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McKinsey Technology Trends Outlook 2022

Report

August 2022

Introduction

by Michael Chui, Roger Roberts, and Lareina Yee

Technology continues to be a primary catalyst for change in the world. Technology advances give businesses, governments, and social-sector institutions more possibilities to lift their productivity, invent or reinvent offerings, and contribute to humanity's well-being. And while it remains difficult to predict how technology trends will play out, executives can plan ahead better by tracking the development of new technologies, anticipating how companies might use them, and understanding the factors that affect innovation and adoption.

To that end, we have worked with the internal and external experts on the McKinsey Technology Council to identify and interpret 14 of the most significant technology trends unfolding today (see sidebar "About the McKinsey Technology Council"). This study builds on the trend research we shared last year, adding fresh data and deeper analysis to provide a more granular assessment of trends in two thematic groups: Silicon Age, which encompasses digital and IT technologies, and Engineering Tomorrow, which encompasses physical technologies in domains such as energy and mobility.

Our analysis examines such tangible, quantitative factors as investment, research activity, and news coverage to gauge the momentum of each trend. We also conducted dozens of interviews and performed hundreds of hours of research to learn which industries are apt to benefit most as they absorb these technologies. And, recognizing that trends can speed up, slow down, or change course, we examined the uncertainties and questions surrounding each trend.

This research overview, an accompanying online interactive, and a set of 14 in-depth trend profiles lay out these considerations in more detail so that executives can better comprehend how the individual trends are developing and interacting, and what these developments might mean for their organizations. Looking across the trends, we also arrived at some general observations that leaders might find instructive.

New dynamics

First, several trends that are based on proven and mature technologies—namely applied AI, advanced connectivity, future of bioengineering, and cloud and edge computing—score more highly on quantitative measures of innovation, interest, and investment than trends based on technologies that are still in the early stages of development. These trends also tend to have viable applications in more industries, which places them closer to a state of mainstream adoption than other trends (Exhibit 1).

The next noteworthy group consists of trends that are closely aligned with sustainability priorities. These trends—which we call future of clean energy, future of sustainable consumption, and future of mobility—display increasing levels of innovation, interest, and investment. Indeed, of all the 14 trends we studied, the clean-energy and mobility trends attracted the most investment. They have also emerged as significant across multiple industries.

Outside the first two major categories, newer and less-proven digital tools power a set of emerging trends: industrializing machine learning, immersive-reality technologies, trust architectures and digital identity, next-generation software development, and quantum technologies. These trends could have major benefits for businesses. For example, industrializing machine learning (ML) can shorten the production time frame for ML applications by 90 percent. But much work must be done to develop, refine, and commercialize the technologies that underpin these trends. As a result, it's unclear how long it will take for these trends to be adopted in multiple sectors, let alone to realize the potential seen by proponents.

About the McKinsey Technology Council

Technology is changing everything in our work and home lives. We launched the McKinsey Technology Council to help understand what is coming and how it will affect us all—taking a "look around the corner" toward the futures that technology change can unlock as well as the tough questions it raises.

We will look at a spectrum of technologies, from computing to biology, and their applications across all sectors, from mining to entertainment. We look at the science, how it translates into engineering, and when it will accelerate to impact—at scale, and around the world. We are doing this with a diverse group of more than 50 senior leaders in McKinsey, who come from a wide range of science and technology backgrounds, and orchestrating exchanges between them and dozens of leading scientists, entrepreneurs, founders, and researchers who are leading pathbreaking work in their fields.

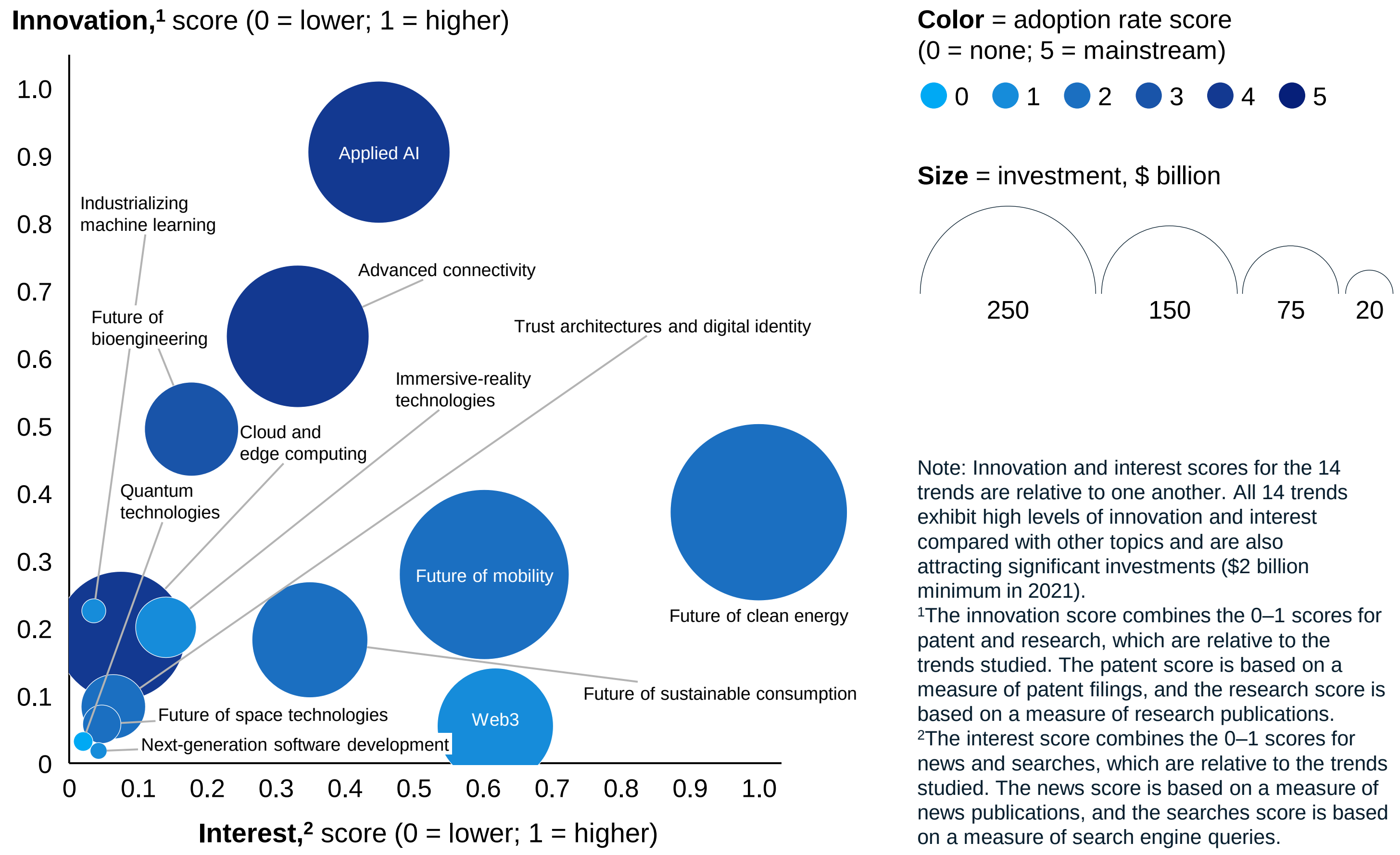
—Lareina Yee, senior partner, McKinsey; chair, McKinsey Technology Council

Introduction (continued)

Exhibit 1

Applied AI recorded the highest innovation score of all 14 trends, while clean energy drew the most interest and investment.

Innovation, interest, investment, and adoption, by technology trend, 2021



Note: Innovation and interest scores for the 14 trends are relative to one another. All 14 trends exhibit high levels of innovation and interest compared with other topics and are also attracting significant investments ($2 billion minimum in 2021).

[1] The innovation score combines the 0–1 scores for patent and research, which are relative to the trends studied. The patent score is based on a measure of patent filings, and the research score is based on a measure of research publications.

[2] The interest score combines the 0–1 scores for news and searches, which are relative to the trends studied. The news score is based on a measure of news publications, and the searches score is based on a measure of search engine queries.

Introduction (continued)

Despite the uncertainty of these newer trends, it's apparent that industries are broadly exposed to changes resulting from technological innovation and the diffusion of new technology-enabled business practices. When we looked at how frequently news reports mentioned companies in 20 sectors alongside different trends, we found that most of these sectors display a meaningful association with five or more trends. The mature and sustainability-focused trends described above exhibit a close connection with multiple industries. Several nascent trends also show a moderately close connection with many industries. Overall, we see that press coverage connects the automotive, manufacturing, telecommunications, and technology sectors closely to at least one trend and moderately to several others (Exhibit 2). We plan to explore the effects that technology trends are having, and could have, on sectors in more depth over the coming months. (For more about how we performed this work, please see the sidebar "Research methodology.")

Looking ahead

We expect changes like these will accelerate and intensify in the years to come, much as they have during the roughly three decades since the start of the internet revolution. The changes will not only alter the competitive landscape but also exert ever-more powerful effects on society: reshaping markets, boosting productivity, spurring economic growth, and enhancing lives and livelihoods.

When we look at these trends, what impresses us more than anything else is the massive effect that technology will have on every sector. The next few decades promise to be a time in which technologies progress ever-more quickly from science to engineering to impact—at scale, and around the world. We also expect to see the multiplying effect of "combinatorial innovation," as different technologies come together in creative ways. For example, this is happening now as organizations combine different technologies to create the metaverse and the many layers that make it up.

Informed by our colleagues and the members of the McKinsey Technology Council, we intend to publish more about the effects of technology trends on particular industries, about the efforts of companies to tap into technology trends, and about the ways that business leaders can manage the implications of technology trends for their strategies, operations, and talent. We invite you to join us in understanding how technology trends evolve and influence the world, and we invite you to share your feedback with us at: techforexecs@mckinsey.com.

About the authors

Michael Chui is a McKinsey Global Institute partner in McKinsey's Bay Area office, where **Roger Roberts** is a partner and **Lareina Yee** is a senior partner.

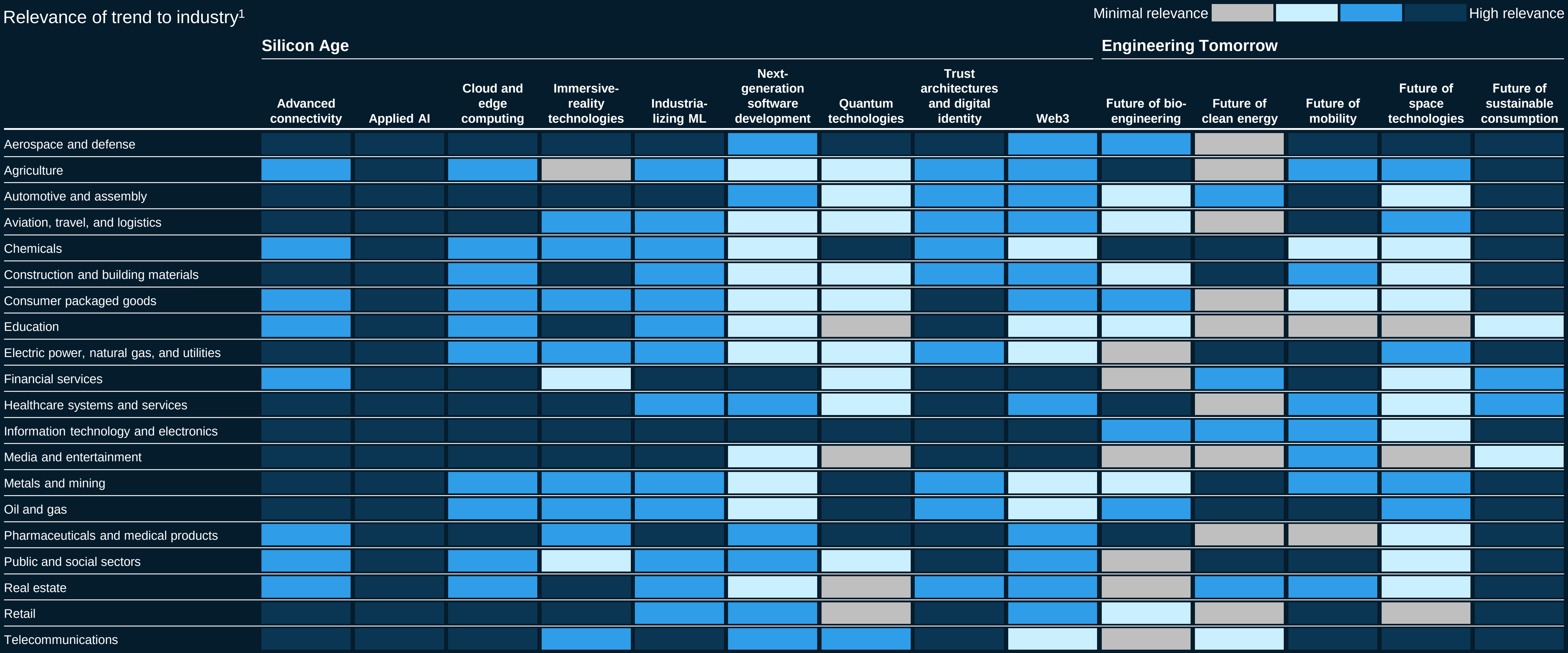
The authors wish to thank the following McKinsey colleagues for their contributions to this research: Soumya Banerjee, Arjita Bhan, Andreas Breiter, Tom Brennan, Ryan Brukardt, Kevin Buehler, Zina Cole, Jacomo Corbo, Chris Daehnick, Ian De Bode, Hugo del Campo, Rayan Elsharkawi, Delfino Garcia, Justin Greis, Liz Grennan, Rob Hamill, Tinashe Handina, Martin Harrysson, David Harvey, Kersten Heineke, Matt Higginson, Nicolas Hohn, Alharith Hussein, Mena Issler, Jesse Klempner, Benedikt Kloss, Charlie Lewis, Martin Linder, Niko Mohr, Timo Möller, Chandrasekhar Panda, Mark Patel, Robin Riedel, Tanya Sheptock, Sven Smit, Shivam Srivastava, Bhargs Srivathsan, Brooke Stokes, Kimberly Te, Kasia Tokarska, Selena Wang-Thomas, Ameera Waterford, Allen Weinberg, Linde Wester, Olivia White, Perez Yeptho, and Matija Zesko.

They also wish to thank the external members of the McKinsey Technology Council.

Introduction (continued)

Exhibit 2

Most industry sectors display a meaningful association with five or more technology trends.



Relevance of trend to industry[1]

Minimal relevance ░ ▒ ▓ █ High relevance

	Silicon Age									Engineering Tomorrow				
	Advanced connectivity	Applied AI	Cloud and edge computing	Immersive-reality technologies	Industrializing ML	Next-generation software development	Quantum technologies	Trust architectures and digital identity	Web3	Future of bioengineering	Future of clean energy	Future of mobility	Future of space technologies	Future of sustainable consumption
Aerospace and defense	█	█	█	█	█	▓	█	█	▓	▓	░	█	█	█
Agriculture	▓	█	▓	░	▓	▒	▒	▓	▓	█	░	▓	▓	█
Automotive and assembly	█	█	█	█	█	▓	▒	▓	▓	▒	▓	█	▒	█
Aviation, travel, and logistics	█	█	█	▓	▓	▒	▒	▓	▓	▒	░	█	▓	█
Chemicals	▓	█	▓	▓	▓	▒	█	▓	▒	█	█	▒	▒	█
Construction and building materials	█	█	▓	█	▓	▒	▒	▓	▓	▒	█	▓	▒	█
Consumer packaged goods	▓	█	▓	▓	▓	▒	▒	█	▓	▓	░	▒	▒	█
Education	▓	█	▓	█	▓	▒	░	█	▒	▒	░	░	░	▒
Electric power, natural gas, and utilities	█	█	▓	▓	▓	▒	▒	▓	▒	░	█	█	▓	█
Financial services	▓	█	█	▒	█	█	▒	█	█	░	▓	█	▒	▓
Healthcare systems and services	█	█	█	█	▓	▓	▒	█	▓	█	░	▓	▒	▓
Information technology and electronics	█	█	█	█	█	█	█	█	█	▓	▓	▓	▒	█
Media and entertainment	█	█	█	█	█	▒	░	█	█	░	░	▓	░	▒
Metals and mining	█	█	▓	▓	▓	▒	█	▓	▒	▒	█	▓	▓	█
Oil and gas	█	█	▓	▓	▓	▒	█	▓	▒	▓	█	█	▓	█
Pharmaceuticals and medical products	▓	█	█	▓	█	▓	█	█	▓	█	░	░	▒	█
Public and social sectors	▓	█	▓	▒	▓	▓	▒	█	▓	░	█	█	▒	█
Real estate	▓	█	▓	█	▓	▒	░	▓	▓	░	▓	▓	▒	█
Retail	█	█	█	█	▓	▓	░	█	▓	▒	░	█	░	█
Telecommunications	█	█	█	▓	█	▓	▓	█	▒	░	▒	█	█	█

[1] Relevance estimated qualitatively by industry experts based on trend's potential to affect an industry; degree of relevance is scaled at both trend and industry levels.

Introduction (continued)

Research methodology

To assess the development of each technology trend, our team collected data on five tangible measures of activity: search engine queries, news publications, patents, research publications, and investment. For each measure, we used a defined set of data sources to find occurrences of keywords associated with each of the 14 trends, screened those occurrences for valid mentions of activity, and indexed the resulting numbers of mentions on a 0–1 scoring scale that is relative to the trends studied. The innovation score combines the patents and research scores; the interest score combines the news and search scores. (While we recognize that an interest score can be inflated by deliberate efforts to stimulate news and search activity, we believe that each score fairly reflects the extent of discussion and debate about a given trend.) Investment measures the flows of funding from the capital markets into companies linked with the trend. Data sources for the scores include the following:

- *Patents.* Data on patent filings are sourced from Google Patents.
- *Research.* Data on research publications are sourced from the Lens (www.lens.org).
- *News.* Data on news publications are sourced from Factiva.
- *Searches.* Data on search engine queries are sourced from Google Trends.
- *Investment.* Data on private-market and public-market capital raises are sourced from PitchBook.

The associations shown on the industry heat map were derived by reviewing the news reports on each trend for references to specific companies within each of the 20 industries.

