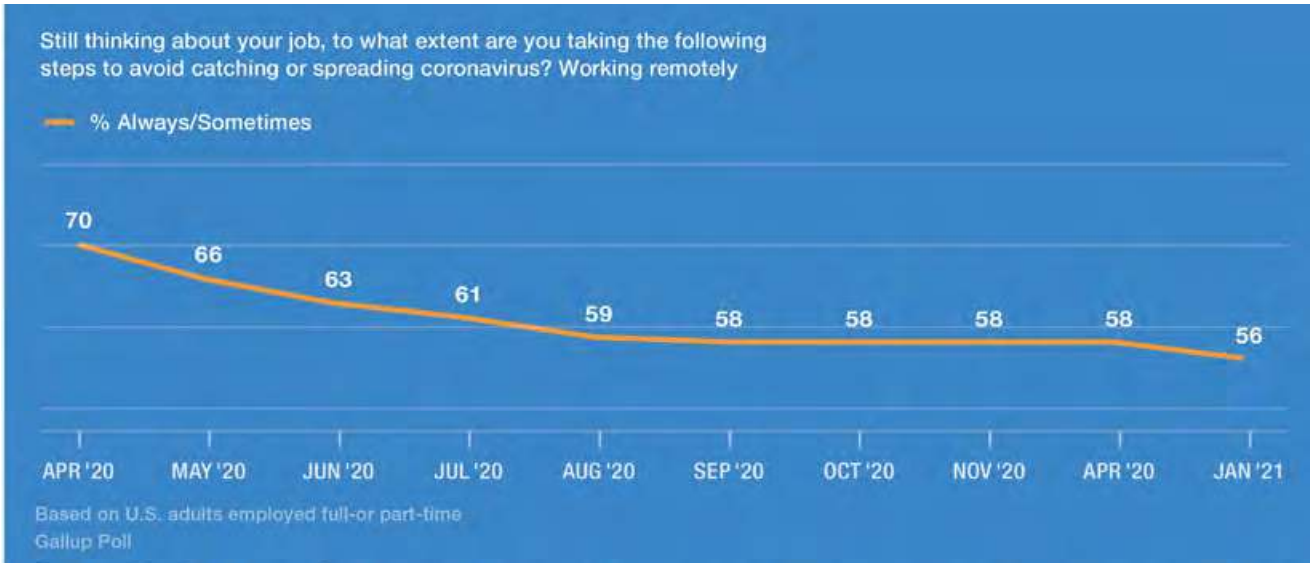
What has become clear is that workers are going into the future with much different expectations of work than the previous norm, and companies that ignore this do so at their own peril. No longer are workers willing to tolerate poor management, mediocre working conditions, or a lack of work-life balance. There is a new demand for flexibility, be it in location or in work hours. Moreover, many companies are taking

FIGURE 5

Predicted Manufacturing Job Openings by 2030

FIGURE 6

Employed U.S. Adults Working Remotely "Always" or "Sometimes"



a hard look at their diversity, equity, and inclusion practices as they strive to build a more representative workplace.

Concurrently, technology can be a driver of this better future for the emerging re-defined workplace. While some futurist visions have predicted factories run almost entirely through automation, there are many reasons to believe that humans will still have a prominent place in manufacturing. While algorithms and machines will be focused on data analysis and certain repetitive, high-risk manual tasks, humans are expected to continue with decision-making, interacting, managing, and communicating.

Remote work offers many potential advantages, including lower operating costs, increased working hours, decreased carbon footprint, better work/life balance, and a benefit in attracting talent. Post-pandemic, it is expected that nearly half of employees will work remotely at least some of the time. While physical production creates a unique challenge for manufacturers vs. digital-first industries, its presence is growing in many factories for the purposes of monitoring production status, tracking machine health, and collaborating with workers in other locations.

It's been said that up to 65% of the job roles that will exist in 2030 don't yet exist today. As alarming as that sounds, consider that 63% of jobs done in 2018 did not exist in 1940, according to the U.S. census. Many new manufacturing jobs will merely be an evolution of those that exist today – augmented by connected machines, AI, and advanced analytics.

And many of the emerging job titles and roles may sound strange to manufacturers. According to research published by MLC in 2017, it was estimated that 165 new digitally oriented job roles would emerge in

manufacturing in the years ahead. Some of these titles were: Lifecycle Digital Twin Architect, Digital Thread Engineer, Data Management Analyst, and Digital Ethicist.

What this means for manufacturers is that HR recruitment and retention strategies will have to undergo substantial change as these new roles and functions begin to be understood and implemented.

› CHAPTER FIVE

CONNECT EVERYTHING

Andrew S. Grove, the late CEO of Intel Corp., was a fountain of both technological and managerial wisdom. One of his sayings was that if something is technologically possible, what the technology makes possible will happen. In other words, what Grove suggested was a kind of technological inevitability.

When it comes to connecting things electronically, Grove's observation is very much in play. Because it is technologically feasible to place sensors in many types of equipment and then connect them using communications networks that transmit data about that equipment, companies indeed do so, and the practice eventually becomes widespread. As experience is gained, a higher degree of knowledge about the equipment can be achieved, potentially leading to greater efficiencies.

More than 20 years ago, Kevin Ashton, a keen observer of technological inevitability, coined the phrase "The Internet of Things."

FIGURE 7

The IoT Market Could Reach $200 Billion by 2030

Source: Prescient Strategic Intelligence

Ashton, co-founder of the Auto-ID Laboratory at MIT, used the phrase to describe a system where the Internet is connected to the physical world via ubiquitous sensors. As industrial companies such as GE and Siemens got behind the idea of an Industrial Internet of Things, which goes beyond machine-to-machine connectivity to include human beings, the IIoT market took off in the mid-2010s.

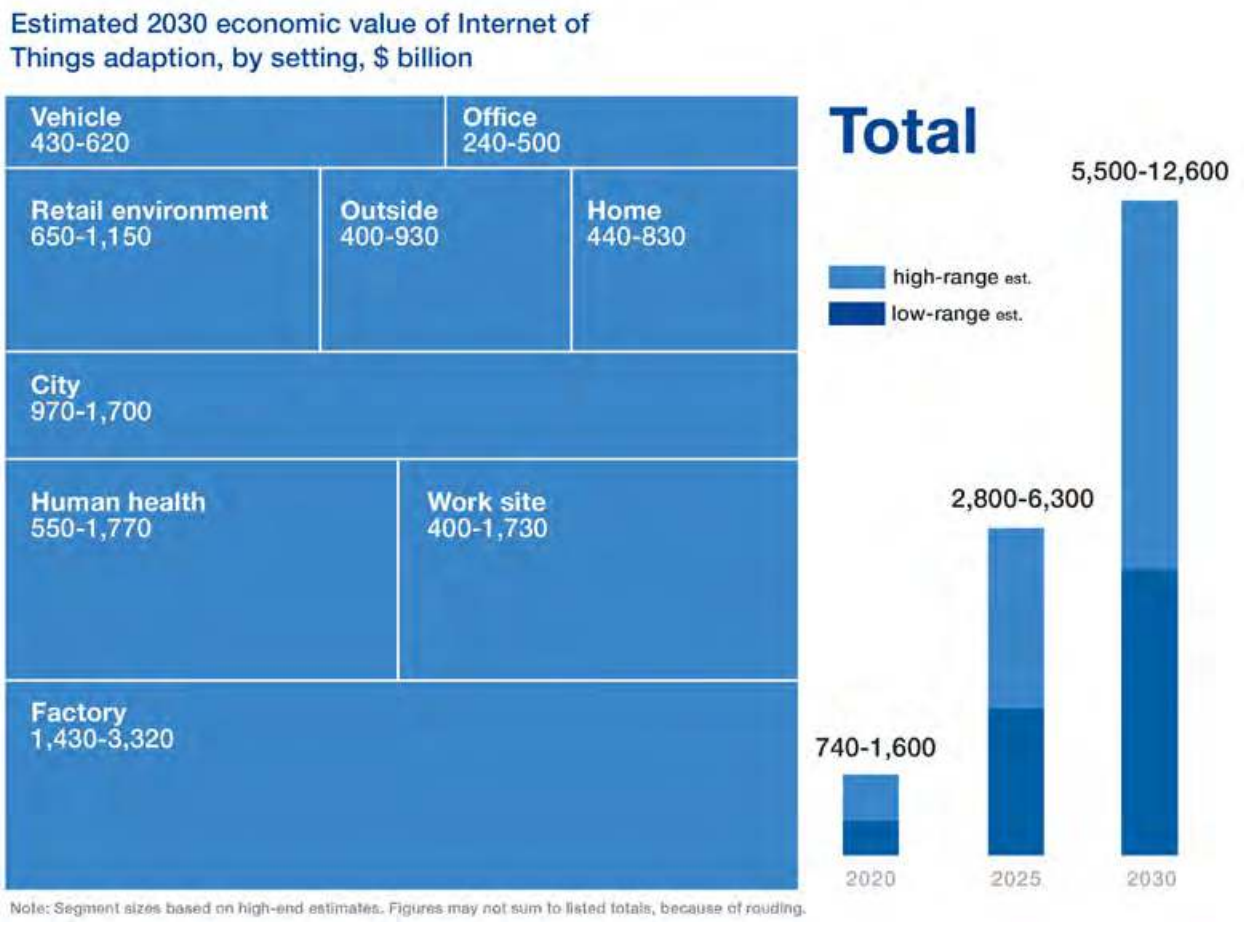
Today, the IoT market in manufacturing is large and growing by double digits. Depending on how it is measured and what is included, various studies indicate the market size anywhere from about $60 billion to nearly $200 billion in 2020-2021, with growth rates ranging from nearly 14% to more than 22% up to 2030.