In addition, we updated the selection and definition of trends from last year’s study to reflect the evolution of technology trends:

- *Trends added since last year’s study:* industrializing machine learning, Web3, immersive-reality technologies, future of mobility, and future of space technologies
- *Trends not carried over from last year’s study:* next-level process automation and virtualization (now considered an implication of several trends) and next-generation materials (partially represented by other trends)
- *Trends with adjusted definitions:* next-generation software development (partly covered under future of programming in 2021), trust architectures and digital identity (partly covered by trust architecture in 2021), future of sustainable consumption (disaggregated from future of clean technologies), and future of clean energy (disaggregated from future of clean technologies)
- *Trends with minor changes to definition:* applied AI, advanced connectivity (previously called future of connectivity), cloud and edge computing (previously called distributed infrastructure), quantum technologies (previously called next-generation computing), and future of bioengineering (previously called Bio Revolution)

Trends at a glance

Silicon Age

Advanced connectivity

Applied AI

Cloud and edge computing

Immersive-reality technologies

Industrializing machine learning

Next-generation software development

Quantum technologies

Trust architectures and digital identity

Web3

Engineering Tomorrow

Future of bioengineering

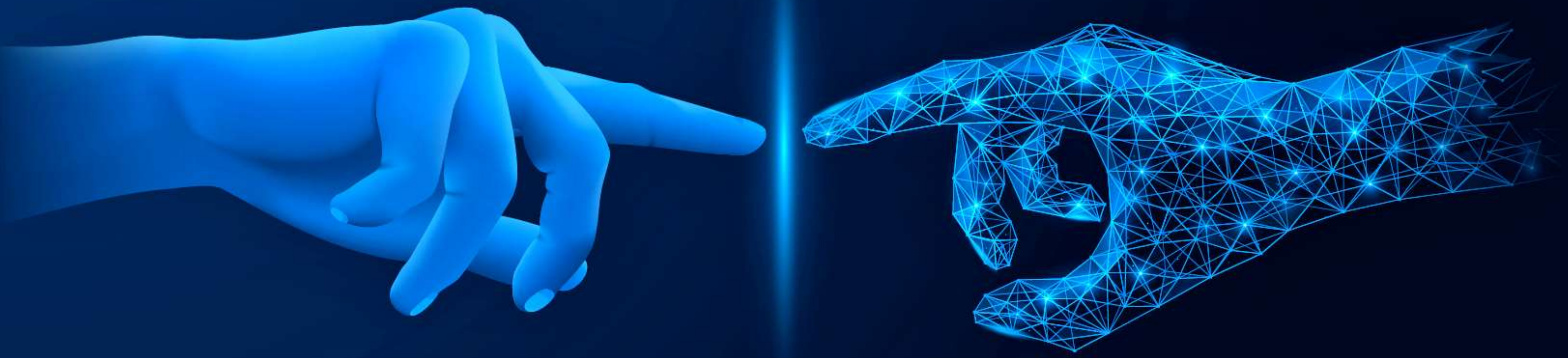
Future of clean energy

Future of mobility

Future of space technologies

Future of sustainable consumption

Trend summaries: Silicon Age



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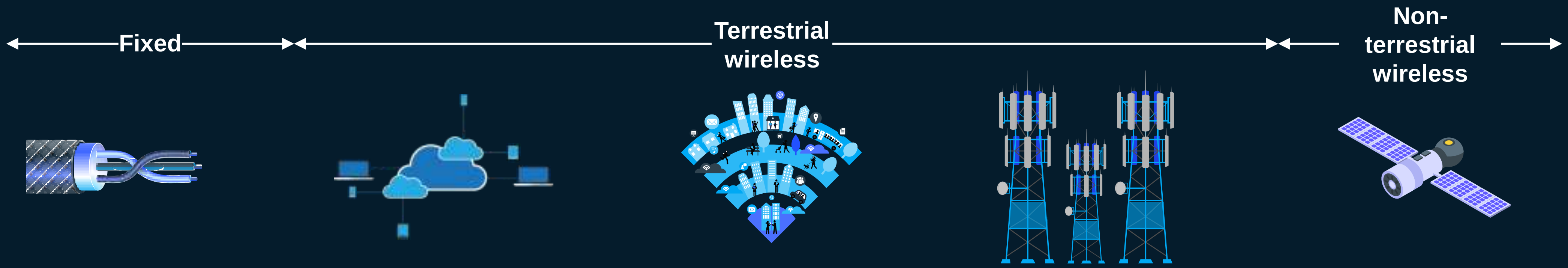
Advanced connectivity

August 2022

What is the trend about, and what are the most noteworthy technologies?

5G/6G cellular, wireless low-power networks, low-Earth-orbit satellites, and other technologies support a host of digital solutions that can help networks increase geographic coverage, reduce latency, reduce energy consumption, increase data throughput, and increase spectrum efficiency. This has led to higher-quality network access for consumers and unlocked new use cases for industrial players



Connectivity technology	Optical fiber	LPWA[1] networks	Wi-Fi 6	5G/6G cellular	LEO[2] satellite constellations
Description	Most reliable high-throughput, low-latency connectivity provided through physical wire	Wireless low-power networks with wide-area coverage supporting a high number of connected devices (eg, NB-IoT,[3] LTE-M, LoRa, Sigfox)	Next-generation Wi-Fi (also called “industrial Wi-Fi”) with higher throughput, more controllable quality of service, and almost “cellular like” level of security	Next-generation cellular technologies with higher-spectrum efficiency, providing high-bandwidth, low-latency services for consumers and industrial verticals	Wide-area coverage with significantly reduced latency vs existing satellite offerings, due to lower-orbit constellations

[1] Low-power wide-area.
[2] Low-Earth orbit.
[3] Narrow-bandwidth Internet of Things.

Source: McKinsey analysis

Why should leaders pay attention?

As advanced connectivity becomes broadly available, industries will find innovative use cases

Monetization opportunities for technology and telecom companies

Uplift in B2B revenues for telecom companies

10–20%

Overall revenue increase from developing 5G-enabled premium connectivity and B2B use cases

Exponentially growing need for network capacity

20–25%

Annual rate of global data creation, which necessitates access to higher-bandwidth networks

Rapid increase in number of connected devices

~51.9 billion

Total number of connected devices expected in 2025, up from 43 billion in 2020

New capabilities for industrial companies and consumers

Impact from industrial use cases

$2 trillion

Estimated global GDP impact, driven by operational enhancements resulting from advanced connectivity in just 4 major industries

Closing the digital divide and enhancing existing connections

~200 million

Number of **individuals accessing the internet for the first time** in 2021, due to new connectivity technologies

Connectivity as an enabler

Enhanced connectivity is an enabler for new and upcoming technologies

- **IoT applications** will increase the need for 5G, Wi-Fi 6, and LPWAN
- **Mobile AR/VR[1] and cloud gaming** are examples of consumer technologies dependent on low-latency, high-throughput wireless networks
- **Edge and cloud computing** technologies, coupled with advanced connectivity, will unlock full benefits of next-gen computing for consumers and industrial verticals

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[1] Augmented reality/virtual reality.

Source: DataSphere Forecast, 2020–2025, IDC; “Connected world: An evolution in connectivity beyond the 5G revolution,” McKinsey, Feb 2020; Simon Kemp, “Digital 2022: Global Overview Report,” Datareportal, Jan 26, 2022; Worldwide Global DataSphere IoT Device and Data Forecast, 2021–2025, IDC

Why are advanced-connectivity technologies interesting, compared with what already exists?

We compared the current generation of advanced connectivity technologies with their predecessors

	Summary	Previous generation	Next/current generation
Optical fiber	Rapid growth has connected millions of people to high-speed internet	Widely used copper had lower throughput and higher cost for an operator	Modern optic fiber brought an exponential increase in **throughput**, much **lower latency,** and lower maintenance costs for telecom companies
LPWAN	Standards designed from the ground up aim to optimize for IoT devices	Relatively costly standard cellular connectivity and low-range tech such as Wi-Fi/Bluetooth drove most IoT applications	Purpose-built LPWAN connectivity standards enable more devices, **higher energy efficiency**, extended **coverage**, and lower connectivity **cost**
Wi-Fi 6	Significantly higher industry readiness has been enabled by improvements in security and connection quality	Wi-Fi 5 brought a marked improvement in indoor wireless connectivity and a major improvement in speed over Wi-Fi 4	Wi-Fi 6 improves upon previous standards in **speed, range,** and **security,** making it more suitable for **industrial applications**
5G/6G cellular wireless	Advanced cellular technology standards are replacing 4G networks, bringing new features and access to new spectrum	4G cellular technology with moderate speed provided true mobile broadband access for the first time	5G/6G offers much higher throughput, device density, **spectrum efficiency, quality of service,** and **security guarantees with** very **low latency** for improved user experiences
LEO satellite constellations	These satellite constellations ensure that the most remote locations on earth have high-quality connectivity	Satellite connectivity was for military and industrial applications, with limited consumer usage for internet or communication	LEO satellites aspire to reduce the cost of hardware and increase accessibility to **satellite internet connectivity** by providing enhanced proximity to users

Source: McKinsey analysis

What disruptions could the trend enable?

Advanced connectivity will catalyze the adoption of technologies to create disruptions in many industries

$1.2T–$2.0T

Estimated global GDP impact from disruption in just 4 major industries

Automotive and assembly	Connectivity could enable **preventive maintenance, improve navigation, prevent collisions**, enable various levels of **vehicle autonomy and carpooling** services, and provide **personalized infotainment** offerings
Healthcare systems and services	Low-latency networks and high density of connected devices and sensors make it possible to **monitor patients at home in real time**, which could be a major boon in the treatment of chronic diseases
Aerospace and defense	From critical communications through nonterrestrial networks (NTN) to connected field assets, connectivity expansions such as 5G networks can vastly boost capabilities and performance for aerospace and defense users
Retail	Connectivity allows retailers to **manage inventory, improve warehouse operations, coordinate supply chains, eliminate checkout activities,** and add **augmented reality** for better product information

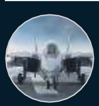
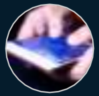
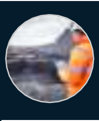
Bridging the digital divide

With broader 5G, optic fiber, and satellite internet coverage, the **digital divide for the next billion internet users is being bridged**

Current users will also see their experiences improve significantly as network speeds and latency improve, enabling use cases previously considered unfeasible

Source: “Connected world: An evolution in connectivity beyond the 5G revolution,” McKinsey, Feb 2020

What disruptions could the trend enable? (continued)

Industry affected	Impact from technology trend
 **Telecommunications**	• Introduce new B2C and B2B service offerings, such as improved cellular services for retail customers and private 5G solutions for enterprise customers
 **Aviation, travel, and logistics**	• Track and trace products and provide data to help customers optimize supply chains using LPWA wireless technology
 **Construction and building materials**	• Building Information Modelling (BIM), onsite 3-D printing, and AR applications will all require high-speed, low-latency, expansive connectivity networks.
 **Information technology and electronics**	• Demand for smart sensors and IoT[1]-enabled devices will grow as connectivity improves and cost drops
 **Media and entertainment**	• Enable high speed, value-creating entertainment experiences within limited disruptions as new devices (eg, AR/VR devices) enter the market
 **Metals and mining**	• Expand coverage to enable “smart mining” and digitization/automation practices that will enhance productivity and safety
 **Electric power, natural gas, and utilities**	• Implement a smart utility grid with smart meters, sensors, and other cloud devices
 **Oil and gas**	• Leverage advanced connectivity technologies to permit and optimize real-time monitoring of drilling and production activities, as well as digital tools and analytics to offshore operators

[1] Internet of Things.

Source: McKinsey analysis

What should leaders consider when engaging with the trend?

Advanced connectivity will be a huge catalyst for change as the value chain and ecosystem continue to mature

Benefits

- **Enabler:** Connectivity is a key enabler of revolutionary capabilities of digital transformations, driving efficiency through automation and enabling technologies reliant on high-quality connectivity such as cloud computing and IoT
- **Experience:** Average consumers’ experiences are enhanced with ubiquitous connectivity and significantly higher quality of service, enabling individuals to work remotely, access bandwidth-heavy services, stream higher-quality content, etc
- **Global aspirations:** Advanced connectivity technologies are aspiring to have a global footprint, as countries from the global south and north stand to benefit significantly in the future, even if the rate of adoption is uneven

Source: McKinsey analysis

Risks and uncertainties

- **Ecosystem maturity:** The ecosystems for evolving connectivity modalities such as LPWA and LEO are maturing, but so far, few players provide solutions and services in markets
- **Business viability:** Commoditization of connectivity has meant that only a few telecom companies have been able to monetize 5G well enough to get a good ROI; the trajectory of capital expenditures and maintenance costs will also be closely watched
- **Availability:** Some technologies, such as high-band 5G and LEO, may be limited by the large capital investments required to build out networks with competitive coverage and performance for mainstream use cases

What industries could be most affected by the trend?

Connectivity technologies are relatively mature with several examples of industries successfully using them to create impact in their operations and services

Cellular wireless, optical fiber, and LPWAN technologies are leading catalysts of change in these industries; applications include ubiquitous connectivity for consumers, industrial automation, and IoT applications such as smart meters

Industry affected	Implications from technology trend
Telecomunications	Telecom companies are using advanced connectivity to introduce new B2C and B2B service offerings, such as improved cellular services for retail customers and private 5G solutions for enterprise customers
Automotive and assembly	Innovative automotive players of the future will introduce self-driving, connected vehicles packed with features that depend on high-quality network access even in remote locations Private 5G, industrial Wi-Fi, and LPWA networks support Industry 4.0 solutions that lift productivity, lower energy consumption, and reduce costs in factories
Aviation, travel, and logistics	LPWA wireless technology lets logistics providers track and trace products and provide data to help customers optimize supply chains, improving overall operational efficiency
Healthcare	Connectivity will be a major boon in the treatment of chronic diseases, as AI-powered diagnostics can be conducted using data from patients while they are monitored at home using connected medical devices; this will improve patient access to healthcare while improving the overall digitization of healthcare services

Source: McKinsey analysis

Who has successfully created impact with advanced connectivity?

Leading players across industries have already leveraged advanced connectivity to optimize their operations

Automotive and assembly

Volkswagen has implemented 5G private networks in their factory in Dresden; VW replaced wired connections between machinery, and now updates finished cars with over-the-air updates and connects unmanned vehicles with edge-cloud servers

Michelin utilized LPWAN to enable real-time inventory management in 2019; using Sigfox standards, Michelin was able to gain up to a 10% reduction of the on-sea inventory and a 40% increase in estimated time of arrival (ETA) accuracy while reducing inventory ruptures caused by exceptional events like critical weather conditions

Bosch equipped their first factory with a 5G private network in 2020; the network enables a range of advanced use cases such as autonomous transport systems at scale, an automation platform connecting hundreds of end points, and robots cooperating with human factory workers by adjusting movements in real time

Telecommunications

Verizon deployed 5G private networks in NFL stadiums to enhance spectators’ experience; these networks allow fans to access real-time stats and data in AR and to access a feed of up to 7 camera angles simultaneously via the 5G multiview offering

What are some topics of debate related to the trend?

Despite relative maturity, advanced connectivity technologies still spark a certain amount of debate regarding their implementation and perceived vs realized benefits

1 **5G Transition**

Can 5G completely replace 4G LTE? What percentage of new networks will have high-band 5G?

- Private 5G networks are a **proven technology, with many players already reaping their benefits**
- Other technologies, such as **IoT and automated guided vehicles,** perform much better when using high-quality networks enabled by private 5G
- However, shifting from 4G LTE to **private 5G may not be cost-effective for all players;** this would depend on a player's technological aspirations and planned use cases

2 **Extraterrestrial networking**

How will satellite constellations shift the balance of bandwidth from terrestrial connectivity to space-to-Earth connectivity?

- A few players are already **piloting internet services;** there are signs that consumer devices with LEO connectivity are on the horizon
- However, due to high capital expenditures and user costs, the **business model and pricing will be a challenge** for scaling up networks, nor can **LEO connectivity fully serve as a substitute for terrestrial networks** for all use cases that rely on cost-efficiency, energy consumption, or overall performance

3 **Choosing LPWA standards**

Will certain LPWA protocols emerge as the standards for particular industries? Or will 5G outcompete LPWA networks for IoT applications?

- Depending on availability of traditional LTE networks, a player might choose **between licensed or unlicensed cellular LPWA standards**; this choice may also be critical when dealing with **stationary and mobile devices**
- LPWA standards vary in terms of **bandwidth, cost, power consumption, range** and other features; depending on the final use case for the player, some standards might be more appropriate than others

Source: Expert interviews; McKinsey analysis

Additional resources

Knowledge center

McKinsey Center for Advanced Connectivity

Related reading

Connected world: An evolution in connectivity beyond the 5G revolution

Interview: Laying the foundation to accelerate the enterprise IoT journey

Unlocking the value of 5G in the B2C marketplace

Reliably connecting the workforce of the future (which is now)

Breaking through the hype: The real-world benefits of 5G connectivity

How tapping connectivity in oil and gas can fuel higher performance

Agriculture’s connected future: How technology can yield new growth

How our latest work helps leaders get ready for the 5G revolution

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Applied AI

August 2022

What is the trend about?

Applied AI uses intelligent application to solve classification, prediction, and control problems **to automate, add, or augment real-world business use cases.** As AI technologies rapidly push new frontiers of innovation, **business adoption** continues to **grow across use cases**

Selected AI technologies[1]
Foundational methods of AI

Machine learning (ML)

- Computer vision
- Natural-language processing (NLP)
- Deep reinforcement learning
- Knowledge graphs

Selected use cases[2]
Applications of AI at work

Risk management

Service operations optimization

Product and/or service development

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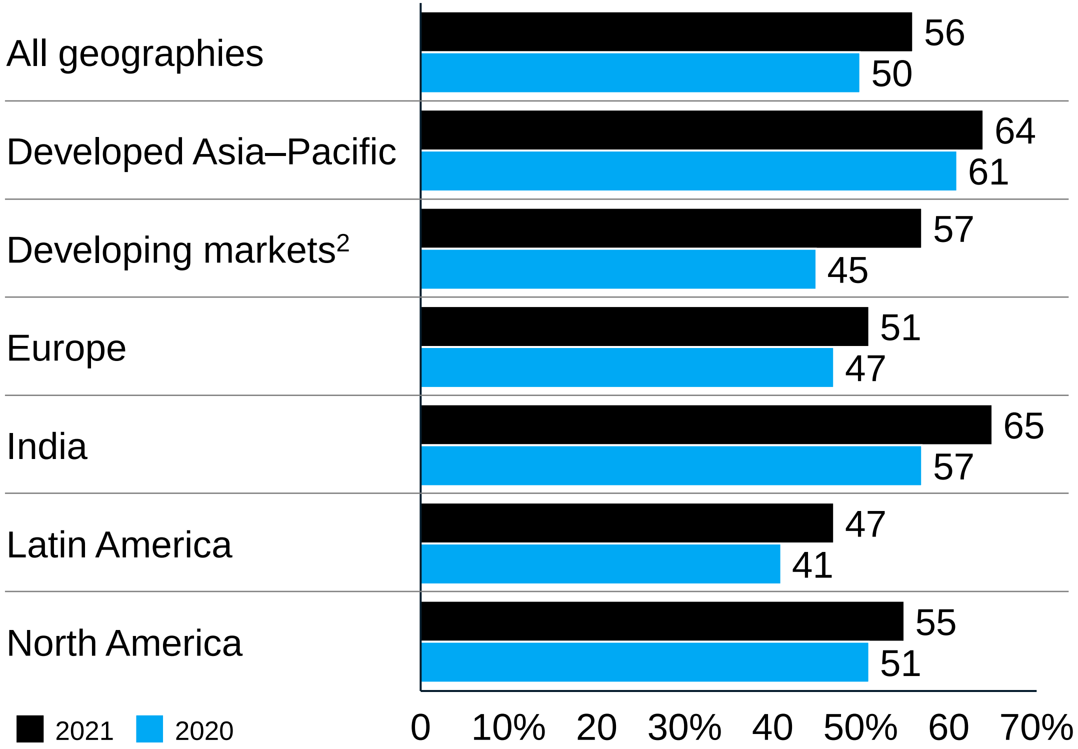
[1] Technologies are nonexhaustive and examples that are at the frontier of innovation and used across industries.
[2] Use cases are nonexhaustive and industry agnostic examples that are leading in business adoption.

Source: McKinsey analysis

Why should leaders pay attention?

AI adoption has continually increased, enabled by its financial investment and development for easier access[1]

AI adoption by organizations, 2020–21, %



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[1] For details about easing ML development and integration, see “Industrializing machine learning,” *McKinsey Technology Trends Outlook 2022*, McKinsey, August 2022.

[2] Including China, Middle East, and North Africa.

Source: Daniel Zhang et al., *The AI Index 2022 annual report*, Stanford University, Mar 2022; “The state of AI in 2021,” McKinsey, Dec 8, 2021

Global expansion of AI

56%

Share of respondents to a 2021 global survey who said their organizations were adopting AI (up 50% from 2020)

Easier and more affordable AI implementation

94.4%

Improvement in training speed for AI models since 2018

Rapidly growing innovation

30×

Relative number of patents filed in 2021 vs. 2015 (compound annual growth rate of 76.9%)

Investment growth and intensified efforts

$93.5 billion

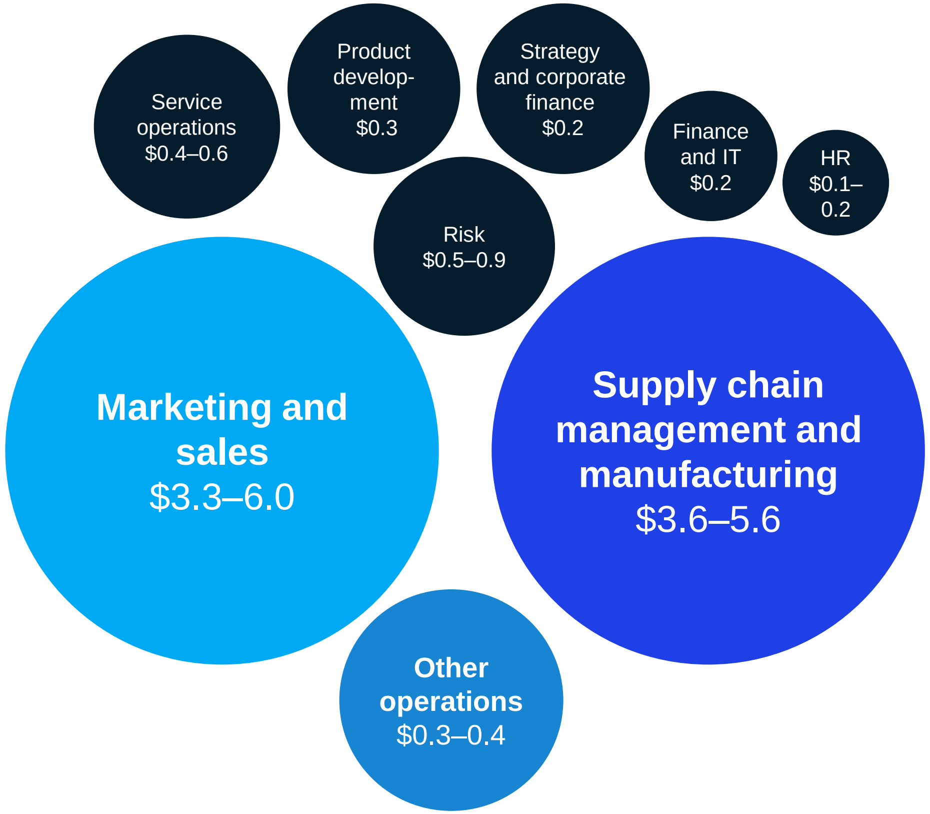
Private investment in AI-related companies in 2021, accompanied by higher concentration of efforts (doubling vs. 2020)

Why should leaders pay attention? (continued)

The potential value at stake from AI is $10 to $15 trillion ...

Global annual potential, forecast

Value at stake, $ trillion



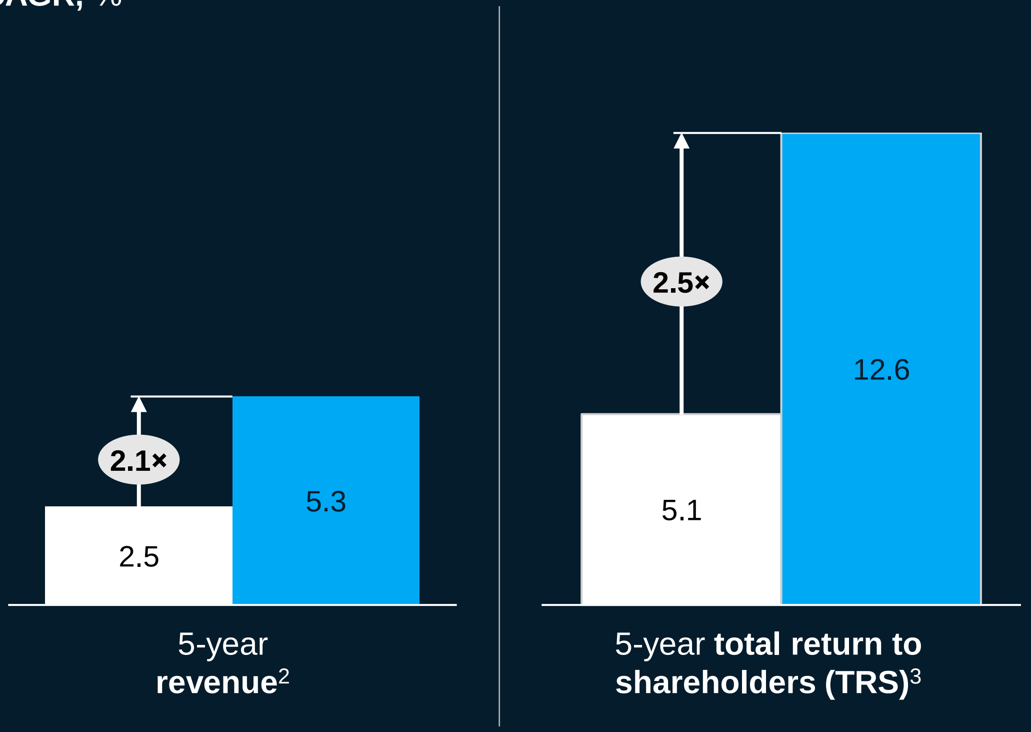
Source: S&P Global, Oct 2020; McKinsey Analytics Quotient data set

… and leaders adopting AI exhibit stronger financial performance

AI maturity and financial performance

⬜ Others 🟦 Analytics leaders[1]

CAGR, %



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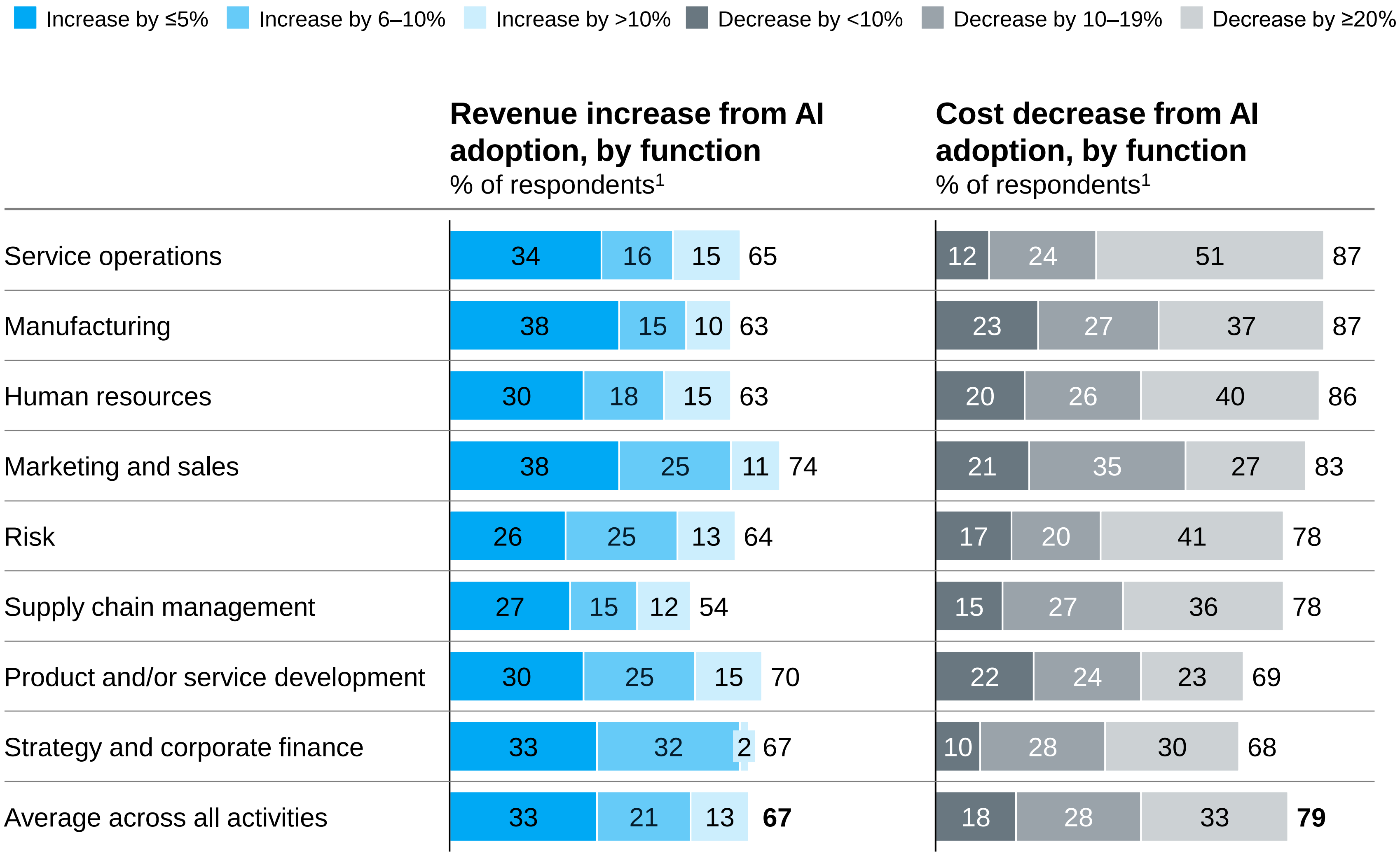
[1] AI leaders are defined as the top quintile of companies that have that taken the McKinsey Analytics Quotient (AQ) assessment.

[2] Includes revenue through fiscal year 2019; during this time, the 5-year revenue CAGR of the S&P 500 index was 4.1%.

[3] Includes TSR through FY 2019; during this time, the 5-year TSR CAGR of the S&P 500 index was 11.7%.

Why should leaders pay attention? (continued)



Revenue increase from AI adoption, by function
% of respondents[1]

Cost decrease from AI adoption, by function
% of respondents[1]

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[1] Earnings before interest and taxes.

Source: "The state of AI in 2021," McKinsey, Dec 8, 2021 (for FY 2020)

Across business functions, AI has already made notable financial impact

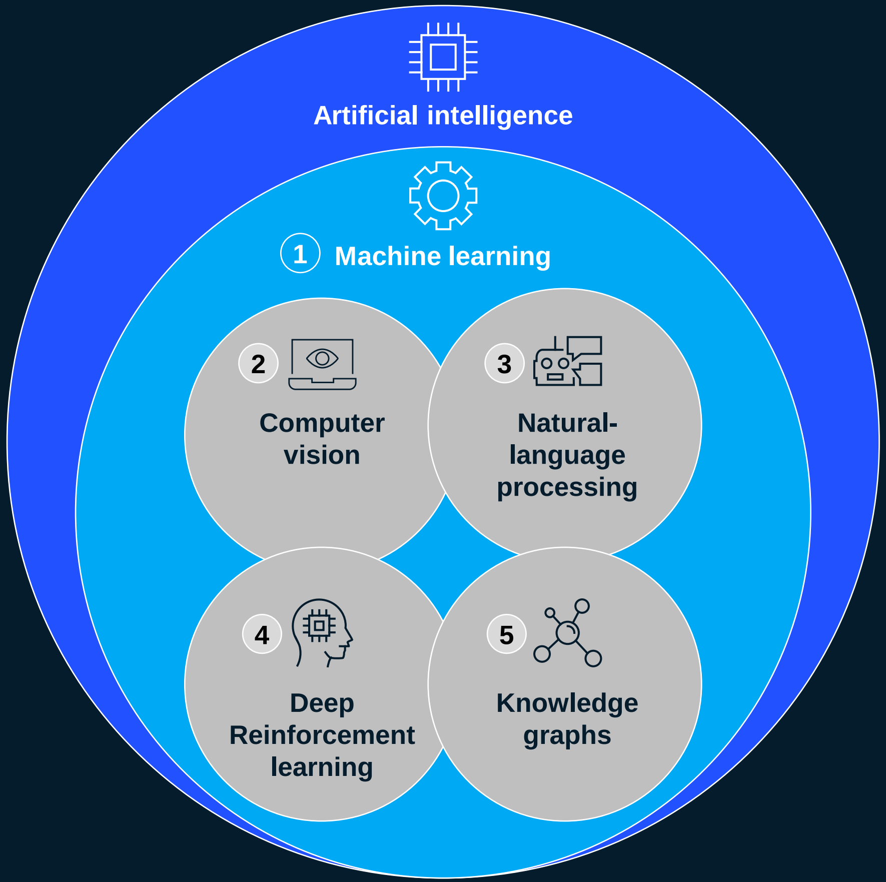
27%
Share of respondents who report at least 5% of EBIT[1] being attributable to AI

67%
Average share of respondents reporting a revenue increase via AI adoption

79%
Average share of respondents reporting a cost decrease via AI adoption

What are the most noteworthy technologies?

AI involves machines exhibiting intelligence,[1] encompassing various interconnected fields of technology[2]



Description	Example use case
① **ML:** Subfield of AI that uses statistical methods to learn from data	Schedule optimization
② **Computer vision:** Subfield of ML using visual data, such as images, videos, and 3-D signals, extracting complex information and gaining rich interpretations	Facial recognition as biometrics
③ **NLP:** Subfield of ML that involves processing, generating, and understanding language-based data, such as written text and spoken word	Speech recognition in a virtual voice assistant
④ **Deep reinforcement learning:** Combination of deep learning and reinforcement learning, in which an agent makes decisions within an uncertain environment using complex algorithms inspired by brain neural networks	Planning robotic-arm motion for the manufacturing line
⑤ **Knowledge graphs:** Collection of data points structured into a network to show complex relationships among themselves	Social-network analysis

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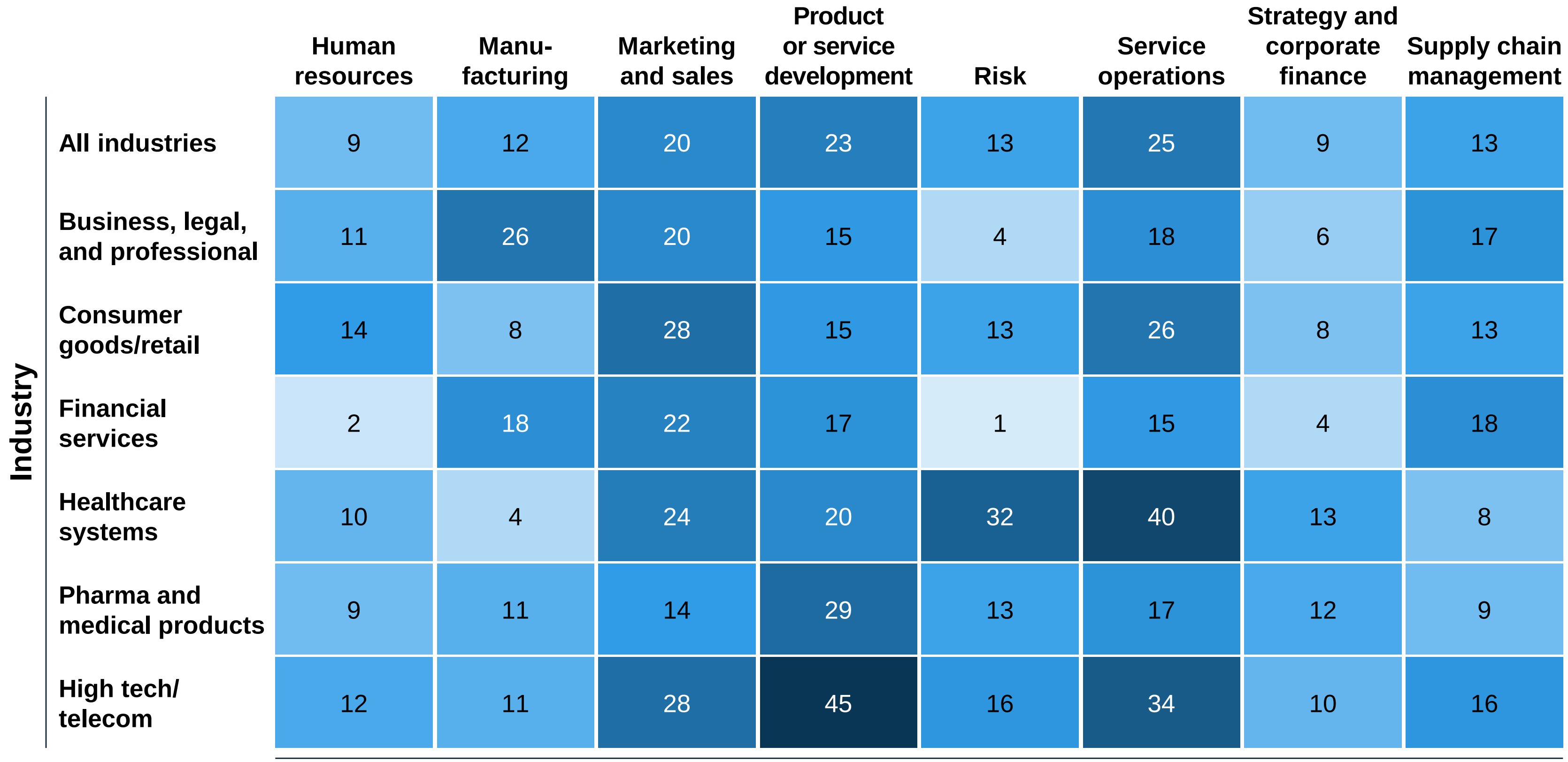
[1] AI is nonprogrammatic intelligence exhibited by machines, in which they perform cognitive functions often associated with human minds. Cognitive functions include all aspects of perceiving, reasoning, learning, and problem solving.

[2] Technologies are not exhaustive and are examples that are at the frontiers of innovation and cut across industries.

Source: Expert input; McKinsey analysis

What industries and functions are leading in the adoption of AI applications?

AI adoption by industry and function, 2021
% of respondents



Industry	Human resources	Manu-facturing	Marketing and sales	Product or service development	Risk	Service operations	Strategy and corporate finance	Supply chain management
All industries	9	12	20	23	13	25	9	13
Business, legal, and professional	11	26	20	15	4	18	6	17
Consumer goods/retail	14	8	28	15	13	26	8	13
Financial services	2	18	22	17	1	15	4	18
Healthcare systems	10	4	24	20	32	40	13	8
Pharma and medical products	9	11	14	29	13	17	12	9
High tech/ telecom	12	11	28	45	16	34	10	16

Source: *AI index report*, McKinsey in collaboration with Stanford University Human-Centered Artificial Intelligence (HAI), Mar 2022

Technology-centric industries are leading adoption by businesses

Product and service development, service operations, and marketing and sales are the business functions leading adoption of AI

What industries are most affected by the trend?

A **diverse set of stakeholders** across all industries are experiencing the impact from applied AI, which can include **disruption in value chains, better financial outcomes**, and **improved operations**

Industry affected[1]	Example impact from the trend
 **Information technology and electronics**	Pervasive use across the tech industry and constituent sectors, such as software, hardware, and electronic devices (eg, use of generative AI models to create 3-D visuals for software simulations)
 **Telecommunications**	Programming AI models to identify recurring customer concerns and deliver solutions before complaints arise
 **Pharmaceuticals and medical products**	Exploring relationships across different medical treatments and their combined outcomes for the discovery of new drugs
 **Aerospace and defense**	Aiding the design process (eg, through visual simulations of aircraft performance under different conditions) as well as for security and risk mitigation processes
 **Healthcare systems and services**	Enhancing healthcare services through functions like automated pathology recognition and diagnosis decision support
 **Financial services**	Supporting risk management in financial services, eg, detecting credit card fraud to reduce incidents of loss
 **Retail and consumer packaged goods**	Boosting sales by using ML to analyze huge sets of purchasing data, discern patterns, and give shoppers customized recommendations
 **Education**	Improving personalized learning based on students' progress
 **Aviation, travel, and logistics**	Leveraging multimodal fusion, enabled by AI, to combine inputs from various sensors that can help operate autonomous vehicles[2]

[1] Not exhaustive and focused on industries where AI has widespread applications with mature adoption.
[2] For more, see "Future of mobility," *McKinsey Technology Trends Outlook 2022*, McKinsey, Aug 2022.

Source: Expert input; McKinsey analysis

What industries are most affected by the trend? (continued)

A **diverse set of stakeholders** across all industries are experiencing implications from applied AI, which can include **disruption in value chains, better financial outcomes**, and **improved operations**

Industry affected[1]	Example impact from the trend
 **Agriculture**	Enabling process optimization through capabilities like productivity forecasting and driverless tractor applications
 **Automotive and assembly**	Automation of quality testing and manufacturing/assembly processes
 **Chemicals**	Optimizing chemical development and production cycles by recognizing molecules, generating chemical compound formulas, and analyzing chemical mixtures
 **Construction and building materials**	Using autonomous machinery and robots, computer-vision enhanced safety procedures, and 3-D design optimization software
 **Electric power, natural gas and utilities**	Optimizing energy production and scheduling, detecting equipment defects early to minimize downtime, and analyzing consumer energy use data to inform personalized recommendations
 **Metals and mining**	Increasing worksite process efficiencies and aiding the development of digital twins that can generate visualizations and models of remote sites
 **Oil and gas**	Exploration of site through computer vision to assess the value of holdings and use AI/ML to customize drilling plans for geologically-complex areas and forecast demand
 **Public and social sectors**	Leveraging AI/ML to expedite delivery of key services (eg, use of NLP for tax FAQ handling); additionally, AI/ML can be used as a tool to help in audit mechanisms to ensure the proper use of resources (eg, predictive tools to help focus tax auditing)
 **Real estate**	Providing personalized customer property recommendations, performing market analyses to help developers manage risk and price volatility, as well as optimizing ROI

[1] Nonexhaustive and focused on industries where AI has widespread applications with mature adoption.