Regardless of the measurement scheme, the trend is inexorable – more and more physical objects and people are and will be connected in the years ahead, generating huge volumes of data that will increasingly be stored in the cloud and analyzed with the help of AI.

The phenomenon of connecting every-

FIGURE 8

The Economic Value Potential of IoT



Source: McKinsey & Company

thing will happen through a combination of device capability and deployment (IoT), software to analyze data (AI), and the network capacity to move data (5G, 6G). A future wave of IoT applications will be based upon intuitive, human-to-machine interactivity. What some are calling "Human 4.0" will allow people and machines to interact in real time over great distances and to have sensory experiences similar to those they have locally.

Such capability will create new opportunities for remote learning, repair, and also enable new procedures in fields such as surgery. Some studies indicate that what is known today as immersive mixed reality applications have the potential in the decade ahead to become the next important platform after mobile.

Even the process of innovation will be improved through the evolution of IoT. The demand for more sustainable products, processes, and services will prompt the manufacturing industry to accelerate its ability to respond, resulting in a move toward more integrated innovation approaches.

These developments have led to efforts to measure the economic impact or value of IoT both broadly and specifically in manufacturing. For example, McKinsey estimates that by 2030, IoT could enable the creation of $5.5 trillion to $12.6 trillion in economic value globally, including the value captured by consumers and customers of IoT products and services. Fifty-five percent of the potential economic value from IoT will be enjoyed in the developed world in 2030, but that percentage is down from 61% in 2020, reflecting the population and demographic shifts noted earlier. The country to watch is, again, China, which is becoming a global IT power not only in manufacturing but also as an end market for value creation.

From an industry sector perspective, manufacturing and health care appear to be the largest potential beneficiaries of IoT's economic value in the years ahead. By 2030, about 26% of IoT's expected economic value is predicted to surface in manufacturing, the hospital sector, and in other areas. Within factory settings, value will be realized by optimizing the day-to-day management of assets and people using IoT technology and the data it generates. Overall, it is estimated that operations management applications could account for between 32% and 39% of the total potential IoT economic value created in manufacturing, quantified as $0.5 trillion to $1.3 trillion by 2030.

"A future wave of IoT applications will be based upon intuitive, human-to-machine interactivity."

Industry

Trends and Themes

› CHAPTER SIX

IDENTITY CRISIS

Labor force growth and labor force participation in the United States are expected to slow in the years leading up to 2030 – growth declining by 0.5 percent per year and participation down to 60.4 percent from 61.7 percent in 2020. Much of this is due to lower fertility rates and restrictive immigration policies. While conventional wisdom says that automation will eventually make jobs increasingly scarce, the more likely reality is that industrialized nations will have more job openings than workers to fill them. Add on an aging population with a need for personal assistance, and it becomes more likely than ever that human workers of the future will find themselves with robot colleagues.

Collaborative robots, those that work alongside humans outside of a cage, are easier to deploy and program vs. their legacy industrial robotic ancestors, and their lower cost makes them a popular choice for small and medium manufacturers. Their usage is continuing to grow. Yearly revenue for collaborative robots is expected to reach $11.8 billion by 2030.

The question that follows is what limits, if any, are there on the rise of machine intelligence? A number of viral videos from Boston Dynamics show that machines are more capable of moving like us (and other living creatures) all of the time, and projects from DARPA and other research entities have combined neural networks with artificial intelligence to bring human thinking into machines as well. This could include anything from brain implants that can control prosthetic limbs and speech synthesizers to a human brain/machine interface that could empower individuals with all cumulative human knowledge available in the cloud.

> **“It is more likely than ever that human workers of the future will find themselves with robot colleagues.”**

Movies, books, and television have provided many fear-inducing images of a world where robots rise and overpower

humankind, and digital experts have often discussed the ethics of limitless AI. But a more likely scenario for the years leading up to 2030 include cell-based production lines for hyper product customization and automated workflows that allow for machine maintenance and product repair with little or no human intervention.

Linking brains and computers has left the realm of science fiction. The impact of that on the real world – and specifically on manufacturing – is a question that will likely have many different answers in the coming decade and beyond.