Source: Expert input; McKinsey analysis

What are some use cases for applied AI?

⬜ Innovation led 🟦 Gaining business adoption

Use case[1]	Technology[2]	Function	Relevant industries[3]	Description	Benefits[4]
Generate 3-D models	Computer vision; ML *Optional:* NLP	Product development	Technology; manufacturing; consumer goods; retail	Apply generative techniques that synthesize 3-D visuals based on singular or multimodal instructions. *Examples:* Models for animation, furniture models, and apparel re-creations	Decrease cost with improved efficiency through quickly generated 3-D models
Prioritize dynamically changing tasks	ML; deep reinforcement learning *Optional:* Computer vision; NLP	Service operations	Any	Optimize changing workflow through multitask learning to prioritize most relevant tasks. *Examples:* Schedule-planning and project management tools	Decrease cost with improved productivity
Fuse multi-modal sensors	Deep reinforcement learning; ML; computer vision. *Optional:* NLP	Product development	Transportation; retail; healthcare	Utilize various sensor inputs to perform tasks. *Examples:* Sales checkout for retail; vehicle sensing for autonomous driving	Decrease cost by automating systems requiring sensor input
Recommend products to purchase	ML *Optional:* Knowledge graphs; NLP; computer vision	Product development	Technology; retail finance; healthcare	Predict and suggest potential products relevant to a customer's interests based on prior customer data (individuals or groups). *Examples:* Online suggestions of products to purchase; movie recommendations	Improve revenue through increased sales via personalized recommendations
Detect fraud	ML *Optional:* Knowledge graphs; NLP	Risk management	Any	Detect fraudulent behaviors to reduce incidents of loss. *Examples:* Detection of fraudulent credit card purchases and account log-in	Reduce losses through stronger detection of risky behaviors

[1] List of use cases is nonexhaustive and highlights those that are at the frontier of innovation and/or rapidly gaining adoption across organizations.
[2] Technologies typically used to implement the use case. Optional technologies can be applied but depend on the specific task for the use case.
[3] Relevant industries are nonexhaustive and highlight industries with visible adoption of the use case.
[4] Nonexhaustive benefits, focusing on major benefits to businesses.

Source: Expert input; McKinsey analysis

What should a leader consider when engaging with the trend?

Benefits

- **Cost savings:** Up to 90% of survey respondents cited cost decreases in 2020
- **Overall revenue increase:** Up to 75% of survey respondents cited revenue increases in 2020[1]
- **New use cases:** New use cases will unlock new business capabilities and opportunities across automation and acceleration
- **Increased access to AI and ease of implementation:** New technologies and practices, such as ML operations and software automation, should make AI more readily available

Risks and uncertainties

- **High up-front investment in talent and resources:** This creates a high barrier to entry related to developing AI and ML workflows for production[1]
- **Cybersecurity and privacy concerns:** Data risks and vulnerabilities are occurring across the technical AI workflow; 55% of survey respondents cite cybersecurity as a leading risk in their business in 2021 and are actively taking steps to mitigate it
- **Increasing regulation and compliance:** New legislation will affect the development of AI's direction
- **AI ethics:** Issues include responsibility, equity, fairness, and explainability

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[1] For more about development of ML systems and tools, see "Industrializing machine learning," *McKinsey Technology Trends Outlook 2022*, McKinsey, Aug 2022.

Source: "The state of AI in 2021," McKinsey, Dec 8, 2021; Stanford HAI; McKinsey analysis

What are some topics of debate related to the trend?

1 Trustworthiness

What does it mean to apply trustworthy and responsible AI?

- Potential risks and concerns increase as AI use cases expand
- According to the EU Commission High-Level Expert Group on AI, responsible and trustworthy AI can be defined by abiding laws, incorporating ethics, and implementing technical and social robustness to mitigate potential harm
- The commission has developed 7 requirements for AI responsibility and trust: human agency and oversight; societal and environmental well-being; technical robustness and safety; privacy and data governance; transparency; accountability; and diversity, nondiscrimination, and fairness

2 Explainability

When is AI explainability needed?

- AI explainability looks at how well we can understand an AI model. Interest in this field is rising as models are growing increasingly complex and high-risk use cases (eg, disease diagnosis) are being explored
- According to Stanford University Human-Centered Artificial Intelligence (HAI), there are three types of AI: engineers' explainability (technically explains how the AI model works), causal explainability (explains why a model input leads to its output), and trust-inducing explainability (information that people need to trust and deploy a model)
- Depending on the situation, organizations may use one type of explainability, a combination of types, or all three types (eg, disease risk evaluation looks at all three types)

3 Applications prioritization

How might companies better determine which AI application provide the most benefit?

- Across industries and organizations, each applications of AI will impact different stakeholders in a unique way; understanding how AI impacts each stakeholder, the organization, and the ecosystem will be particularly important for leaders as they decide which AI applications to leverage
- Understanding what impact on a use case an AI application will have will be more essential in prioritization decisions for leaders as they build the capabilities to deploy and monitor AI at scale

4 Other risks

What are other areas of risk that are relevant?

- According to Stanford HAI, leading areas of risk for organizations include cybersecurity, regulatory compliance, explainability, individual privacy, organizational reputation, and equity and fairness
- While customers, shareholders, and regulators are calling for increased scrutiny on these topics, subjective topics (eg, privacy, equity, and fairness) are not high strategic priorities within organizations, as they lack resources and capabilities to fully understand and address these concerns

Source: European Commission High-Level Expert Group on Artificial Intelligence; expert interviews; Stanford HAI; McKinsey analysis

Additional resources

Knowledge center

QuantumBlack, AI by McKinsey

Related reading

The state of AI in 2021

The AI Index Report: Measuring trends in artificial intelligence

It’s time for businesses to chart a course for reinforcement learning

McKinsey
& Company

McKinsey Technology Trends Outlook 2022

Cloud and edge computing

August 2022

What is the trend about, and what are the most noteworthy technologies?

Networks of the future consist of traditional cloud data centers and a variety of computational resources located at network edge nodes closer to end users to reap the benefits of traditional cloud computing while gaining advantages such as better data latency and increased data autonomy

Tomorrow's networks will consist of devices at many locations computing simultaneously

	Edge networks closer to the user					Hybrid cloud
	Device edge	**Remote edge**	**Branch edge**	**Enterprise edge**	**Telecom/MEC[1] edge**	**Cloud**
Compute location	Smartphone Camera Wearable tech	Connected vehicle Resource extraction site Remote filming locations	Branch Retail outlets Restaurants	Factories Hospitals Airports	Network aggregation points Network access points	Regional data centers Co-location data centers Hyperscale data centers
Use cases	Remote patient monitoring Real-time fleet tracking Worker safety monitoring	Remote asset management Remote content rendering	Building energy management Real-time personal promotions Immersive-content experiences	Smart construction and manufacturing Passenger analytics at airports Proactive equipment maintenance	Smart city infrastructure Air quality monitoring Media/content delivery	Streaming media delivery Real-time multiplayer gaming Local content exchange

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[1] Multi-access edge computing.

Source: McKinsey analysis

Why should leaders pay attention?

Cloud has already effected change across industries and will remain an important tech disruption

Cloud computing is a huge opportunity for all organizations

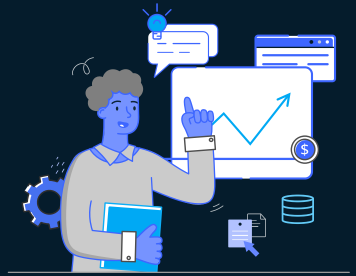
$1 trillion

Opportunity in run-rate EBITDA[1] across Fortune 500 companies in 2030 through cloud cost optimization levers and value-oriented business use cases

Cloud is no longer public or private but is increasingly hybrid

~90%

Share of **cloud users** who **have a multi-cloud strategy**, with over 80% having a hybrid mix of private and public cloud



The market for public cloud continues to grow rapidly

~$300 billion

Worldwide public cloud services market in 2020, growing at a CAGR of ~25%, driven by growth in IaaS, PaaS, and SaaS[2]

Security and access in the cloud remain a top concern for users

~75%

Share of enterprises where cloud security issues are a top concern, with the top challenges being infrastructure configuration, access, and insecure APIs

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[1] Earnings before interest, taxes, depreciation, and amortization.
[2] Infrastructure as a service, platform as a service, and software as a service.

Source: "Cloud's trillion-dollar prize is up for grabs," McKinsey, Feb 2021; Flexera 2022 state of the cloud report, Flexera, Mar 2022; Worldwide Semiannual Public Cloud Services Tracker, IDC, May 2021; 2022 cloud security report, Check Point

Why should leaders pay attention? (continued)

Edge computing might soon become an operational necessity for many organizations

Data regulation is taking center stage around the world

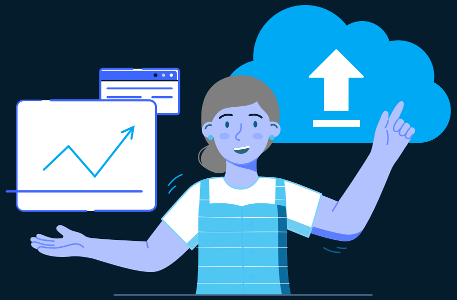
>60

Number of countries reporting data protection localization requirements in 2021; requirements can be fulfilled by adoption of edge storage and computing

Enterprise edge computing spend is growing rapidly

~$250 billion

Projected worldwide spending on edge computing in 2025, growing at a CAGR of ~10%



Data volume and velocity are growing at an unprecedented pace

<20%

Share of data generated by enterprises that is ultimately used, due to challenges with latency and costs of moving data across environments

Distributed computing is getting more popular, unlocking real-time insights

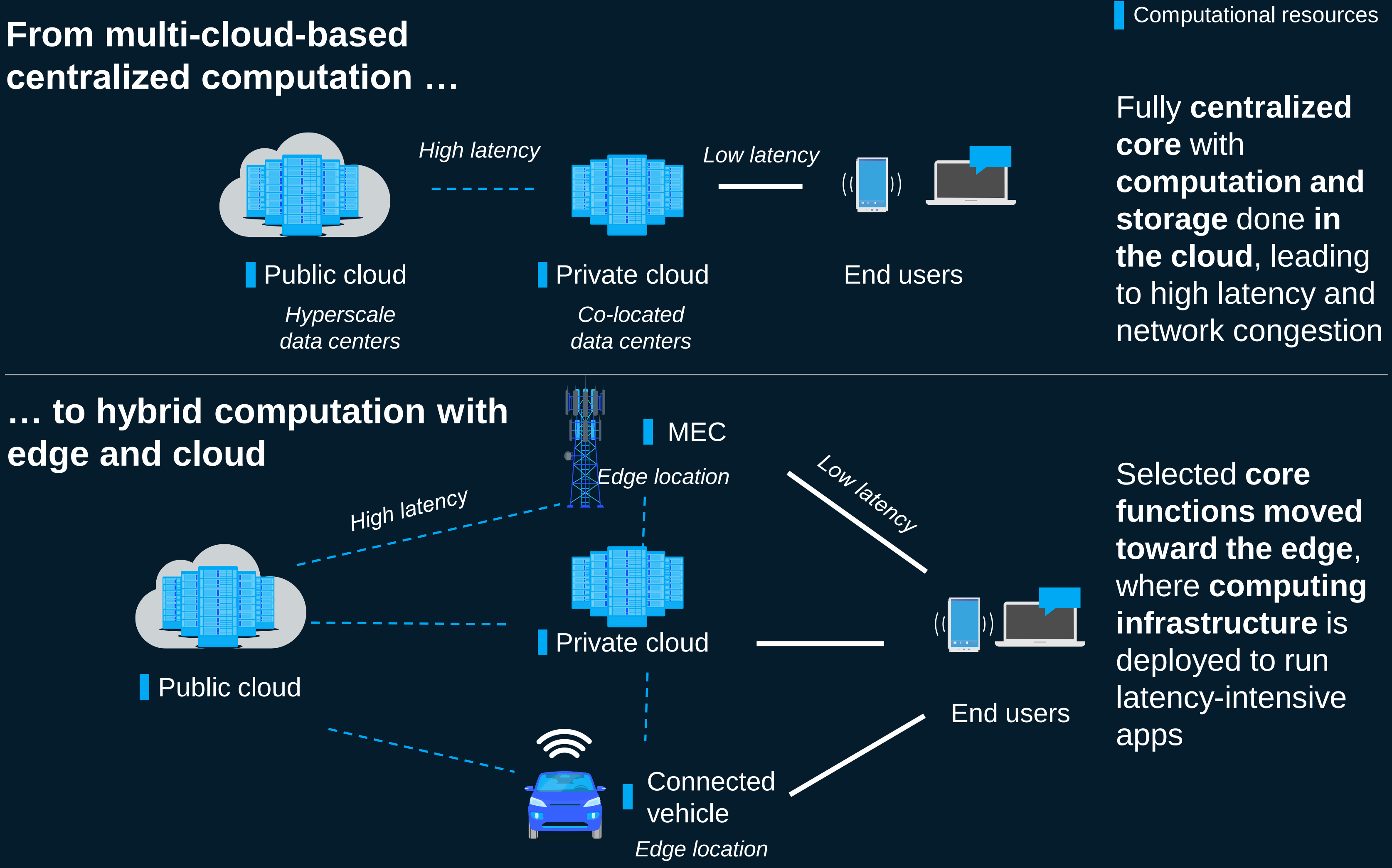
26%

Forecast **share of servers** shipped in 2024 that will be **deployed at the edge**—up from 20% in 2019

Edge computing provides flexibility for organizations to achieve **greater data sovereignty, greater autonomy, better security, and better latency** while unlocking a variety of use cases that rely on real-time data processing

Source: IDC; Omdia

What distinguishes edge computing from traditional cloud?



Fully **centralized core** with **computation and storage** done **in the cloud**, leading to high latency and network congestion

Selected **core functions moved toward the edge**, where **computing infrastructure** is deployed to run latency-intensive apps

Edge computing will leverage many types of networking technology to connect end users to a decentralized core of **computing infrastructure located closer to the end user**

Reduced distance to end users will **shrink data transmission delays and costs,** as well as provide **faster access** to a smaller, more relevant set of data, which helps companies **comply with data residency laws**

Traditional public cloud will continue to play a critical role in the networks of the future by **performing non-time-sensitive computing use cases** at better **economies of scale** at a distance from the end user

Source: McKinsey analysis

What disruptions could the trend enable?

Disruptions from edge computing will have impact on almost all industries and functions

The impact can be described in terms of 2 broad categories:

Network service improvements

Improvements in the **performance of the network** and in the **quality of experience** for users

Content/CDN[1] caching

Mobile backhaul optimization

Media delivery optimization

New services unlocked by improved quality of experience

B2B services that usually do not benefit the end user directly

Active-device location tracking

Real-time personal promotions

Drones/smart robots

Connected cars

B2C services that generally benefit the end user directly

Cloud gaming

Remote desktop applications

Cognitive assistance

Augmented and assisted reality

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[1] Content delivery network.

Source: McKinsey analysis

What should a leader consider when engaging with the trend?

Benefits

Data latency: Edge will enable use cases that had been challenging to implement effectively, due to data latency (eg, cloud gaming, smart factories, autonomous vehicles)

Data residency compliance: Edge will ensure compliance with local data residency laws necessary to experience the benefits of both cloud and edge

Data autonomy: Edge will ensure much more granular control over individual and enterprise data by limiting reliance on public cloud

Data security: Edge provides a security advantage over public cloud infrastructure, which is often susceptible to breaches enabled by the infrastructure-sharing model and misconfigurations

Risks and uncertainties

Business model: Telecom companies and IT service providers need to figure out partnership, services, and infrastructure management approaches to unlock cost-efficiency and avoid major cost increases resulting from greater technical complexity

Technical challenges: Cloud and edge involve managing resources over networks that require interoperability among a wide variety of devices and sensors to deliver value

Scaling hurdles: The growing number of edge nodes and devices will be challenging, since edge doesn't benefit from the same economies of scale as traditional cloud computing

Source: McKinsey analysis

What industries are most affected by the trend?

Edge computing is **quickly approaching maturity;** several players have successfully used it to create impact in their operations and services

Synergetic technologies (**5G, MEC, SD-WAN,**[1] and other advancements in networking) are **driving adoption for edge** to create major impact across many industries

Industry affected	Implications of technology trend
Telecommunications	Increase in revenue streams from technologies such as MEC, given the telecom company role as the primary owner of the networking infrastructure required for distributed computing
Automotive and assembly	Increase in overall efficiency of transportation routes through schedule management, route optimization, etc; reduced reliance of connected/autonomous vehicles on large, distant data centers for access to compute
Electric power, natural gas, and utilities	Increase in employee safety and efficiency at work sites through real-time tracking and optimization; improvements in equipment efficiency through condition monitoring, real-time data processing, and predictive maintenance
Manufacturing	Improvements in networking and data latency, increasing effectiveness of other Industry 4.0 technologies, leading to better overall productivity
Financial services	Sensors and monitors in vehicles, helping insurance players reduce collision and theft
Retail	Improvements in advanced analytics use cases (eg, personalization, staff allocation, theft detection)
Healthcare systems and services	Improvements in most digital use cases (eg, remote diagnostics, active drug tracking, fitness trackers)

[1] Software-defined wide-area network.

Source: McKinsey analysis

What industries are most affected by the trend? (continued)

Edge computing is **quickly approaching maturity;** several players have successfully used it to create impact in their operations and services

Synergetic technologies (**5G, MEC, SD-WAN,**[1] and other advancements in networking) are **driving adoption for edge** to create major impact across many industries

Industry affected	Implications of technology trend
Aerospace and defense	Better networking and data latency, which make automated manufacturing technologies more effective, leading to higher overall productivity for aerospace players, while flowing data to cloud platforms for efficient analytics
Aviation, travel, and logistics	More effective demand forecasting, schedule management, and route optimization; well-orchestrated data decentralization can also provide resilience against data loss
Information technology and electronics	Increase in products and services the industry can offer, spanning cloud and edge environments
Media and entertainment	Maximizing streaming performance and delivery of large volumes of digital content with minimal delays and downtime; enabling flexible server capacity to meet unpredictable consumer demand while maintaining high quality of service
Pharmaceuticals and medical products	Accelerated drug discovery by enabling better use and storage of AI/ML models; continuous monitoring of equipment that improves quality, safety, and yield of drugs and formulations.

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[1] Software-defined wide-area network.

Source: McKinsey analysis

Who has successfully created impact with cloud and edge computing?

Industry	Case example
 **Telecommunications**	**AT&T** has created a new service line providing customers with multi-access edge computing by partnering with system integrators to connect customers' enterprise data centers with LTE and 5G infrastructure
 **Automotive and assembly**	**Tesla**'s vehicles are powered by homegrown full self-driving (FSD) processors that act as edge nodes to run machine learning algorithms trained in the cloud to unlock self-driving capabilities
 **Retail**	**Walmart** is planning to use edge computing not only to improve its own Internet of things (IoT), real-time analytics, and customer experiences but also to leverage its nationwide coverage of supercenters to provide edge computing services to customers near these locations

What are some topics of debate related to the trend?

Cloud and edge computing will undoubtedly create tremendous change, but experts are still debating several key questions

1 Impact of edge computing

Will edge truly be more disruptive than cloud?

- Edge is **extremely flexible** and supports a **wide array of devices** while lying in a **business and regulatory sweet spot**
- However, traditional cloud enables economies of scale that would **be impossible for edge computing** networks that require a **high level of interoperability and commonality of standards** currently absent in networking

2 Outlook

Will hyperscale cloud providers win the edge race?

- Public cloud providers have already **created services and partnership ecosystems** to provide seamless edge and cloud connectivity to their customers
- **Telecom companies with 5G-enabled MEC** can choose to either contend or partner with hyperscalers
- **OEMs and networking and edge service providers** will be important as edge networks scale up and customers require custom solutions

3 Security vulnerabilities

Will the increase in number of storage and processing units lead to security vulnerabilities?

- Keeping **sensitive data at edge locations** away from centralized servers helps restrict access and minimize risks in the event of a major attack
- However, increasing the number of edge locations increases the **attack vectors for malicious actors;** if proper precautions aren’t taken, security vulnerabilities may arise

4 Energy consumption

How will cloud and edge evolve in line with the sustainable IT paradigm?

- Data centers are increasingly relying on green IT measures such as **sustainably sourced energy** and **energy-efficient cooling systems**
- Edge computing further reduces overall energy requirements, as **less data is transmitted across the network** and more is processed and stored locally
- However, as networks expand, the amount of critical infrastructure and number of devices, data centers, and **related energy requirements will continue to increase**

5 Meeting demand

How will cloud and edge resources cope with growing demand?

- As sensor costs drop and performance increases, will new technological advances in the space be able to meet the growing demand for data movement and AI-enabled analytics which rely heavily on the cloud?
- Increase in network capacity and performance may increase demand for cloud-based workloads and reduce the need for specialized edge services

Source: Expert interviews; McKinsey analysis

Additional resources

Knowledge center

Cloud Insights

Related reading

New demand, new markets: What edge computing means for hardware companies

Cloud foundations: Ten commandments for faster—and more profitable—cloud migrations

The cloud transformation engine

McKinsey
& Company

McKinsey Technology Trends Outlook 2022

Immersive-reality technologies

August 2022

What is this trend about?

The immersive-reality space has 4 key components

Technology	**Blending technology into the world** …	to see the **world differently …**		… or see a **different world**
				
	Spatial computing Software enables interaction	**Mixed reality (MR)** Graphics linked to reality	**Augmented reality (AR)** Information not linked to reality	**Virtual reality (VR)** 100% computer graphics
Description	Interprets physical space and introduces virtual 3-D objects, allowing users to **interact with environments that feature virtual elements**	**Modifies the real world** through a device, augmenting or diminishing the user's view of the world	**Interacts directly with** and **overlays** onto the dynamic **external reality** (eg, AR glasses with live translation); runs **interactively in 3-D** and real time	**Replaces the real world** (eg, via headsets) by **placing** the **user in** an **entirely digital experience** that uses external cameras/ sensors to render movements in virtual worlds
Experience	N/A	**Merging of reality and MR:** User's sense of being immersed is gone	**Partly immersive:** User holds a sense of presence in the real world with digital overlay	**Fully immersive:** User's visual sensation is controlled by the system inside the virtual world

Immersive-reality technologies will have a significant role to play in the metaverse

Source: McKinsey analysis

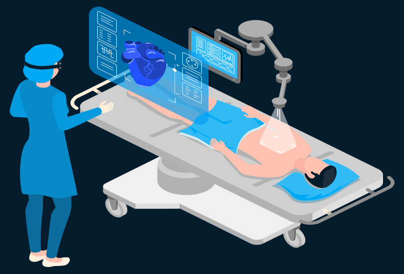
What is this trend about? (continued)

Most mature immersive-reality solutions fall under a few key themes

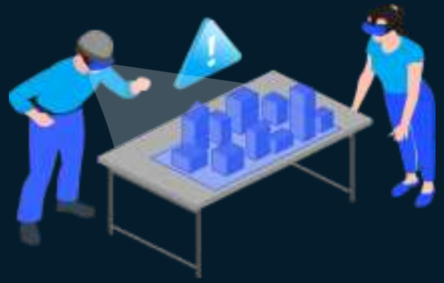
Not exhaustive

Learning and assessment

Learning and training: Hands-on skills and procedures training—especially useful for simulating unusual or dangerous edge cases that are difficult to simulate safely in real life, thus building muscle memory



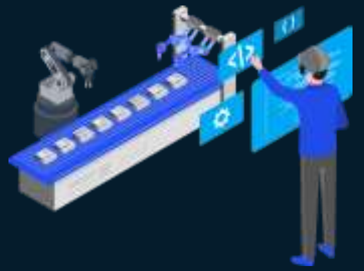
Assessment: Use of the same infrastructure (eg, 3-D models, procedure rules) to stress-test the workforce’s knowledge, skill, and capability in safety and efficiency and target further training needs



Product design and development

Product design: Creation of digital twins to enable virtual walk-throughs of a physical environment (eg, construction site) or a physical product (eg, new space satellite), enabling more efficient product prototyping and test simulations

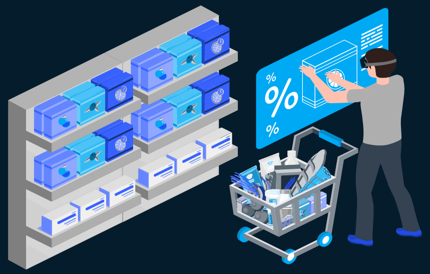
Development: Simulation of process design, such as a software engineer “grabbing” blocks of code overlaid virtually onto factory equipment to redesign the process flow, then pushing the equipment back into production



Enhanced situational awareness

Overlay of data visualization enables more productive assessment of situations

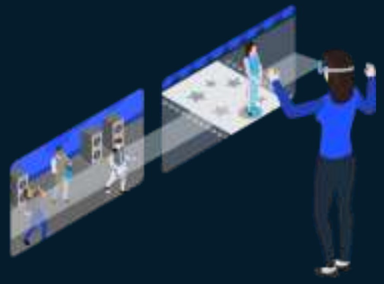
Retail example: Store manager observes store while wearing AR glasses that display sales data overlaid on sections and products



Manufacturing example: Lead engineer conducts factory operations and maintenance remotely; VR tech enables workers to conduct virtual walk-throughs, with visualized data and pop-up decision options for areas requiring maintenance or repair

B2C use cases (eg, gaming, fitness, retail)

Live events: Gaming, virtual workouts, and other virtual events mimicking real-life experiences such as concerts, conferences, sporting events, and fashion shows



Virtual showroom: Shopping by virtually walking through stores, trying on new products, etc

Source: McKinsey analysis

Why should leaders pay attention?

Overall trends

~$1.2 trillion market size by 2035

Global immersive-reality market size is expected to grow at a CAGR of ~24% until 2035, facilitated by several factors, including increased use of smartphones and connected devices and rising adoption of 5G networks

Increasing innovation

2× growth in immersive-reality patents from 2018 to 2021

Growing venture capital investments

~$3.9 billion of venture capital investments made into VR/AR start-ups in 2021, the second-best year historically (after ~$4.4 billion in 2018) as venture capital interest recovers from COVID-19 pandemic

2.2× growth in average ticket size from 2020 to 2021; 1.3× growth from 2018

Growing B2B adoption

~66% CAGR in enterprise adoption of AR through 2026

Need for more collaboration platforms (eg, Virbela, ARuVR) triggered by COVID-19 pandemic to enable remote work

Increasing functionality across industries

Product and service enablement

Rapid prototyping (eg, driven by early-stage amendments and powerful visualization) shortens time to market and **reduces costs drastically**

New services unlocked by engaging consumers in new ways

Development and training scalability

Scalability of training expands across all sectors, particularly for non-desk workers (eg, situational/ emergency training without risking users), while ensuring standardization in quality of training

Process improvement

Faster and more efficient processes possible via early-warning-detection mechanisms, risk management, improved quality assurance, reduced assembly/ construction efforts, and reduced guesswork in manual labor

Source: "Demand for augmented reality in enterprise and consumer markets to create US $175 billion AR market by 2026," ABI Research, June 10, 2021; Chris Metinko, "VR/AR investments increase just as metaverse talk heats up—but that may not be the only reason," Crunchbase News, Jan 21, 2022; "Extended reality market size, share, trends, by type," Emergen Research, Feb 2021; McKinsey analysis

What are the most noteworthy technologies?

AR

- Augmented reality (AR) is **a partly immersive** experience in which **users interact directly with a 3-D overlay** onto the **external reality in real time**
- Examples of AR technology devices include AR projections from phone devices, AR windshield on cars, AR glasses
- Capabilities needed to advance this technology include common use higher resolution displays (eg, 8K), more precise eye sensing and tracking technology to reduce lags and errors in display overlay, etc

VR

- Virtual reality is **a fully immersive** digital experience in which **computer-graphics-rendered virtual worlds replace the real world**
- Examples of VR technology devices include headsets for a fully immersive VR experience
- Capabilities needed to accelerate this technology include specialized lower-latency hardware, improved sensors that allow for full-body virtual tracking, etc

Significant advancements are still required for AR/VR and are 8–10 years out

While some capabilities are technically possible today in isolation, **device makers need to consider features** such as battery life, weight, and ergonomics, which adds challenges (eg, 8K displays exist but are too heavy and expensive for common use)

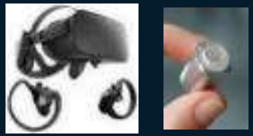
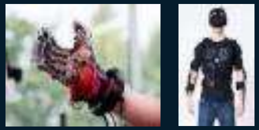
AR requires technology that is significantly superior to that of VR

Unlocking scalability will require **reducing prices by >50%**

Source: McKinsey analysis

What are the most noteworthy technologies? (continued)

A diverse set of sensors and input will be needed, expanding the peripherals market 10−20× from today

Type	Overview	
On-body sensors	On-body sensors are tools to track and identify users and the objects around them to **accurately reflect their limb movements and the physical objects around them in the virtual world** (eg, devices that are handheld or concealed in wearables)	
Off-body sensors	Off-body sensors allow for more **precise recreation of elements of the physical world** in virtual spaces with consumer applications like Nintendo Wii or enterprise applications such as spatial-mapping hardware	
Haptics	Haptic devices (eg, haptic gloves or vests) **convey the sense of touch to the user** with vibrations to augment virtual experiences	
Holography and volumetric video	Holograms and volumetric video diffract light across multiple wave fronts to display **high-quality, 3-D representations that can be seen without using a headset** (eg, Microsoft Mesh or Google Project Starline)	
Electromyography (EMG)	EMG is a neuro technology that **detects and records electrical activity from muscles to control movement and manipulate objects** in virtual spaces and is being used in wearables to augment AR/VR headset devices	
Microelectromechanical system (MEMS)	MEMS uses midair ultrasonic waves to **allow users to physically feel tactile experiences without any wearables**	

What disruptions could the trend enable?

Maturity level

	Near term 0–3 years	**Medium term** 3–10 years	**Long term/end state** 10+ years
AR 	AR **exists mostly as a proof of concept** with **few enterprise use cases;** experiences occur within **narrowly defined environments** (eg, warehouses) and overlay low-fi visuals over the real world	**Consumer AR** is introduced as a **low-fi experience** while **enterprise AR improves**, with augmented visuals interacting more fluidly with external inputs and **usability expanding** out of preprogrammed spaces and use cases	**Consumer AR shrinks and use cases proliferate**, with a seamless digital layer acting as an overlay to the real world; as users navigate fluidly throughout their day, external sensors interpret, interact with, and enhance the physical environment
VR 	**Medium-fidelity VR** experiences offer **limited virtual worlds and experiences;** avatars are manipulated using external peripherals that limit immersion	**High-fidelity** and **comfortable VR** experiences are **available at scale;** avatars are manipulated via body movements captured by sensors	**Virtual worlds** in VR are **almost indistinguishable from real life**, and haptics have improved to give a realistic sense of feel across the body

Source: McKinsey analysis

What industries could be most affected by the trend?

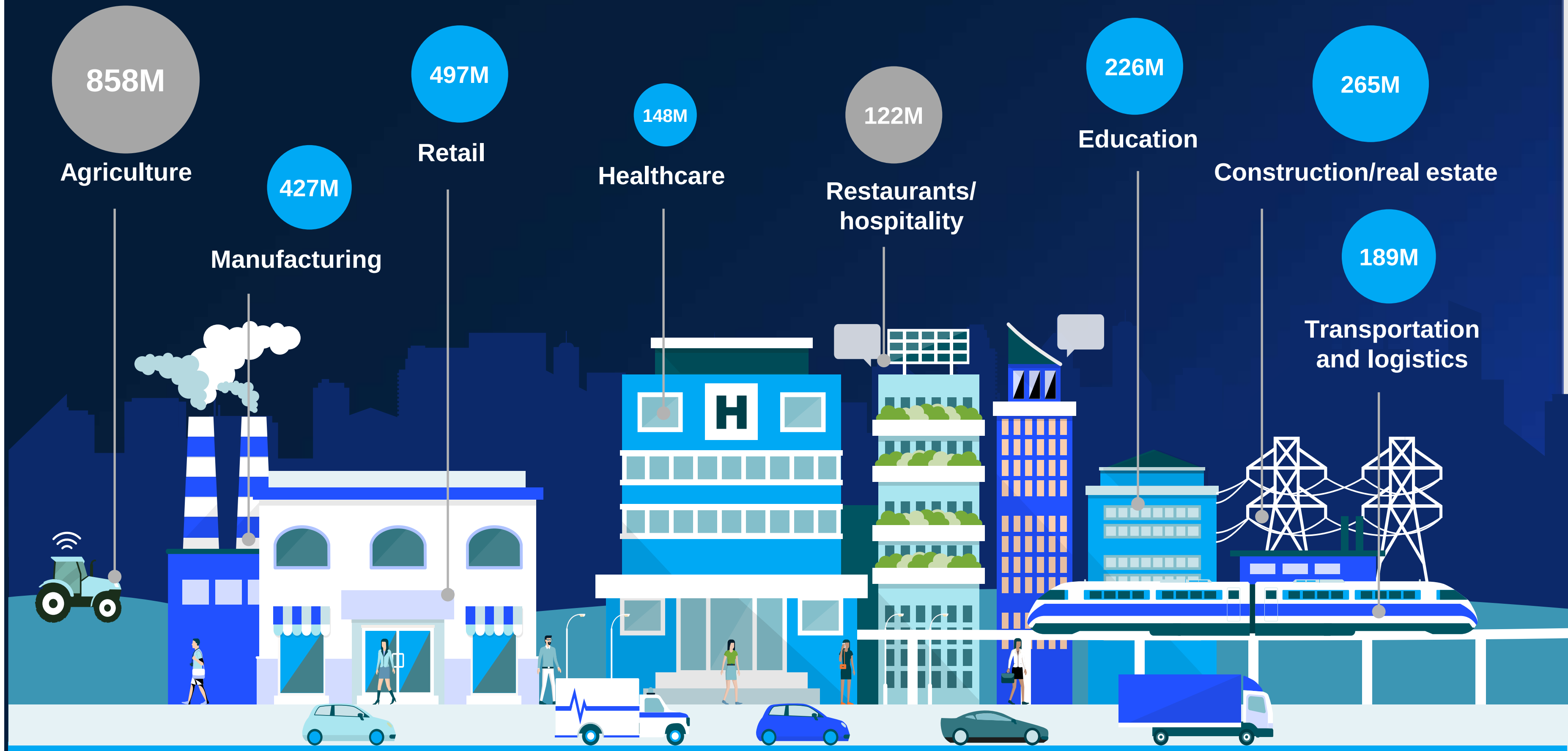
Overall, industries with a higher proportion of non-desk workers are leading in adoption

~75% of deskless workers spend most of their time at work using some form of tech, with >60% reporting lack of satisfaction or feeling the need for improvement in the tech they use

Source: “The rise of the deskless workforce,” Emergence, 2018; McKinsey analysis

● High expected impact
● Insignificant impact

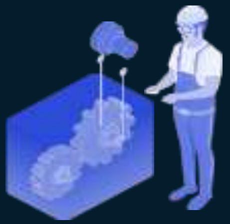
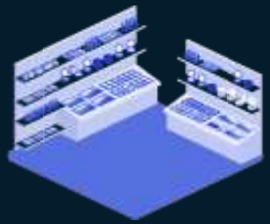
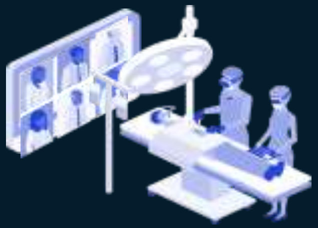
The world’s **2.7 billion** deskless workers, representing **~80%** of the global workforce, are concentrated in 8 industries and present huge potential for scaling immersive-reality technology



What industries could be most affected by the trend? (continued)

Use cases are emerging both horizontally and vertically across industries

Not exhaustive

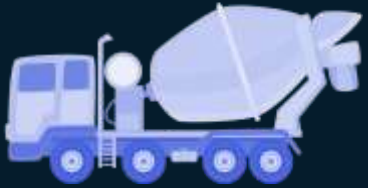
Industry	**Education**	**Automotive and assembly; aerospace and defense**	**Retail**	**Healthcare systems and services**
Example use cases	Learning and development Remote collaboration Field-worker assistance Conferences and events	Digital twins/operations Factory design Product design Training Remote assistance Safety	3-D catalog Virtual store/digital showrooms Interactive try-on Store layout and design Warehouse optimization	Surgical assistance (AR) Telemedicine (mental health, pain management, etc) Imaging/pathology Training R&D/simulations
				
Significance	**63%** of companies that are metaverse adopters have undertaken learning and development for employees in the metaverse	**~100%** of design of physical products/spaces (eg, factories, warehouses) could be simulated in a synthetic environment	**~33%** of customers who are active on the metaverse have purchased real-world items there	**Increasing efficacy** of immersive-reality solutions in treating mental disorders

Source: Nilufar Baghaei et al., "Extended reality for anxiety and depression therapy amidst mental disorders: A systematic review," ResearchGate, Mar 2022; "Value creation in the metaverse: The real business of the virtual world," McKinsey, June 2022

What industries could be most affected by the trend? (continued)

Immersive reality could change the way energy and materials industries operate

Not exhaustive

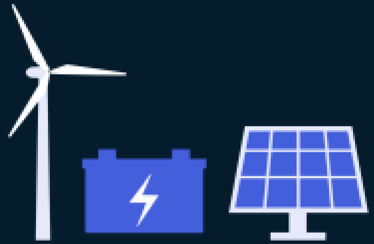


Construction and building materials

Creating immersive, virtual environments, giving architects a better sense of a space before it physically exists

Real estate

Designing interior spaces along with floor and furniture planning, and providing virtual tours of properties to enhance customer experience



Electric power, natural gas, and utilities

Using AR to view overlaid visualization of underground assets and complex components for improved operational safety (eg, advising field technician on what actions to take)

Aviation, travel, and logistics

Diagnosing flow constraints in warehouses and managing vehicle fleets

Media and entertainment

Participating in virtual events mimicking real-life experiences such as concerts, conferences, sporting events, and fashion shows

Source: McKinsey analysis

Who has successfully created impact with immersive-reality technologies?

Many industries have started to experiment with AR applications

Information technology and electronics

Fujitsu uses **AR in the sales process** to allow customers to see all product characteristics

Aerospace and defense

Boeing leverages AR to improve manufacturing process efficiency and has achieved a **90% quality increase** and **30% speed increase** on its pilot projects

Aviation, travel, and logistics

Japan Airlines is experimenting with Microsoft HoloLens AR as a **technical training tool** for its maintenance technicians

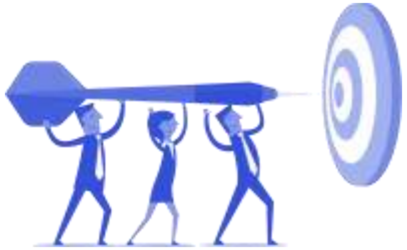
Automotive and assembly

Porsche has **shortened operational time** spent on **addressing issues by 40%** through the use of AR headsets to simulate virtual models of problem vehicles

Source: Company websites

What should leaders consider when engaging with the trend?