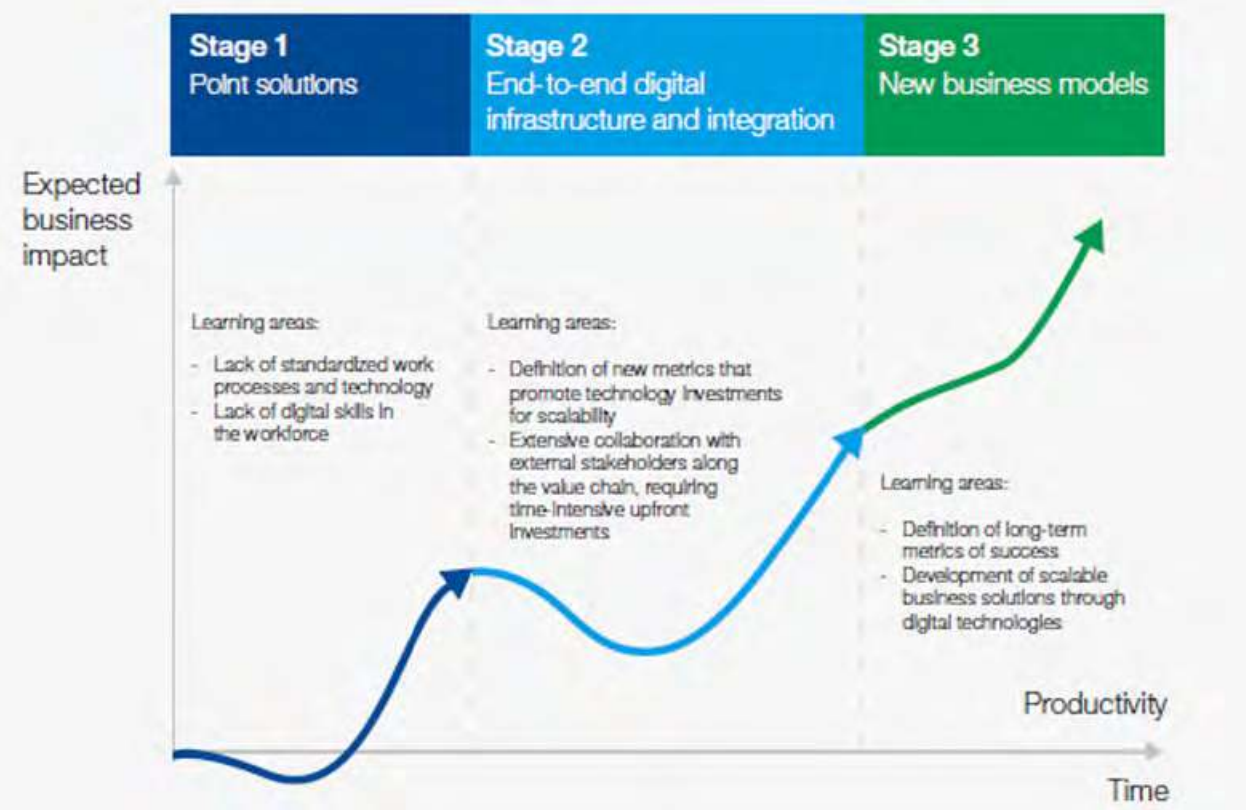
› CHAPTER SEVEN

THE HAYSTACK PARADOX

"If you torture the data long enough, it will confess." Attributed to British economist Ronald H. Coase, that 1970s-era quote still has relevance today. Manufacturers find that they can collect more data than ever but face a much bigger

FIGURE 9

Main Stages of the Journey



Notes: [x-axis] Productivity improvement over time: for example, labour, machine or material is measured at a whole-system level incorporating the full manufacturing value chain. The x-axis therefore spans from a single-point solution application at a particular point in the system (e.g. a machine within a factory) to the extended factory network and supply chain, through to a system-wide perspective incorporating suppliers and end users.

[y-axis] Expected business impact: in terms of margin improvement and revenue uplift, but also broader measures on sustainability/environmental, social and governance, as well as inclusivity.

The learning curves can be accelerated by leveraging the key strategies learned from leading companies and summarized in this White Paper (Section 4).

Source: World Economic Forum

challenge in selecting the data that is most relevant and analyzing it in a manner that is useful. It requires selecting which data sets can have a business impact while also ensuring data accuracy and fidelity – in other words, making sure that data is really telling the truth.

Advanced analytics, especially in combination with AI and machine learning, continue their ever-deeper reach not just into shop floor operations but other facets of business, including finance, human resources, supply chains, and beyond. Research has projected that AI will contribute anywhere between $13 trillion and $15.7 trillion to the global economy by 2030.

AI and advanced analytics are becoming essential for business competitiveness with vast potential for enhancing operational KPIs like productivity and efficiency, improving customer experiences, and minimizing supply network disruptions. The investment curve could be steep moving toward 2030. Most manufacturers rate themselves in the middle range of digital maturity, and most AI use cases in manufacturing will be adopted in the next 3-7 years. Adoption will vary by level of digital maturity, size, and other factors; however, more than half of manufacturers are already either using AI currently or plan to do so in the next 2 years.

Some of the highest value areas where AI can benefit manufacturing operations include demand planning, inventory management, quality, product optimization, and safety. AI's subset machine learning also represents a $4.5 trillion opportunity across the manufacturing value stream, in particular to enhance supply chain decision making, to usher in smart manufacturing, and to stay connected with products and customers.

> **"AI's subset, machine learning, represents a $4.5 trillion opportunity across the manufacturing value stream."**

As manufacturing continues to lag other industries for automation in data management, it's not difficult to see that it is making efforts to catch up. It's not an effort without challenges, however – manufacturers are currently held back by a lack of sufficient skills and capabilities to leverage data, data security risks, a lack of effective analytics applications, internal governance, and a lack of leadership. These will be essential to address if manufacturers are to realize the massive benefits that could be realized by effectively leveraging data and AI.

› CHAPTER EIGHT

THE BIG ENCHILADA

In June of 2004, the organization that gave rise to the Manufacturing Leadership Council – Thomas Publishing Co.'s Managing Automation Magazine – published a report that envisioned a new way of manufacturing based on advanced technologies. Called Progressive Manufac-

turing, the vision included what the magazine called Business Model Mastery, the notion that advanced technologies could open whole new ways of not only running operations but also doing business in the future.

Today, the idea that building upon what has been learned in manufacturing operations over the years to create new competitive business advantages in product and service offerings, in operating models, and by leveraging ecosystems of partners and customers has indeed become the new frontier for manufacturing companies in the next decade and beyond.

“Maximizing the potential of digital requires cross-functional integration, from product design and development to customer service and support.”

Understanding the trends that are influencing this frontier and developing strategies to create true digital business enterprises will be both a key opportunity and challenge for manufacturing executives.

One of the most important lessons operational executives have learned about digitization over the years is that digital is agnostic about functional boundaries. Digital just wants to flow and connect. That’s why maximizing the potential of digital requires cross-functional integration, from product design and development to customer service and support. The opportunity ahead, though, is to extend the digital model externally and include partners, suppliers, and customers in a digitally-powered business ecosystem. But it is an idea with many challenges around data sharing and transparency, intellectual property protection, cybersecurity, and managing a complex web of internal and external relationships.

The business imperatives of doing so, and the benefits that will accrue to those most successful in reinventing their business models, will require manufacturers to meet those challenges. They include meeting new customer requirements for personalized products and seamless buying experiences; achieving sustainability targets including Net-Zero emissions; and develop greater organizational agility and speed.

What Gartner calls “hyper-automation” will be a significant technological tool for building the truly connected business ecosystem and, in the process, realizing new business models that will create competitive advantage.

“As robotics and AI technologies such as machine learning continue to mature and be used more broadly, hyper-automation will be applied to increasingly sophisticated tasks across product development, manufacturing operations, supply chains, sales and marketing, and customer service,” Gartner said.