Not exhaustive



Benefits

More efficient product prototyping and test simulations through the creation of digital twins to enable virtual walk-throughs of physical environments or new physical products

Process improvement through early-warning-detection mechanisms, risk management, improved quality assurance, on-the-job visual guidance, and more

Introduction of new products and services by engaging consumers in new ways and enhancing customer experiences

Increased collaboration by facilitating more engaging virtual-team interactions, without the need of being physically present

Scalability of trainings by allowing users to develop hands-on skills, especially when simulating unusual situations, all while ensuring consistency in the quality of training provided

Cost savings as a result of effective product development, improved processes, and scalable, quality-assured trainings

Source: McKinsey analysis

Risks and uncertainties

Pace of hardware improvements to enable miniaturization/weight reduction, ruggedness; sensor advances for increased precision, nausea mitigation, etc

Cost reductions required to make many more applications commercially viable and scalable

Uncertainty on whether consumer applications will target niche customer segments or focus broadly on mass markets

End-user devices could take multiple forms, from independent platforms to peripheral accessories for smartphones or a mix of both

Exposure to complex security vulnerabilities must be mitigated, as typical AR/VR applications need access to many technologies (eg, smartphones, body sensors, glasses) and may be linked with social-media accounts and external applications

Concern about user's ability to control what data are collected and how data are processed or shared with third parties (eg, to what extent will users be surveilled?)

What are some topics of debate related to the trend?

Not exhaustive

1 **Ways of working**

Will immersive reality shift the new wave of (remote) work?

Many business are reconsidering their remote vs in-person work operating models as COVID-19 measures are relaxed. As immersive-reality tech boosts collaboration and facilitates remote operations, will remote work be here to stay?

2 **Scalability**

Will initial ideas continue to stall at proof of concept—or begin to break through to scale? What will be the triggers for breakout success?

Significant tech advancements still required for AR/VR are approximately 8–10 years out. Although some of the required individual capabilities are technically possible today, device makers still need to produce these features (eg, battery life, weight, ergonomics) in conjunction with each other to improve sensory precision, mitigate security and privacy concerns, and broaden consumer applications, among other factors.

3 **Enterprise architecture integration**

How will consumer-oriented pioneering platforms integrate with enterprise tech architectures?

Adopting immersive-reality solutions puts a strain on tech architecture. Enterprises will have to evolve their capabilities to integrate with these new technologies while mitigating privacy and security concerns; the investments required to do so are unclear.

4 **False information**

To what extent can immersive reality facilitate the spread of false information?

Deepfake technology and mixed reality facilitate misrepresentation (eg, facial-swap features), which could have social implications such as cultural appropriation or the spread of "fake news" for targeted political influence or any other malicious intent.

5 **Virtual crimes**

How can virtual crimes be mitigated and regulated?

Ethical questions are emerging around the potential psychological effects of immersive-reality technologies, raising questions around how to deal with different forms of harm, such as virtual violence, bullying, and trespassing.

Source: McKinsey analysis

Additional resources

Related reading

Augmented and virtual reality: The promise and peril of immersive technologies

Product development gets a makeover—with virtual reality

Meet the metaverse: Creating real value in a virtual world

Value creation in the metaverse

McKinsey
& Company

McKinsey Technology Trends Outlook 2022

Industrializing machine learning

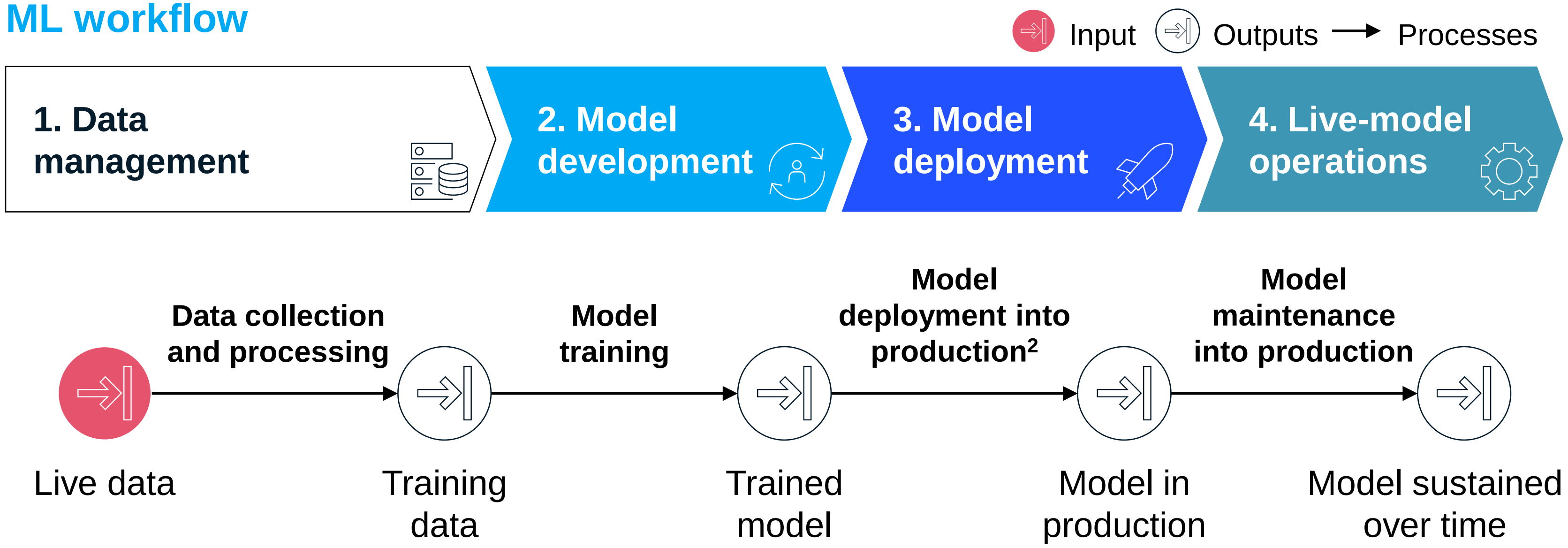
August 2022

What is the trend about?

Machine learning (ML) workflows are the processes that bring AI and ML into production for real-world business use

Solutions industrializing ML provide the **software and hardware technologies to scale ML workflows and ease the development and deployment of ML** for organizations[1]

ML workflow



● Input ○ Outputs → Processes

1. Data management

2. Model development

3. Model deployment

4. Live-model operations

Live data

Data collection and processing

Training data

Model training

Trained model

Model deployment into production[2]

Model in production

Model maintenance into production

Model sustained over time

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[1] To differentiate applied AI and industrializing ML, this tech trend refers to the systems that put AI (including its subfields such as ML) into production for real-life business use. Applied AI refers to the real-world business use cases after the technical infrastructure is implemented.

[2] Once performance standards are met.

Source: McKinsey analysis

Future progression

ML production for organizations is **delivered reliably** and **at scale,** featuring:

- deployment scaled across networks
- modular structure with high reuse
- robust monitoring and testing
- automation of common processes
- low maintenance cost, lower risk, higher ROI

Why should leaders pay attention?

Solutions for industrializing ML address the technical challenges that prevent organizations from unlocking the full potential of AI and ML

AI is becoming essential for success …

AI has massive potential across industries

$10T–$15T
global impact potential

AI is disrupting traditional business models

5
of 10 largest global companies did not exist 25 years ago

AI leaders have stronger financial performance

2.5×
greater 5-year total shareholder returns

… but challenges remain

72%

of organizations surveyed have not successfully adopted and scaled[1]

Challenges include:

- Difficult transition from pilots to products
- Model failure in production
- Stalling team productivity
- Limitations in protection against potential risks from unknown variables

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[1] McKinsey survey with >1,000 company executives who launched transformations. Organizations get stalled in the pilot phase or during scaling, or they have limited impact despite scale.

Source: “Notes from the AI frontier: Applications and value of deep learning,” McKinsey Global Institute, April 17, 2018; S&P Capital IQ (Oct 2020); McKinsey analysis

Why should leaders pay attention? (continued)

Industrializing ML has potential for impact on all industries by reducing hurdles to develop ML in a reliable manner[1]

Value levers	Impact potential within 1 year[2]
Maintain performance	**~60%** less value erosion 12 months from model deployment because of live-model operations
Accelerate time to value	**~8–10×** less time from proof of concept to production system because of standardization from data management to model deployment
Reduce risk	**100%** of production models integrated into enterprise risk governance and fully auditable because of interoperable systems
Increase productivity	**~30–40%** resource reduction for ML operations with improved automation

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[1] Impact also associated with the applied-AI tech trend.

[2] Based on observations from ML operations deployment in 5 large-scale analytics transformations supported by McKinsey.

Source: Expert input; McKinsey analysis

Why are the technologies interesting, compared with what already exists?

This emerging tech stack is moving toward simplicity, scalability, and interoperability across the full ML workflow life cycle

	From	To
Overall ML workflow	**Outdated tools** operated in an **inefficient manner** **Fragmented technology landscape** creating inconsistent standards and **limiting collaboration** between teams	**Tooling optimizing ML workflows** Technology enabling **learning to be shared** and **collaboration** across the business, including technical and nontechnical employees
Data management	**Massive manual effort** for **one-off use** with **no controls** over quality and drift, which can damage overall performance	**Automated** data management for **high-quality data** **Data reuse** across hundreds of solutions with **robust controls**
Model development	**Individualistic, artisan** experimentation **Highly manual** work that needs **refactoring before use**	**Structured and collaborative** development **Solutions assembled from prebuilt components** and tooling with high degree of **automation**
Model deployment	**No control** over what is running in production **Manual and error-prone** deployment with **poor testing and validation**	**Controlled production release** decisions **Model management providing full transparency** on production solutions **Automated, efficient CI/CD**[1] for **test and validation of all releases**
Live-model operations	**Performance degrading,** often undetected, **eroding model value** **Unstable solutions** down for weeks at a time	End-to-end ML **system monitoring** with instant alerts enabling rapid issue resolution

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[1] Continuous integration (CI) and continuous delivery (CD).

Source: Expert input; McKinsey analysis

What are the most noteworthy technologies?

Software solutions across the ML workflow

ML workflow

	1. Data management	2. Model development	3. Model deployment	4. Live-model operations
ML subprocesses	Data discovery and creation • collection Data transformation • labeling • validation Data versioning	Feature engineering Model development and optimization • model selection • training and tuning Experimentation and testing	Model registry and management Model testing and validation Model deployment • continuous integration • continuous deployment	Monitoring (eg, infrastructure, data, model, key performance indicators) Model maintenance • continuous improvement Model explainability
Examples of technology solutions	Data platforms for data discovery and extraction Synthetic data Automated data labeling Reproducible data pipelines	Model libraries Centralized repository for experimentation Experiment tracking and model visualization tools Developer environments (notebooks and IDEs[1])	Packaged testing and deployment platforms Version and result tracking	Monitoring of live-model, data pipelines, and related issues Continuous retraining with periodic refreshing of data sets

↔

Plug-and-play end-to-end platforms

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[1]Integrated development environments.

Source: Expert input; McKinsey analysis

What are the most noteworthy technologies? (continued)

Hardware solutions for software interconnection and workload optimization

Integrated hardware

Solutions connecting physical hardware chips and software frameworks

Vertically integrated hardware systems

Specialized hardware–software solutions that are tailored to specific ML tasks; service-based examples include access management service to GPUs and data flow as a service

Horizontally integrated hardware

Hardware offering a diverse and broad set of solutions (eg, simplifying use of distributed compute)

Heterogeneous computing

Solutions optimizing computational workloads by allocating different hardware chips based on specific task[1]

Graphical processing units (GPUs)

Hardware useful for linear-algebra-based computations

AI-specific GPUs are being tailored with faster training speeds, faster transfer speeds, and stronger computing power

Tensor processing units (TPUs)

Specialized hardware useful for deep-learning computations and able to handle complex linear algebra (eg, “tensor” or matrix multiplications)

Neuromorphic processing units (NPUs):

Early-stage hardware chip based on brain neural-network architectures with potential impact for low energy consumption

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[1] With the end approaching for Moore’s law and Dennard’s law, where computational growth grows exponentially, new solutions for optimizing computing are being explored. The solutions here are different computer chips that can be leveraged for different tasks.

Source: Expert input; McKinsey analysis

What should leaders consider when engaging with the trend?

Benefits

Accelerated AI adoption due to reduced technical barriers and requirements to implement AI

Improved productivity for technical employees across ML life cycle

Easier collaboration between technical and nontechnical experts on ML model development

Scalability and interoperability leveraging bigger, richer reused data sets

Reduced cost through faster development and deployment, standardized processes, improved technical performance

Improved security and privacy along with reduced risk due to greater standardization and process automation, transparency, and robustness

Risks and uncertainties

Upfront investment and resources for setup, where organizations need ML-savvy talent and processes to build capabilities and accelerate the learning curve across the organization

Dependency on 3rd-party vendors leading development of ML technologies for initial onboarding and continuous support

Fast-developing market, where processes and accountability for maintaining ML solutions have been poorly defined

Increasing regulation and compliance, where legislation can affect ML’s development (eg, data governance policies affecting data management solutions)

Increasing need for responsible and trustworthy ML systems to address concerns about ethics, privacy, equity and fairness, explainability, accountability, security, and governance

Source: Expert input; McKinsey analysis

Who has successfully created impact by industrializing ML?

Solutions for industrializing ML have generated value for organization as part of large-scale analytics transformations

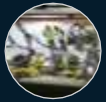
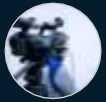
	Global pharma company	Asian digital bank	North American retailer
Context	Integrating **personalized recommender system** for **>**50 country and drug combinations **Sales uplift of 10–20%**	Industrializing and scaling AI use cases to become a truly data-driven bank Enabling >**150 use cases** annually	Applying solutions industrializing ML to address scaling pain points Scaled up **end-to-end analytics transformation** from only 5 models in production
Technology used[1]	**Software for model development** **Software for model deployment** **Software for live-model operations**	**Software at all stages** **Hardware at all stages**	**Software for model deployment** **Software for live-model operations**
Impact achieved	**Time to market**: 4 months → 1 month **Code compatibility check**: 2 weeks → 2 hours **Tech setup time**: 3 days → 15 minutes	**Lead time to production**: 18 months → 3 months **Asset reuse**: <10% → >50% **Enterprise risk coverage**: 0% → 100%	**Deployment process**: Manual and error prone → Automated and reliable **Deployment lead time**: 2 weeks → 1 day **Deployment time**: >8 hours → 15 minutes

[1] Diverse solutions used according to the technology type and subprocess.

Source: Expert input; McKinsey analysis

What industries could be most affected by the trend?

A **diverse set of stakeholders** across a range of industries are experiencing implications from the industrialization of ML; impact from this trend is most expected in industries where accelerating production of ML application yields a competitive advantage

Industry affected	Examples of impact from tech trend
 **Information technology and electronics**	Designing hardware and software so that devices become more integrated and connected with the natural world (eg, AI models to interpret voice commands, sensors)
 **Telecommunications**	Deployment to aid business functions from marketing and sales (eg, upselling or cross-selling engines) to customer service (eg, call center volume forecasting and predictions) and network optimizations
 **Pharmaceuticals and medical products**	Supporting the development of new drugs, (eg, through exploring relationships between molecules and chemical compounds) and enabling support functions (eg, manufacturing, supply chain optimization) for various medical treatments
 **Aerospace and defense**	Augmenting design and manufacturing processes through optimizations from AI/ML models (eg, AI models to aid in the 3-D simulations for aircraft design, supply chain optimization for manufacturing, security risk management)
 **Automotive and assembly**	Using AI/ML to enhance design and manufacturing processes such as predictive maintenance, automated quality testing, and demand forecasting and to provide customer service features such as navigation
 **Financial services**	Supporting key services in the financial sector including risk management and assisting in many other processes—eg, by detecting credit card fraud
 **Media and entertainment**	Provision of high levels of personalization in media and entertainment experiences (eg, tailored recommendations)

What are some topics of debate related to the trend?

1 Impact of ML industrialization on organizations and technical talent

How can solutions that industrialize ML change organizations, their operating models, and their engineering roles?

The technologies are part of a wider effort in scaling ML operations toward a **modular, automated, monitored life cycle approach** to AI/ML—potential impact:

- **reduce resourcing needs and production times**
- **'democratize'** (ie, use nonspecialized) **data scientists** working horizontally on **most value-add tasks,** assisted by standardized tooling
- reduce technical barriers and enable **closer collaboration with nontechnical SMEs,**[1] offering greater visibility and expanding potential use cases

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2 Selection criteria for solution that industrialize ML

How should organizations select which solutions that industrialize ML are most relevant to their needs and strategy?

- **Industry-specific use cases** influence **ML workflows,** varying drastically across risk levels, required data governance, SME relevance, and model complexity
- Potential long-term dependency on 3rd-party vendors means organizations may have **long-term partnerships rather than solution providers,** often making trade-offs between **best-of-breed vs end-to-end/cloud-native ML platforms** and **open-source vs supported enterprise software**

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3 Accountability for AI and ML

As the solutions that industrialize ML grow, how can roles of accountability be defined to ensure trustworthy and responsible AI/ML?

- Processes and accountability for maintaining ML solutions are **currently poorly defined,** with **lack of clarity on roles** of responsibility across the ML workflow
- As with applied AI, organizations will have to make **trade-offs on which aspects of trustworthy AI** are priorities for their business, which will have downstream impact on their decisions and interactions with solutions industrializing ML

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[1] Small and medium-size enterprises.