› CHAPTER NINE

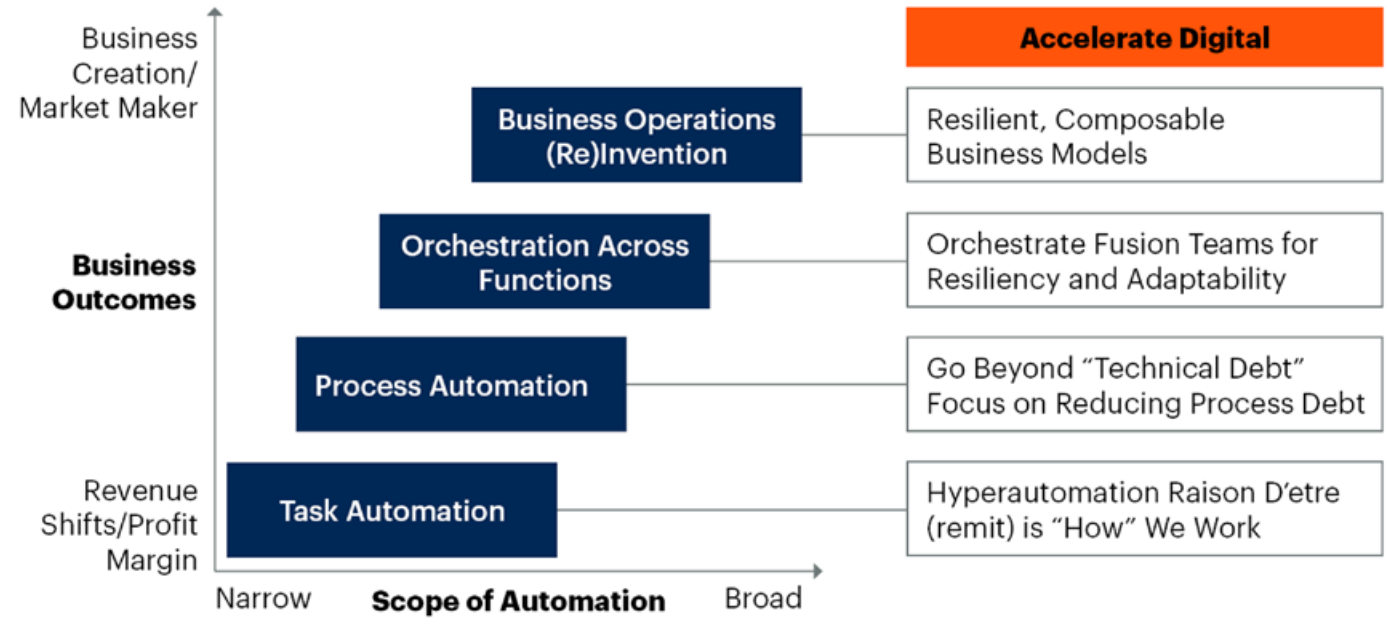
IMMERSE IN THE METAVERSE

These days, before a new product leaves the factory for the first time, and even before the first one goes into production, a manufacturer can know how that product will perform and the approximate length of its lifecycle, as well as its potential points of failure. It is possible to test different processes and optimize product design without ever running a machine. Manufacturers can create digital replicas of production lines, supply chains, warehouse and transportation networks, and just about any product or process through a digital twin. Integrating aftermarket feedback within this digital backbone also enhances future designs, streamlines production processes, and opens the door to new business models.

Thanks to connected machines and faster, ever-more-powerful data networks, digital twins and other simulation and visualization technologies aren't just a nice tool to have – they are becoming the norm. MLC research indicates 58% of manufacturers either already have extensive digital plant floor networks or will within two years' time. Additionally, 56% say they've already invested in digital twin technolo-

FIGURE 10

Hyperautomation Principles are the Foundation for the "Future Work"



Source: Gartner

gies or will soon. Digital twins can speed up product development, improve sustainability, and allow for real-time operations data to optimize performance.

But in addition to digital twins, many manufacturers are finding the benefits of AR and VR for applications like worker training, equipment troubleshooting, safety, quality, field service, and collaborating with workers at other sites or with partners and vendors. During the pandemic's early days, these technologies were essential to bringing people "on site" when they had limited ability to travel in person. Now that manufacturers have seen these new capabilities, it seems there is no turning back. AR and VR are expected to add $1.5 trillion to GDP by 2030, and shipments of VR headsets and AR smart glasses are predicted to grow 42% through 2026.

"Will companies trust AI-enabled systems enough to try to achieve truly light's out status in their plants and factories?"

These are the emerging days of the industrial metaverse, a place that is always connected, always collaborative, and always updated in real time. While the metaverse is most frequently thought of in terms of consumer experiences – primarily retail and entertainment – there are many opportunities presented by an industrial counterpart that can include the entire value chain. This can include all functions of manufacturing operations, but also suppliers, vendors, partners, and customers. Creating this ecosystem will not be without significant challenges, but if the industry can rise to the challenge, the potential benefits could be undeniable.

› CHAPTER TEN

FLYING ON AUTOPILOT

In March 2022, Yokogawa Electric Corp. said it had successfully completed a field test using artificial intelligence to autonomously run a chemical plant for 35 consecutive days. The test, which Yokogawa did in conjunction with JSR Corp., was said to confirm that reinforcement learning, which is the training of machine learning models to make a sequence of decisions, could safely be applied in a plant.

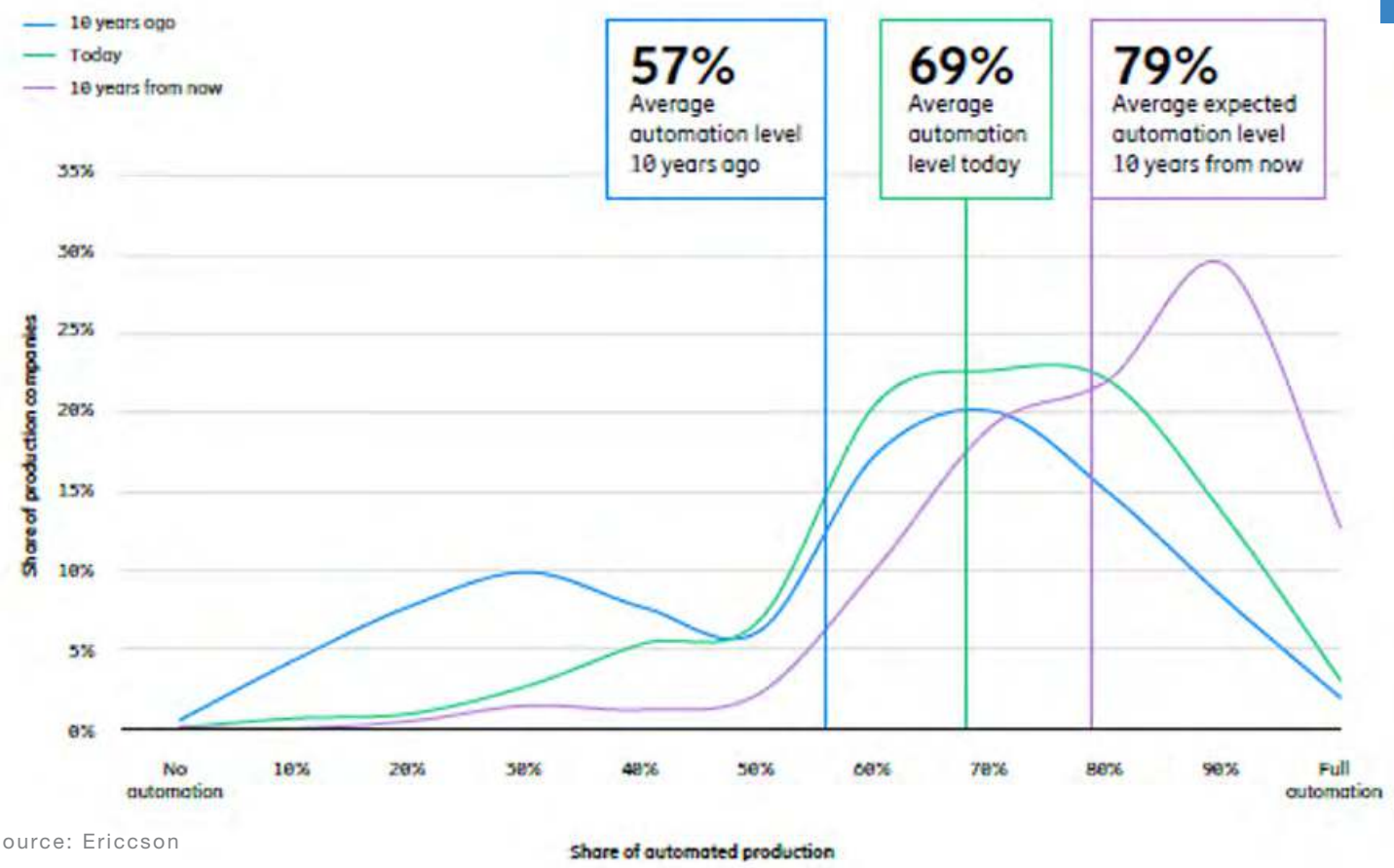
The AI used in the Yokogawa plant experiment is called the Factorial Kernel Dynamic Policy Programming protocol, which was jointly developed by Yokogawa and the Nara Institute of Science and Technology in 2018. The protocol has been recognized at an IEEE International Conference on Automation Science and Engineering as the first reinforcement learning AI that can be used in plant management.

The Yokogawa field test will undoubtably be followed by other field tests, experiments, and, later, actual implementations of AI and machine learning to operate plants in an autonomous fashion as the industry evolves from a focus on automation to understanding the benefits and chal-

FIGURE 11

Automation Levels to Rise

Share of decision makers stating the automation level for their respective production companies 10 years ago, today and in 10 years (self-reported)



Source: Ericcson

lenges of autonomous operation. Autonomous systems, which employ a range of M4.0 technologies including AI, machine learning, and data analytics, enable plants to adjust and optimize operations on the fly and even customize at the point of manufacture, compared with plants that have some level of automation and require human intervention to adjust what is a fixed process.

The lure of being able to operate plants in an autonomous fashion appears to be powerful. Some reports indicate that autonomous systems will enable on-demand and flexible manufacturing to a greater degree than ever before, at a lower price point and in a more sustainable way than anything that's being done currently. As a result, plant workers can have a greater opportunity to transition from repetitive work to higher level positions.

The key question the industry will have to grapple with in the years ahead is to what extent it really wants to embrace

autonomous systems. Will companies trust AI-enabled systems enough to try to achieve truly light's out status in their plants and factories or will they proceed in a more targeted approach, with only certain elements of plant operations run autonomously or mostly autonomously?

› CHAPTER ELEVEN

A BRIGHTER SHADE OF GREEN

Reassuringly for both the planet and its billions of inhabitants, many manufacturing companies are already embracing the global sustainability challenge across their end-to-end operations. MLC research shows that by the end of 2021 around half of manufacturing companies already had a formal, corporate-wide sustainability strategy with publicly stated goals in place, up from 39% in 2019. Around a third had also announced specific Net Zero targets to reduce their C02 emissions to zero, with around 14% aiming to achieve their Net Zero goal by 2030, and another 14% by 2035. Some companies like Volvo Cars, for example, expect to meet that goal much earlier – by 2025.

"Digital tools are now regarded as essential to meeting new levels of regulatory compliance and achieving individual corporate sustainability targets."

There are many reasons for manufacturing companies to do so. They can improve basic operational efficiencies by reducing energy usage, leaning key processes, and better managing waste, as well as enhancing reputational credibility with customers, investors, and employees. But there's also another factor – an increasingly urgent necessity for companies to ensure compliance with the growing number of environmental regulations now being introduced worldwide by both international organizations and regional and national governments.

MLC Board member company Lexmark, for example, recently tracked the increasing velocity of these formal regulations since the early 2000s, showing an exponential rise during the last 10 years alone from around 5,000 to over 20,000 requirements. And the curve is still trending steeply upwards as we move further into the decade to 2030.

What's more, these regulations now cover a far broader range of aspects than ever before, from material usage restrictions to more stringent requirements for deep supply chain transparency and data reporting stretching down multiple partnership tiers.

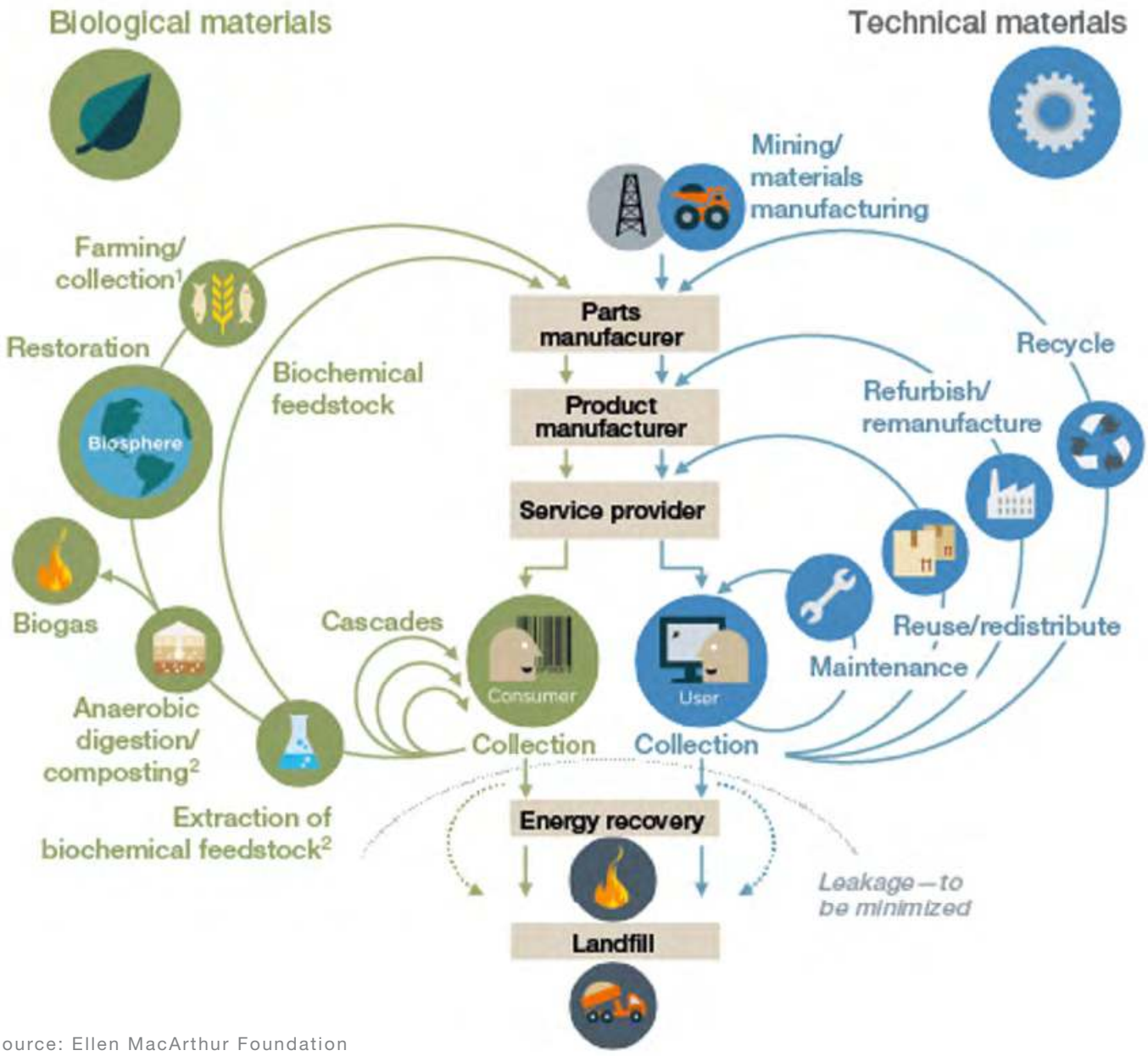
Digital tools and technologies are now regarded as essential to both meeting these new levels of regulatory compliance and achieving individual corporate sustainability targets. Over half of the companies in the recent MLC survey now believe that 4.0 technologies will be either extremely or fairly significant to achieving their sustainability and Net Zero goals by 2030. AI, AR and VR, 5G networks, additive manufacturing, and digital twin technologies are predicted to have the most significant

impact on enabling those companies to achieve their goals by 2030.

The World Economic Forum and McKinsey & Company have also identified multiple areas that can directly benefit manufacturing enterprises from this digitally empowered 4.0 sustainability journey, from improved data-driven decision making across both production lines and the end-to-end value chain, to measurable improvements in operational performance including productivity, costs, agility, and quality.

FIGURE 12

The Circular Industrial Economy



Source: Ellen MacArthur Foundation

Yet, while many manufacturing companies are still focusing on their direct emissions targets and regulatory compliance, there are also a number of more forward-thinking industrial enterprises that are already taking a bigger picture view of their sustainable future by embracing the concept of a circular industrial economy. This approach replaces the traditional and often wasteful linear industrial paradigm of "Take, Make, and Dispose," and focuses future manufacturing strategies towards a more circular and regenerative economic model characterized by "Recycle, Reuse, Refurbish, and Remanufacture."

"A number of forward-thinking industrial enterprises are already taking a bigger picture view of their sustainable future by embracing the concept of a circular industrial economy."