Source: Expert input; McKinsey analysis

Additional resources

Knowledge center

QuantumBlack, AI by McKinsey

Related reading

Scaling AI like a tech native: The CEO’s role

Operationalizing machine learning in processes

Transforming advanced manufacturing through Industry 4.0

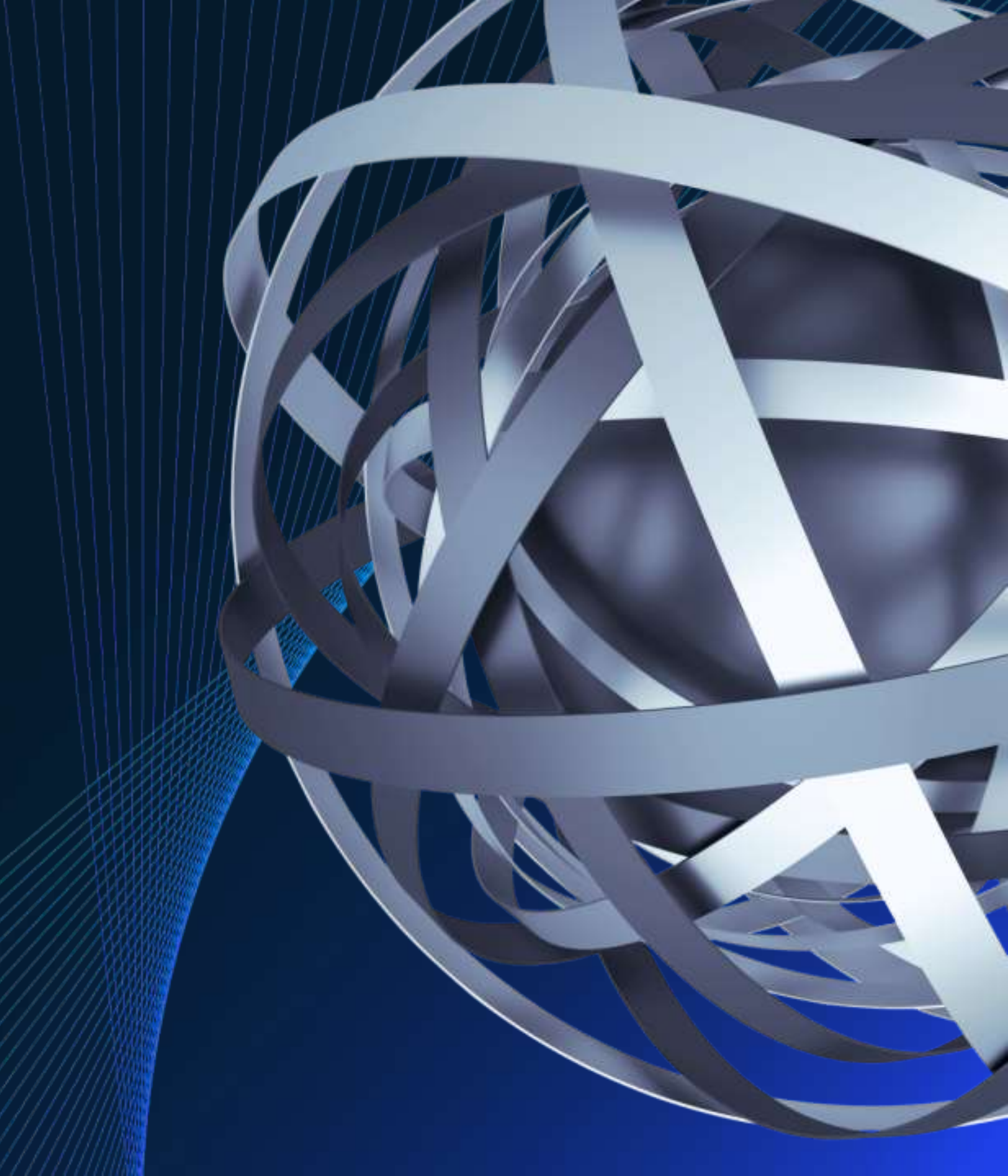
Derisking machine learning and artificial intelligence

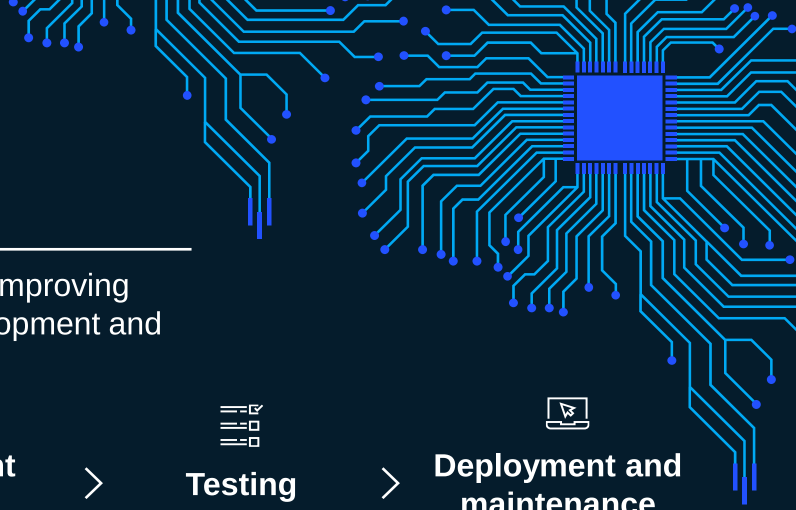
McKinsey
& Company

McKinsey Technology Trends Outlook 2022

Next-generation software development

August 2022

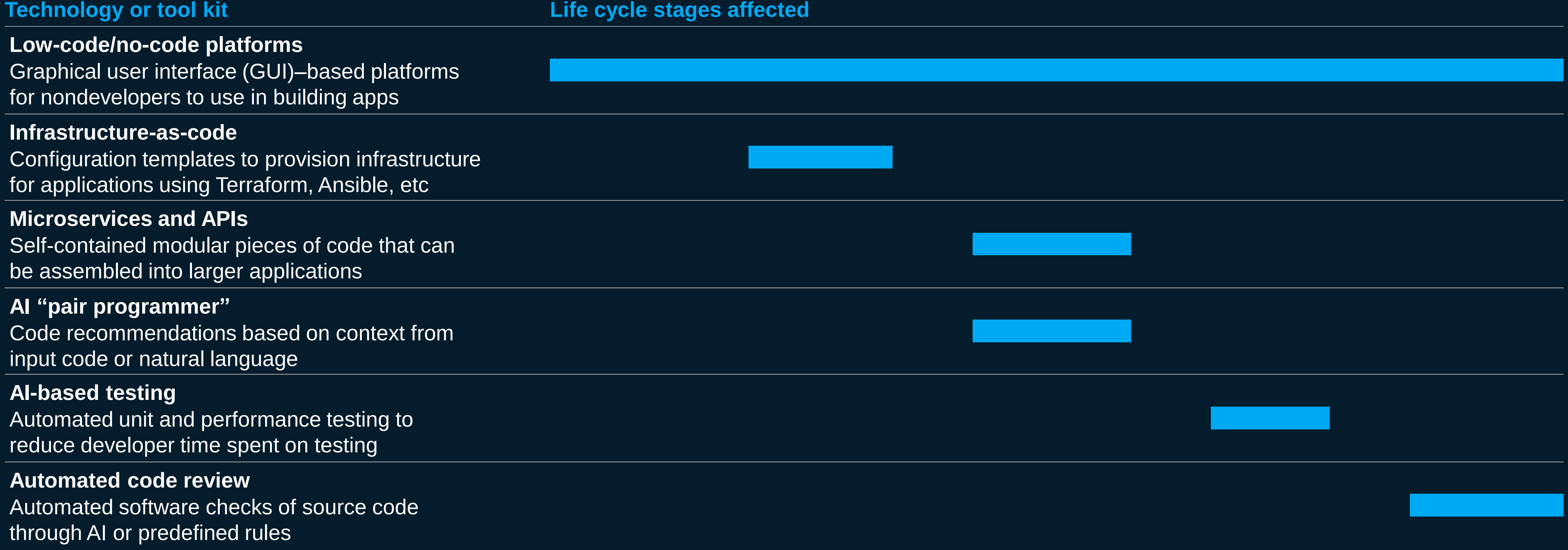




What is this trend about?

The next generation of software development involves tooling that aids in the development of software applications, improving processes and software quality across each stage of the software development life cycle, including AI-enabled development and testing, as well as low-code/no-code tools

Planning and analysis > **Architecture design** > **Development and coding** > **Testing** > **Deployment and maintenance**



Low-code/no-code platforms
Graphical user interface (GUI)–based platforms for nondevelopers to use in building apps

Infrastructure-as-code
Configuration templates to provision infrastructure for applications using Terraform, Ansible, etc

Microservices and APIs
Self-contained modular pieces of code that can be assembled into larger applications

AI "pair programmer"
Code recommendations based on context from input code or natural language

AI-based testing
Automated unit and performance testing to reduce developer time spent on testing

Automated code review
Automated software checks of source code through AI or predefined rules

Source: McKinsey analysis

Why should leaders pay attention?

Developers will focus more on the capabilities their applications would enable than on the details of building the apps

Growth in market and adoption

Greater adoption

~70%

Share of new application development that will leverage low-code/no-code by 2025 (vs <25% in 2020)

Growth in market size

~21%

Growth in size of market for software development, **CAGR for 2021–26,** reaching ~$600 million by 2026

Augmented capabilities

Faster development

Up to **~90%**

Reduction in development time due to low-code/no-code applications

Faster deployment

~2×

Increase in deployment speed reported by ~60% of developers, driven by practices such as continuous integration and continuous delivery (CI/CD)

Faster code testing

~37%

Share of respondents saying they **use AI and ML to test better** and faster

Reduced resolution time

<1 day

Time to resolve configuration issues reported by ~75% of companies with automated infrastructure-as-code security testing

As repetitive tasks become automated and resource requirements to build digital products decrease, developers will **focus on adding new, innovative features**

Many methods, including CI/CD and infrastructure-as-code, will **benefit from cloud migration** and accelerate this transition

Source: Gartner; “Software development AI market overview,” IndustryARC; *Intelligent process automation and the emergence of digital automation platforms*, Red Hat, February 2018; *A maturing DevSecOps landscape*, GitLab, May 4, 2021; Forrester Analytics Business Technographics Developer Survey, 2020; *Infrastructure as code security insights*, Snyk, 2021

Why are the technologies interesting, compared with what already exists?

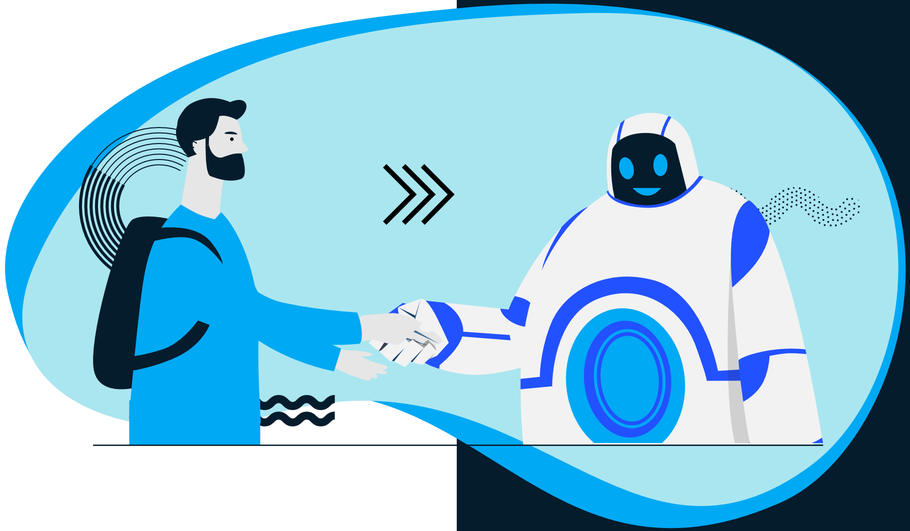
From manual, time-intensive work flows and techniques …

Reliance on dedicated developers to participate in every step of the development cycle, from planning to maintenance, contributes to higher costs and talent gaps

Manual infrastructure configuration and monitoring involve high mean time to restore (MTTR), security risks, and task repetition, leading to inefficient resource utilization

Developers working together to write code as 'pair programmers' on the same workstation expend a high number of person-hours to build the program

Development cycles are slow because teams experience interruptions, code has more defects, and time is spent on manual tasks



… to automated, simplified, and faster development techniques

Greater participation of 'citizen developers' (business users who have insignificant technical experience but are able to build business applications without involving technical teams) facilitates quick development of solutions more aligned to business needs

Automated configuration and monitoring through infrastructure-as-code reduces downtime and increases overall productivity and security

AI-based pair programmers are making solo developers more efficient and improving quality of code

Fully automated CI/CD pipelines enable lower disruption, higher code quality, and drastically shorter development cycles

Source: McKinsey analysis

What are the most noteworthy technologies?

Across the entire software development life cycle, technologies are already improving developer velocity

Not exhaustive

1. Planning and analysis

2. Architecture design

3. Development and coding

4. Testing

5. Deployment and maintenance

Infrastructure-as-code

Higher scalability as configuration templates are used to set up new environments rapidly and consistently

Reduced risks as configuration templates eliminate possibility of human error

AI pair programmer

Rapid development as developers **code faster** with reduced friction to aid “developer flow”

Enabler of automatic translations and **low-code/no-code tools**

Microservices and APIs

Faster development as microservices and APIs serve as building blocks companies use to effortlessly add functionality to software, unlocking significant business agility

New revenue streams as APIs can be provided to customers in an as-a-service model and externally to other businesses for integration

AI-based testing

Faster, more efficient testing via smarter automation

Improved test coverage and effectiveness, with automated script writing expected to exceed 80% of test coverage within the next decade and to auto-generate insights for improvement

Automated code review

Faster, more efficient code reviews with greater coverage as a result of eliminating manual inputs and removing human biases

Low-code/ no-code platforms

Standardized tools and processes that scale tech innovation via reuse of components

Acceleration application development through plug-and-play software components

Stronger business alignment as a result of bringing technical requirements closer to business units

Automated deployment of models into production applications

Augmented monitoring and maintenance (eg, model retraining) to minimize performance degradation

Source: Expert interviews; McKinsey analysis

What industries could be most affected?

Beyond the information technology and electronics industry, these technologies will have an **impact on software development across all industries** by reducing digitization challenges

Many industries are already reaping the benefits of low-code/no-code platforms, given their **common qualities** and requirements

▌High industry relevance ▌Medium industry relevance

Industry	Examples	Common industry qualities	
Financial services	Evolving business rules for processes such as onboarding, know your customer (KYC), and customer due diligence can be continuously handled by business analysts for efficiency	Compliance requires a **wide variety of frameworks, protocols,** and **regulations,** which typically vary by region, license agreement, etc	**Heavily process-based** industries **Significant customization requirements** **Rapid pace of innovation** to meet evolving customer needs
Healthcare systems and services; pharmaceuticals and medical products	Case management processes for handling customer data, tailored and specific processes for high-risk patients, development and testing of new drugs, etc, can be customized by healthcare providers		
Manufacturing processes in automotive and assembly and aerospace and defense	Production floor management allows industrial engineers to optimize operations, reduce training expenses for new developers, reduce production floor failures, and standardize safety/handover protocols		
Retail	Consumer-friendly front-end applications can be rapidly created and tailored to the needs of an organization and its customers		

Source: Expert interviews; McKinsey analysis

Who has successfully created impact with next-generation software development?

Leading players across industries have already leveraged advanced DevOps tools to optimize their SDLC[1]

Stage of SDLC[1]	Technology	Example
Architecture design	**Infrastructure-as-code**	**Decathlon used infrastructure-as-code to automate infrastructure deployment,** reducing deployment time from weeks to 30 minutes, allowing IT teams to focus on more complex tasks
Development and coding	**Automated CI/CD**	**Capital One leverages microservices and automated CI/CD to increase delivery speed without compromising quality** through reusable building blocks and generation of templated pipelines
Testing	**AI-based test automation**	**Goldman Sachs uses the AI-based tool Diffblue Cover to generate unit tests** for legacy software, leading to a 180× increase in the speed of writing tests for a core back-end application
Deployment and maintenance	**AI-based code reviews**	**Atlassian uses AI-based tools by Amazon Web Services to improve code performance** by identifying code paths that demonstrate poor CPU[2] utilization or latency

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[1] Software development life cycle.
[2] Central processing unit.

Source: Company websites; expert interviews

What uncertainties must be resolved for the trend to achieve scale?

Low-code/no-code platforms

Modest amount of customization is possible, compared with traditional programming languages

Monitoring and debugging applications is **difficult**, especially when they are integrated across several low-code/no-code platforms

Infrastructure-as-code

Comprehensive monitoring and version control is required to ensure errors do not spread across servers

Fragmented vendors could disrupt integrated applications, given uncoordinated changes and upgrades

AI "pair programmer"

Generated code **may be unusable or inefficient** and may **have security vulnerabilities**

Coders can be steered in the wrong direction if tools are not regularly updated with the standards or trained on clean, fast code

Microservices and APIs

Customizing APIs is difficult without significant time and effort

APIs **introduce security risks** by adding another attack layer that can be exploited

AI-based testing

Autonomous tools are typically specialized (eg, by programming language, test type)

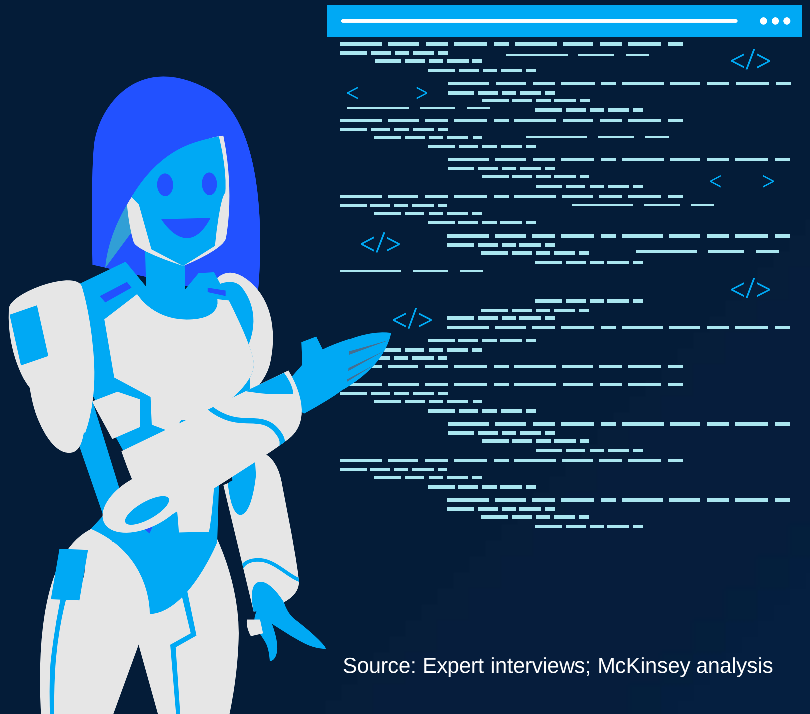
Automated code review

Tools **do not identify all defects and inefficiencies** in code

Companies over-rely on automated testing/reviews when this tech scales; humans do not consistently check for errors in test and review outcomes

Source: Expert interviews; McKinsey analysis

What are some topics of debate related to the trend?



Source: Expert interviews; McKinsey analysis

1 To what extent can no-code tech reduce the need for traditional software developers?

While low-code/no-code platforms help teams rapidly prototype or enable citizen developers to take over some of the work developers do, they are still not flexible enough to reduce development work at every stage of the software development life cycle (eg, when legacy systems require upgrades)

2 From a cultural standpoint, will teams—both developers and non-developers—embrace or resist next-generation technologies?

Automation technologies reduce time spent on development, which raises concerns for employees whose workflows are highly automatable; developers, testers, and analysts may be reluctant or eager to switch to new technologies, depending on job security, technical comfort, etc

3 What intellectual-property issues might affect code written by an AI application?

As companies leverage AI generation tools, there is a concern around ownership: Will the company that developed the application own it, or will it belong to the AI-enabled code generation tool provider?

4 To what extent will business units take responsibility for the ‘health’ of applications?

As next-generation software brings development capabilities to “citizen developers” embedded in business units, questions about organizational structure and responsibilities emerge—eg, as business users create applications, who is responsible for maintaining them?

Additional resources

Related reading

Developer Velocity: How software excellence fuels business performance

Security as code: The best (and maybe only) path to securing cloud applications and systems

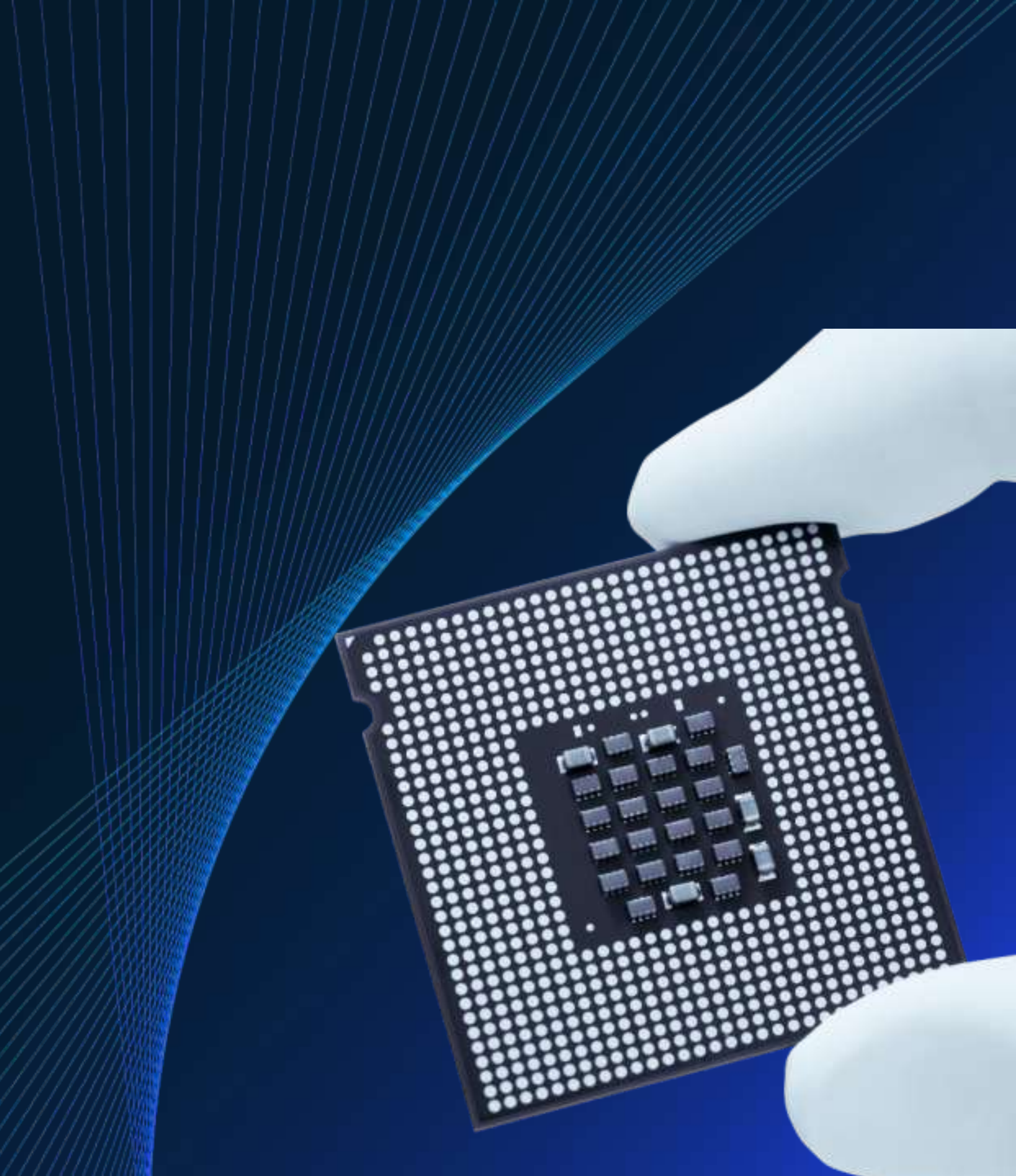
Developer Velocity at work: Key lessons from industry digital leaders

McKinsey
& Company

McKinsey Technology Trends Outlook 2022

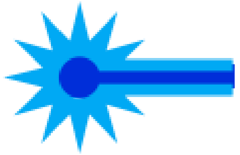
Quantum technologies

August 2022

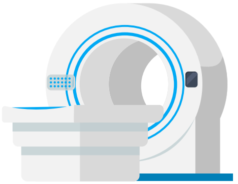


What are the most noteworthy technologies?