Such a strategic shift requires new kinds of circular manufacturing business models for the future. These include products being intentionally designed for disassembly and recycling from the early concept stage. Using reclaimed materials in leaner and greener production processes. Extending product lifecycles and usability to deliver longer value for customers. And establishing new, cross-sector partner networks to support end-of-life programs that maximize the value of all materials and resources at every stage of the industrial lifecycle, potentially also offering new revenue streams, too.

This more holistic sustainability trend is already well underway in many sectors and is set to expand significantly in the decade ahead. Combined with a transition to more renewable energy sources, the greening of key industrial processes to reduce emissions and waste, and the development of more sustainable and recyclable products, the future of manufacturing may not just look brighter by 2030, but a brighter shade of green, too.

› CHAPTER TWELVE

NEW BOXES

The increasing deployment of digital technologies across the manufacturing ecosystem over the next few years will open up new opportunities for manufacturers to think outside the traditional industry box. By the end of the decade, many companies will have introduced innovative new ways to drive new digital business models, develop new products and services, create new revenue streams, improve the way they serve and connect with customers, and increase their competitiveness.

Collaborative Innovation: By 2030, metaverse technologies will provide rich virtual environments for the collaborative development of new ideas by creating shared virtual spaces for researchers, planners, developers, and engineers to work together to innovate and simulate new products, processes, and services. MLC research already predicts a rapid increase in the industry's adoption of digital

twins and virtual, mixed, and augmented technologies over the next few years. This trend will prepare those manufacturing companies with the advanced technical foundations, experience, and collaborative skills they will need to make this virtual future effective.

These shared virtual spaces will enable contributors from multiple remote locations, partners, academic institutions, and research institutes to collaborate in real time to innovate and test new concepts and physical innovations in a virtual world before moving to physical prototyping or production. In many ways, the manufacturing industry's current deployment levels of virtual technologies already makes it one of the most advanced sectors in understanding how to effectively prepare for, collaborate, and innovate in the emerging metaverse of the decades ahead.

Outcome-based Products and Services: The introduction of additional product-related services for manufacturing customers is already well established, initially with the simple provision of consumables, and more recently by using online monitoring systems to schedule maintenance programs for the equipment on customer sites. But as digital platforms mature and products become increasingly smart and connected, the decade ahead may see a boom in more outcome-based services. This is where the customer doesn't buy a physical product itself but signs up to pay for the guaranteed outcomes that product or system delivers. Early examples like Rolls Royce's 'Power by the Hour' where revenues are based on the efficient miles flown by an aircraft engine, rather than a physical customer purchase have pioneered such an approach.

But such a shift in approach requires manufacturers to adopt a very different business model. It will require establishing a new infrastructure rich in predictive analytics, remote communications, and consumption monitoring. It also requires a mindset change for the traditional manufacturing focus on units and costs, to focusing more on product lifecycles, performance levels, and usage. These outcome-based services may initially be more complex to set up, but when developed successfully, they promise to establish much closer manufacturer-to-customer relationships, create new revenue streams for the future, and strengthen a company's competitive profile.

> **"By the end of the decade, many companies will have introduced innovative new ways to drive new digital business models."**

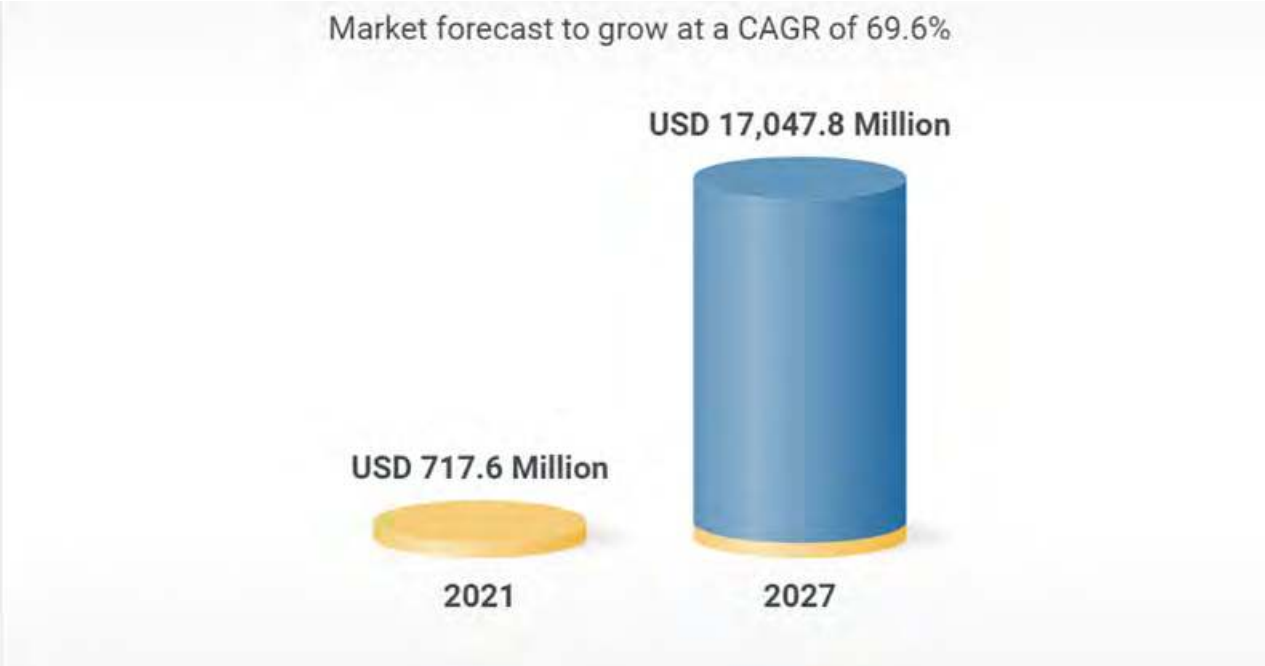
Blockchain Networks: The need to automate, secure, and accelerate the processing of key transactions across industrial ecosystems is rising exponentially as manufacturing companies pursue more digital models of doing business with their trusted partner networks. Blockchain technologies, supported by a compelling business case, promise a viable solution.

Essentially, a blockchain is a decentralized database, an electronically distributed ledger or list of records that is accessible to multiple users. Using deep cryptography, blockchains record, process, and verify every transaction, making them safe, trusted, permanent, secure, and transparent. A recent report by PwC revealed that a quarter of industrial CEOs are already planning, piloting, or implementing blockchain technologies to help ensure provenance, quality, and regulatory compliance.

The Blockchain Council also predicts that by 2030, the blockchain will be leveraged for a majority of world trade, helping to provide the secure traceability and provenance needed to prevent physical product counterfeiting, grey markets in medicines, and even the adulteration of the global food supply chain. In an increasingly digital world, high levels of trust between partners is critical. By 2030, blockchain networks may help provide that trusted foundation.

E-Manufacturing Marketplaces: The pandemic experience clearly showed how companies with more advanced digital platforms, often from entirely different sectors, were able to pivot or expand production to create sometimes new kinds of products in rapid time – from ventilators to PPE equipment, to new medicines and vaccines. Over the next decade, that digitally empowered production line adaptability will provide a foundational infrastructure to give large companies the option to offer

FIGURE 13 **Global Blockchain in Manufacturing**



Source: Research and Markets

spare and unused production capacity to other companies to meet market demands as they surge and wane in different sectors.

This not only maximizes the return on a large company's production line investments but can also generate new revenue streams for the future. The combination of virtual design systems and increased connectivity has made the process of initiating production runs at remote contract locations far easier and faster in recent years.

Smaller prototyping and contract manufacturing companies around the world have already created many highly profitable businesses from such approaches. Combined with B2B e-commerce systems and virtual e-marketing marketplaces, it will become ever easier for designers, engineers, or smaller companies to connect with a large pool of qualified producers with the technology and capacity to deliver and scale final product production. The opportunity for both small and large companies to increasingly turn their factories from cost centers into profit centers looks set to create new business models for the decade ahead.

› CHAPTER THIRTEEN

BREAKING CHAINS

By 2030, manufacturing supply chains are likely to look very different from the way they do today. Many will have dispensed with traditional approaches such as Just-In-Time, the SCOR model, long and complex interdependent global supply networks, and the resulting high levels of vulnerability to sudden climatic, economic, or political events.

Instead, manufacturing supply chains will be transforming into far more collaborative and rapidly adaptive partner ecosystems, delivering often locally produced and highly customized products and services in rapid time at any location. They will be characterized by deep, multi-tiered visibility, interpretive analytical predictability, increasingly autonomous capabilities, and significantly improved levels of resiliency to potential disruption.

Many lessons have been learned as the decade began following the widespread supply disruptions caused by the lingering pandemic, severe weather events, material and component shortages, and global shipping delays. These have now forced many supply chain leaders to rethink their whole strategic approach to managing their supply networks for the decade ahead, especially since many supply chain leaders predict that high levels of disruption are here to stay for at least the next two years, if not more, according to the latest MLC research.

> **“ Manufacturing supply chains will be transforming into far more collaborative and rapidly adaptive partner ecosystems. ”**

Increasing levels of supply chain digitization, now well underway, also offer

manufacturers many opportunities for improvement over the next few years. Three-quarters of companies already confirm that as they accelerate digital adoption, they are also taking the opportunity to reduce complexity, according to MLC research, while 72% are also redesigning their supply chain processes to maximize the benefits of being more digitally driven.

At a physical level, this digital transformation is increasingly using data to improve real-time visibility and traceability across the end-to-end supply chain, tracking what is being produced, by which partner, in what quantity, where it is located or en route, and when it is due.

“As the decade progresses, interconnecting digital supply chain threads will form the fundamental fabric of a new kind of digital supply ecosystem.”

Intelligent automation systems, meanwhile, as well as blockchain technologies will automatically handle all the associated ordering, contractual, transport, trading, and payment transactions required across end-to-end supply chain processes, ensuring administrative efficiency and speed, product provenance, and compliance.

Harnessing the predicative power of advanced AI and ML techniques will also provide companies far more accurate forecasting about market trends, customer demands, and potential supply issues before they happen, allowing companies to take remedial action to mitigate the effects.

All these key developments will, of course, require the regular and extensive sharing of large amounts of data between closely interconnected partners across the network to be effective.

As the decade progresses, these interconnecting digital supply chain threads will form the fundamental fabric of a new kind of digital supply ecosystem where shared data provides all actors with a better understanding of potential opportunities and risks, accelerating the speed of response to changes in supply and demand, autonomously optimizing processes, increasing resiliency by minimizing the impact of disruptions, and driving increased competitiveness.

This transition to more data-driven, collaborative, and rapidly adaptive supply partner ecosystems is not as far away as some may think. Industry researcher Gartner, for example, is already predicting that by 2026, 50% of large organizations will compete as collaborative digital ecosystems rather than discrete firms, sharing inputs, assets, and innovations, and ultimately providing the basis for their networks to become the competitive entity for the future.

The industry’s challenge for the decade ahead is that companies of all sizes will need to ensure they have the right levels of digital deployment and maturity to be able to participate in these future ecosystems. In some cases, since small and medium enterprises may have inherent barriers to

entry, that may require larger industrial organizations to actively encourage, incentivize, or even directly assist their smaller partners in getting there.

By 2030, if that challenge can be met, this innovative, competitive, digital supply ecosystem approach may well become the dominant supply strategy for all companies in the manufacturing industry.

› CHAPTER FOURTEEN

KEEPING IT SIMPLE

The Forrester Research analyst Jost Hoppermann has defined business complexity as "the condition of having several interdependent and interconnected stakeholders, information technology systems and organizational structures."

The definition is a relevant starting point for what is happening in manufacturing as companies embrace the digital model and attempt to electronically connect people, equipment, supply chains, business partners, and customers in what will be growing and evolving connected ecosystems. The effort will lead to more complex structures and systems, which, by definition, are difficult to understand and manage.

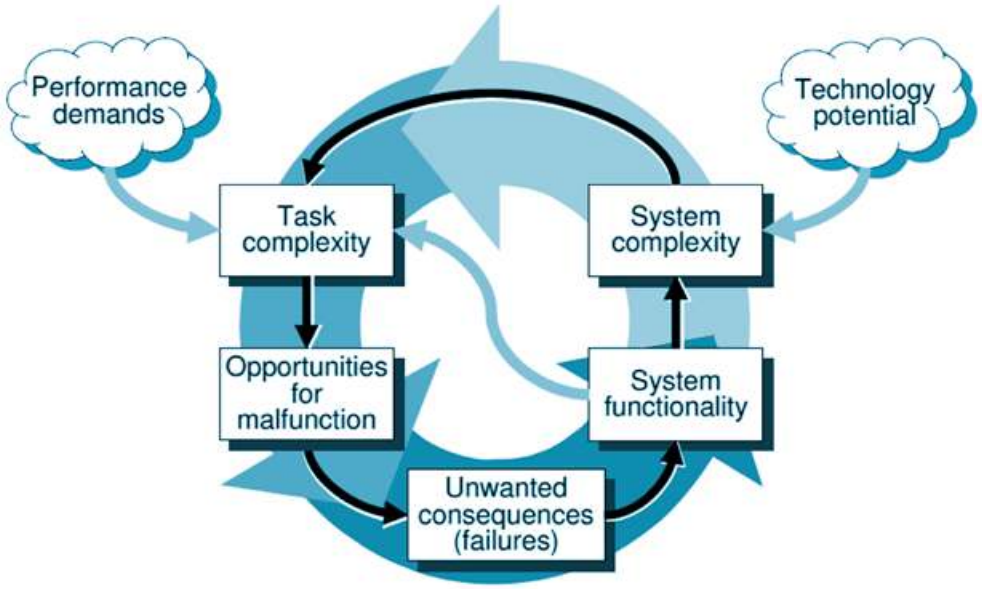
And something that is complex, says Webster's dictionary, can be "a group of obviously related units of which the degree and nature of the relationship is imperfectly known."

Could there be a more apt description of what is happening in manufacturing today as the industry marches toward the M4.0 paradigm?

MLC has long held that the successful adoption of M4.0 requires mastery across three dimensions – technology, organiza-

FIGURE 14

Self-Reinforcing Complexity Cycle



Source: Joint Cognitive Systems

tion, and leadership. Once new technologies such as IoT, artificial intelligence, 3D printing, and simulation, among others, are injected into the manufacturing corporate body, the structural DNA of the organization inevitably changes, leading to flatter organization structures, more information-empowered employees, different ways of organizing work and conducting problem-solving, and more collaborative decision-making processes. In short, the power structure changes. As a result, leaders need to adapt and lead differently internally and, in what will be a first for some, in increasingly important industry collaborations.

But the M4.0 playbook to document these changes is still being written and therefore the relationship among the three variables is imperfect. But what we do know is that as manufacturers connect more people and objects, a complex structure of operational and information technology platforms, applications, and networks is being built and will get even more complex as M4.0 increasingly migrates from within the four walls of a manufacturer to its broader business ecosystem.

“ Leaders need to adapt and lead differently internally and, in what will be a first for some, in increasingly important industry collaborations. ”

Add to this the rising sophistication and frequency of cyber attacks and what is emerging is an era of unprecedented physical and cyber complexity, one that the manufacturing industry must learn to manage in the decade ahead.

A central problem in the management challenge is that complexity and resiliency have an inverse relationship; the more complex a technological infrastructure, the more difficult it is to make it resilient. Innovation, too, can be slowed because of the difficulty in changing the technological infrastructure.

Most manufacturers’ current operating infrastructures are compartmentalized. For more than 40 years, the industry has compartmentalized hardware and software systems by function. But by its nature, M4.0 requires cross-fertilization by function and system. The common, but misleading, way the required transition has been discussed is that manufacturers have to “break down silos.” But the more useful and realistic approach, and one that industry will need to accomplish in the years ahead, is to both retain the benefits of functional expertise and weave together functions by process and systems, thereby creating a digital fabric that can integrate and empower the whole organization.

Some researchers have called the central challenge the “irony of automation.” The theory is that system complexity increases as the technology is put to work as a kind of unintended consequence, leading to greater complexity even with individual tasks. This may be a reason why identifying productivity gains from technology has been so difficult historically.

The answer to mitigating the effects of what appears to be an inexorable growth in complexity stemming from a greater number of more sophisticated technologies being deployed is the adoption of a rational information architecture, and one that can encompass what will be emerging business ecosystems, that can minimize redundancies. Inherent in the architectural choice is the question of what style or model can work best to avoid risk and vulnerability. Is a centralized model best or would a distributed model afford more protection? The question may be a classic 'all eggs in one basket' or not discussion.

But also necessary to consider are corporate technology purchasing strategies that can control uncoordinated buying without constraining the needs of individual business units seeking to innovate. Technologies coming into a company through acquisition and legacy systems – it has been estimated that there are still one-quarter of a trillion lines of COBOL code still in production – also have to be dealt with.

Organizationally, the shift underway from command-and-control operating models to collaborative ways of working and managing, a trend charted by MLC for more than 10 years, adds a layer of behavioral and structural complexity in how manufacturing companies operate today and will operate tomorrow. Empowerment should not lead to slower decision-making processes. More data should not lead to analysis/paralysis. Decision-making processes will need to be rethought and redesigned. As always, bold and decisive leadership will be key.

All in all, it appears that manufacturers face a future of increased technological and organizational complexity. In order not to either forfeit the advantages of agility, flexibility, and speed that advanced technology can confer, or to experience these benefits sub-optimally because of an inability to effectively manage the complexity, manufacturers will need to continually rationalize, streamline, and simplify wherever they can. The future will belong to those that strike the right balance.

> **"Manufacturers will need to continually rationalize, streamline, and simplify wherever they can."**

Importantly, no single manufacturer can tackle the complexity issue alone. Smaller manufacturers will need their own kind of help because the whole industry will lose if capability fragments between large and small companies. The risk that manufacturers will face if they do not think broadly about complexity is not only potentially forfeiting in whole or in part the advantages of agility, flexibility, and speed, but, perhaps most dramatically, not being able to stay in business at all.

Decision Points on the Road Ahead

What will manufacturing look like in 2030? Will the vision of factories and plants as highly efficient, high-tech engines capable of mass producing nearly limitless variations of smart products with little or no environmental impact quickly and at affordable prices finally be realized? Will the industry be a magnet for the best and the brightest, drawn to the excitement and challenge of being on the cutting edge of science and technology?

Will the year 2030 become a historical milestone, one we will look back on and say it marked a turning point when advanced technologies, new forms of production and new ways of defining and organizing work, as well as enlightened leadership all came together to herald a new era in manufacturing, one that by mid-century with its new business models, new job roles and functions, and new products and services will be almost unrecognizable from just a generation before?

It's possible.

What will determine whether manufacturing crosses the bridge to the probable is the collective courage, will, and stamina to use a growing set of ideas and tools to create a better future.

Manufacturers will be aided by a digital foundation that is growing in power and capability. In the next 10 years, the electronics that power computer systems and enable the running of increasingly more sophisticated programs, particularly AI systems, will leap in capability, offering greater opportunities for increased efficiency, productivity, and cost savings.

A new era of automation will ensue, freeing workers from routine, repetitive, and even sometimes dangerous tasks and, in the process, enabling them to take on more fulfilling and rewarding work in many new job roles and functions.

Most importantly, the next phase of Manufacturing 4.0 will see manufacturers begin to unlock the true potential of digitization – the reinvention of their businesses that will encompass how they build things, how they organize their companies, the people they attract to work in them, and

3 Conclusion

how they serve customers.

Manufacturing in 2030 looks bright indeed, but it will not come about without many challenges to address and solve. Among the decision points ahead are:

› **Achieving Data Mastery.** The central premise in creating the manufacturing vision for 2030 and beyond is the ability to gather, organize, analyze, and use information from all facets of manufacturing to not only produce a step change in efficiency, cost effectiveness, and productivity, but also reveal the "undiscovered country" – things we haven't thought of before that can advance value creation and competitiveness. As data volumes from increasingly connected enterprises grow dramatically in the years ahead, manufacturers will need to devise new ways of organizing around the data opportunity.

"The next phase of Manufacturing 4.0 will see manufacturers begin to unlock the true potential of digitization."

› **Defining the Human/Machine Relationship.** As machines become more intelligent, the industry faces a consequential decision: how and to what extent will people work with and alongside machines? The industry must decide what roles and functions should be automated, and, most importantly, what decisions increasingly AI-powered systems should make without human intervention.

› **Understanding the Extent of Autonomous Operations.** Grove's Law holds that if something can be done technologically, it will be done. As technology advances and matures, the industry will inch toward more autonomous operations. The challenge for industrial companies will be to plot the trajectory toward autonomous and decide what constitutes acceptable reach, including understanding the implications for workforce roles and functions.

› **Governing Artificial Intelligence.** With its ability to actually learn, AI is perhaps unique among advanced technologies, offering great promise from everything to mining and extracting insights from data to creating smarter and more automated manufacturing operations. As such, AI will affect both objects and people. Industrial companies will need to decide what rules, if any, should apply.

› **Extending M4.0 to the Rest of the Enterprise and to Business Ecosystems.** To create true end-to-end digital businesses, manufacturing companies will need to digitize all facets of their business ecosystems, including all enterprise functions, using operations as a role model. Corporate leadership will need to develop the vision and the managerial competencies to orchestrate extensive change both inside and outside the four walls.

› **Reconciling National Needs and Globalization.** Population, demograph-

ic, and economic trends suggest a future in which manufacturers of all sizes will be increasingly operating in global markets with significant growth opportunities for those prepared to take advantage of them. Yet, recent events such as the pandemic, the Ukraine war, and tariff-based trade barriers have compelled some manufacturers to rethink their supply chains including their factory and plant footprints. Over the coming years, manufacturers will have to identify the balance point between guarding against disruption and emphasizing resiliency without sacrificing growth opportunities globally.

› Growing the Workforce of the Future. Forecasts of worker shortages by 2030 are well documented. The industry faces an existential challenge in attracting and retaining the next generation workforce even as the jobs the workforce needs to perform shift to higher level skill requirements. Manufacturers will need to devise new policies and strategies to compete effectively with non-manufacturing industries for talent in the digital era.

› Greening Industrial Processes and Ecosystems: There are few more pressing or critical challenges for manufacturing in the decade ahead than the need to rapidly accelerate the transformation of industrial operations to become cleaner, more sustainable, and more environmentally responsible. Both the industry's global reputation, and its potential for future growth and expansion, will increasingly depend on it. Manufacturers will need to reassess fundamental aspects of their business, from product design priorities to materials sourcing, production processes, energy usage, and value chain impacts to become truly eco-efficient and globally compliant.

The list of challenges above are certainly considerable but they are outweighed, this white paper suggests, by the opportunities ahead. As individuals, companies, and the industry at large forge ahead, they will all contribute to redefining the art of the possible in manufacturing.

In every era, every period of profound change, manufacturers have risen to the challenges before them. As the industry looks forward to 2030 and beyond, the challenges ahead may be new and even in some cases unique. But the resolve of the men and women who make things to adapt and change for the better is steadfast.

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Research, Writing and Production Team

David R. Brousell

Co-Founder, Vice President & Executive Director, Manufacturing Leadership Council

Paul Tate

Co-Founding Executive Editor and Senior Content Director, MLC

Penelope Brown

Senior Content Director, MLC

Robert Best

Best & Co.

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Matt Jackson

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