Quantum technology has been around for a long time …



Lasers work using the quantum mechanical effect known as *stimulated emission*

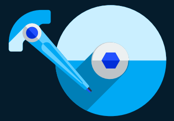


Magnetic resonance imaging uses the quantum phenomenon known as *magnetic resonance*

Source: McKinsey analysis

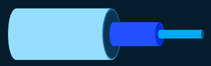
… but a few emerging technologies merit our focus now

These futuristic technologies aspire to change our computational, networking, and sensory infrastructure in the coming decades, unlocking use cases and capabilities previously unimaginable



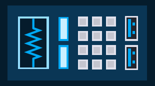
Quantum computing uses quantum properties of particles to process information at a much higher rate than a classical computer can

For some computational problems, quantum technology could make computation exponentially faster than with classical computers



Quantum communication is the transfer of encoded quantum information between distant locations based on an optical fiber network or satellites

A central feature is the quantum-secure connection through quantum encryption



Quantum sensing could provide measurements of various physical quantities at a sensitivity that is orders of magnitude higher than classical sensors can achieve

Applications include radar, microscopy, and magnetometers

Why should leaders pay attention?

The quantum age is just over the horizon …

$300 billion–$700 billion

Conservative estimate of the value at stake of quantum use cases in industries such as automotive, chemicals, finance, and pharmaceuticals

Rapid acceleration in investments

$1.7 billion

Investment in quantum start-ups in 2021, more than double the amount in 2020

Technology approaching maturity

<10 years

Estimated timeline to unlock several of the currently identified use cases as the technology matures and scales

Market expected to grow rapidly

~$10 billion

Projected market size of quantum-computing services in 2027, up from ~$400 million in 2020, growing at 50% per year

However, quantum technology is still very much in its nascent phase, and it would be difficult to predict when or if this technology will mature and scale up

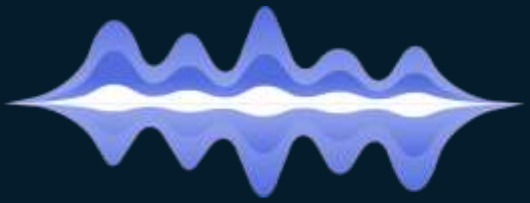
Source: *Worldwide quantum computing forecast*, 2021–25, IDC, Nov 2021; *Quantum computing: An emerging ecosystem and industry use cases*, McKinsey, Dec 2021; Frank Arute et al., “Quantum supremacy using a programmable superconducting processor,” *Nature*, 2019, Volume 574, pp. 505–10 (2019)

Why is quantum computing interesting compared with what already exists?

	Classical computer	Quantum computer
Information storage	Information is stored in *bits,* where each bit can be either 0 or 1 	The information is stored in *qubits* (quantum bits), where each qubit represents **any possible combination** of 0 or 1 with each other 
Computation	Results can be read **directly from the bit string** of 0s and 1s	Results of the computation are retrieved via **statistical analysis** of repeated quantum measurements
Performance	The performance scales **linearly** with the number of bits	The performance may scale **exponentially** with the number of qubits for certain problems
Pros and cons	⊕ Good for general-purpose computing ⊕ Mature technology with low error rates ⊕ Robust and cost-effective ⊖ Cannot scale well for certain problems	⊖ Cannot perform general-purpose computing ⊖ Nascent technology with high error rates ⊖ Currently requires expensive specialized infrastructure ⊕ Good at solving certain specific problems

Source: McKinsey analysis

Why is quantum communications interesting compared with what already exists? (continued)



The **ambition** of quantum communications is to offer transfer of encoded quantum information between distant locations through a universal quantum-communication network

Quantum communications enables major applications

Enhanced security based on quantum mechanics

Secure quantum communications guarantees full security of information transfer in the presence of a quantum computer

It will enable the following:

- verified randomness for generating shared keys
- quantum encryption
- tamperproof communications

Enhanced quantum-computing power

Quantum communications enables

- **distributed quantum processing,** where 2 or more quantum computers are connected to enhance computing power
- **blind quantum computing,** where a remote quantum computer is accessed such that it learns nothing about the performed operation

Source: Expert interviews; McKinsey analysis

What disruptions could quantum computing enable?

Quantum computing could unleash significant business value across industries, but achieving this will require extensive research and development

Applications

Most known use cases can fit into 4 archetypes:

Quantum simulation	Simulation of quantum-mechanical systems such as molecules, chemical reactions, or electrons to enable use cases such as **lead identification in drug discovery** or **simulation of proteins in pharmaceuticals and agriculture**
Quantum linear algebra	Algorithms that can provide an exponential speedup over conventional algorithms and be used in tasks such as providing **financial advice, autonomous driving, automated trading,** and **predictive maintenance**
Quantum optimization	Real-time optimization by compressing computation times from hours to seconds, enabling use cases such as **generative design, traffic management,** and **portfolio optimization** in almost every industry; current quantum-optimization approaches yield only a quadratic speedup, which when accounting for the overhead of using quantum versus traditional computing does not yet yield a significant performance improvement
Quantum factorization	The earliest identified application of quantum computing, efficient quantum factorization is readily applicable to **breaking RSA encryption,** the basis of most of today's secure data-transfer protocols; achieving this will require managing many more high-quality qubits than have currently been done

Source: *Quantum computing: An emerging ecosystem and industry use cases*, McKinsey, Dec 2021

What disruptions could quantum communications enable?

Quantum communications enables secure communication of quantum information across distant locations

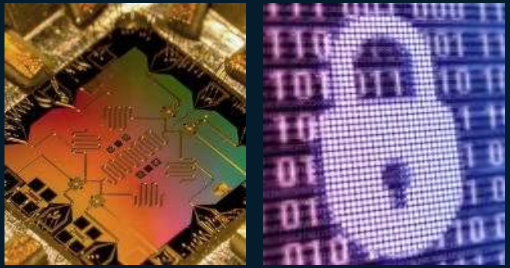
Applications

Quantum-enhanced (classical) cryptography

Quantum random-number generators (QRNG)

Enhanced security of classical cryptography protocols—eg, cryptography, personal identification numbers, lotteries, numerical simulations

Quantum cryptography



Quantum encryption protocols

Secure communication enabled by a quantum-generated confidential key shared between distant partners—eg, quantum key distribution (QKD), BB84

Quantum internet

Quantum communication infrastructure

Quantum-information exchange across continental or global distances to enable:

- long-distance secure communication
- distributed quantum computing

Source: Expert interviews; McKinsey analysis

Who has successfully created impact with quantum technologies?

Recently, many public and private entities have made announcements regarding their early applications of quantum technologies

	Case example
Quantum communi-cations	The **University of Science and Technology of China,** in collaboration with industry partners, has deployed an integrated communication network with QKD spanning more than 4,600 kilometers
	Toshiba and the University of Cambridge have deployed quantum-encryption protocols through existing citywide fibers with high-bandwidth data traffic
Quantum computing	Companies such as **Alibaba, Amazon, Google, and IBM** have already launched commercial quantum-computing cloud services with varying levels of customer adoption and technical maturity
	BMW has used quantum machine learning for autonomous vehicles by using it to train highly accurate models with massive amounts of data and has used quantum computing for car fleet routing optimization
	Pfizer is applying quantum computing to predict the behavior of electrons in a molecule to determine its 3-D structure in order to understand more about new molecules that are potential drug candidates

Source: Company websites; expert interviews; McKinsey analysis

What industries could be most affected by the trend ?

Quantum computing is still in the nascent stage, with few, isolated examples of players adopting it for solving optimization challenges

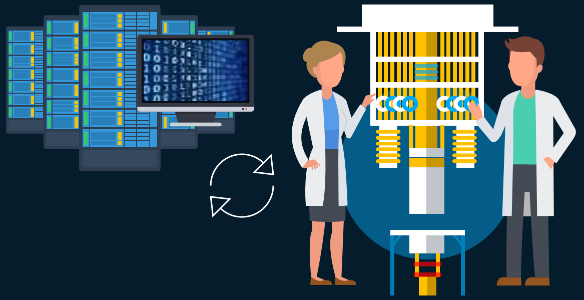
Quantum communications is relatively more mature, with several players globally establishing networks with QKD and reaping the benefits of this technology

Industries affected	Example impact of tech trend
 **Information technology and electronics**	Improving network security through QKD technology; providing capabilities or forming partnerships to offer quantum-computing services
 **Metals and mining; oil and gas**	Increasing the efficiency of companies' exploration and extraction activities
 **Aerospace and defense**	Using quantum technologies to enable tamperproof communication systems and develop augmented navigation systems
 **Chemicals; pharmaceuticals and medical products**	Leveraging quantum computers for molecular simulations involved in creating new materials and identifying potential drugs

Source: McKinsey analysis

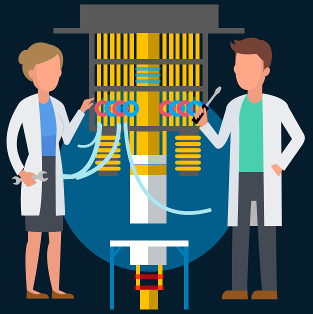
What should leaders consider when engaging with the trend?

Initially, incremental value from quantum technologies will be created through hybrid solutions with high-performance computing



Before ‘impossible tasks’ become solvable, we expect incremental value creation through hybrid solutions with conventional supercomputers:

- Solving business-relevant optimization problems in certain niches would be **10% faster** than previously possible
- Simulating the properties of small molecules with **5% higher accuracy** can enable the creation of new products, such as simulating surfactants to develop a better carpet cleaner
- Better data sampling to train AI may take longer, but the trained algorithm gives **20% better answers**



Meanwhile, researchers work on improving quantum computers with 2 major goals:

- **Improved processors:** Create stand-alone, fully capable quantum processors with a high count of quality qubits in order to achieve “quantum advantage” over classical computers
- **Market-ready tech stack:** Overcome engineering challenges and build a technology stack of hardware and software in order to make state-of-the-art quantum computers market ready

Source: Expert interviews, McKinsey analysis

What should leaders consider when engaging with the trend? (continued)

Advantages

Early-mover advantage: Organizations can begin investing in talent and infrastructure, establish or join quantum-technology ecosystems early, and prepare for upcoming disruption by identifying relevant use cases for their businesses while the technology matures through fundamental scientific research

Short-term applications: Many industries stand to gain from the benefits of quantum computing in the very short term, even if it needs to be paired with traditional high-power computation

Uncertainties and risks

Technical challenges: This includes the ability to manage a sufficient quantity and quality of qubits over enough time to derive meaningful computational results

Cost-effectiveness: Most calculations performed by enterprise quantum computers can be performed reasonably well by traditional supercomputers and at a much lower cost; this is expected to change once quantum advantage is achieved and general-purpose quantum computers take center stage

Uncertain road map: Current advancements in quantum technologies paint a promising future, but there may be potential barriers to adoption (eg, regulatory, technological, financial) that are not yet apparent

Nascent ecosystem: Only a handful of proven hardware platforms are commercially available, and talent skilled in quantum computing is exceedingly rare; this may change as the technology matures and adoption increases

Source: McKinsey analysis

What are some topics of debate related to the trend?

Quantum technologies are nascent, with many unanswered questions; despite generally optimistic outlooks, these technologies still face an uncertain future

1 Technology readiness

Will quantum tech be ready in the next 10 years?

- Many organizations have claimed that their quantum computers are outperforming classical supercomputers, hinting at **mature products within a decade**
- However, **research is often disputed,** and experts have refuted claims of quantum supremacy in the past
- Moreover, quantum computers **have not yet replaced classical computers** in any specific niche despite claims of supremacy, indicating that technologies have yet to mature

2 Impact and disruption

Will quantum tech be as disruptive as projected?

- Organizations from nearly every industry are already **experimenting with or showing interest** in quantum computing, while **quantum communications is already being piloted** by customers in many parts of the world
- Despite years of research, quantum computers **are still not consistently better than classical computers at solving any major business problem**
- Currently, the best quantum approaches to optimization yield only a quadratic speedup, which is not clearly superior to traditional computing when the additional overhead associated with quantum computing (such as error correction) is accounted for
- Quantum computing is **not expected to affect most computational work** and will be useful only for niche tasks

3 Organizational preparedness

How should companies prepare for quantum tech?

- **Talent acquisition** will be a major challenge for organizations in the near term, as companies rush to hire the few experts in the field
- **Identifying effective use cases** before quantum technologies mature will give an upper hand to forward-thinking organizations
- Current **quantum computers require massive investments** to operate, yet they provide computational power similar to that of less costly traditional computers
- Since the quantum-technology stack has yet to mature, companies may find it **difficult to predict which hardware paradigm** for quantum computers will dominate in the next 10 to 15 years

Source: Expert interviews; McKinsey analysis

Additional resources

Knowledge center

The Rise of Quantum Computing

Related reading

Quantum computing use cases are getting real—what you need to know

A game plan for quantum computing

The growing potential of quantum computing

Shaping the long race in quantum communication and quantum sensing

McKinsey
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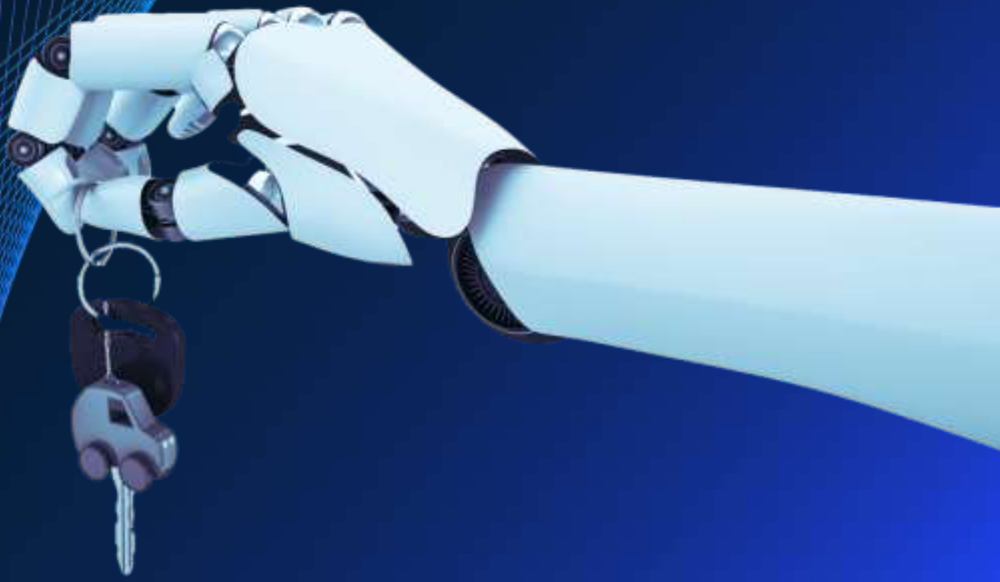
McKinsey Technology Trends Outlook 2022

Trust architectures and digital identity

August 2022



What is the tech trend about?

Increasing cyberattacks and data breaches continually pose new challenges by leveraging trending technology (eg, quantum computing for encryption breaking). **Digital-trust technologies** empower organizations to gain a competitive advantage by building, scaling, and maintaining the trust of stakeholders (eg, customers, regulators) in the use of their data and digital-enabled products and services.

High-growth technologies[1]

Zero-trust architecture (ZTA)

IT security system design where **all entities,** inside and outside the organization’s computer network, **cannot be trusted by default** and need to prove trustworthiness

Includes access management, device protection, network security, data encryption, continuous monitoring, and more

Digital identity

Mechanisms for providing full information that **characterizes** and **distinguishes an individual entity** (eg, system, person, organization) in the digital space

Entities’ **identities** consist of distinguishing **attributes** (eg, name, identifier, characteristics)

Privacy engineering

Techniques used to enable oversight, implementation, operation, and maintenance of privacy

Includes reducing risks to data privacy, resource allocation, and embedding privacy enablement into existing systems

Explainable artificial intelligence (XAI)

Techniques for building **understanding of** and **trust in AI models** for real-world deployment

Addresses fairness, accountability, responsibility, transparency, and ethics

Digital trust addresses digital risk across data, cloud, AI and analytics, and risk culture

[1] Technology areas and specific technologies are not exhaustive of all developments in cybersecurity.

Source: McKinsey analysis

Why should leaders pay attention?

Digital-trust technologies can reduce risk and potential negative impact from cyberattacks

Cyberattacks and cyber regulations are accelerating …

1 out of 3

global organizations experienced a cyberattack in 2019 (+36% vs prior year)

Increasing complexity and frequency of cyberattacks

220×

Increase in spam from Feb–Mar 2020 due to COVID-19 outbreak vulnerabilities

Rising costs and losses from cyberattacks

~$10.5 trillion

Forecast costs and losses related to cybercrime by 2025, representing a 15% annual increase

Growing regulation in the US and globally

+31

New national cyber policies in the US in the past 5 years, with greater numbers globally

… so technology must keep up

$101.5 billion

Projected spending on service providers in digital trust by 2025[1]

3–13%

Predicted economic benefits of digital identity by 2030, expressed as a share of GDP

85%

Share of small and midsize enterprises that intend to increase IT security spending until 2023

~85%

Share of companies that are victims of digital-identity-related fraud each year

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[1] Service providers include consultants, hardware support, implementation, and outsourcing.

Source: Center for Strategic International Studies; IBM; Identity Theft Resource Center; Kaspersky Lab; National Cyber Security Centre; PurpleSec data survey; Statista; McKinsey Cyber Market Map, McKinsey Global Institute

Why should leaders pay attention? (continued)

Digital trust offers value creation, enabling organizations to scale faster and become more effective

Increasing opportunities …

- Exponential potential for stacked wins
- Increased speed of digitization
- High potential-market-value advantage
- Better ability to engage in risk reduction

… in a landscape of complications and pitfalls ...

- Increasingly aggressive regulatory scrutiny, resulting in substantial fines and penalties
- Heavy reliance on legacy governance processes and technologies
- Hard-to-understand AI algorithms, which are more complex and less predictable than traditional analytics
- Growing scrutiny from public, media, and watchdog organizations
- Increasing global uncertainty

… leading to economic impact and value

Build a strong foundation of digital trust with customers, enabling increased acquisition

Leverage digital trust to scale internal data and analytic programs sustainably

Advance strategic position for advantage over competitors across AI and analytics, data, cloud, and risk culture

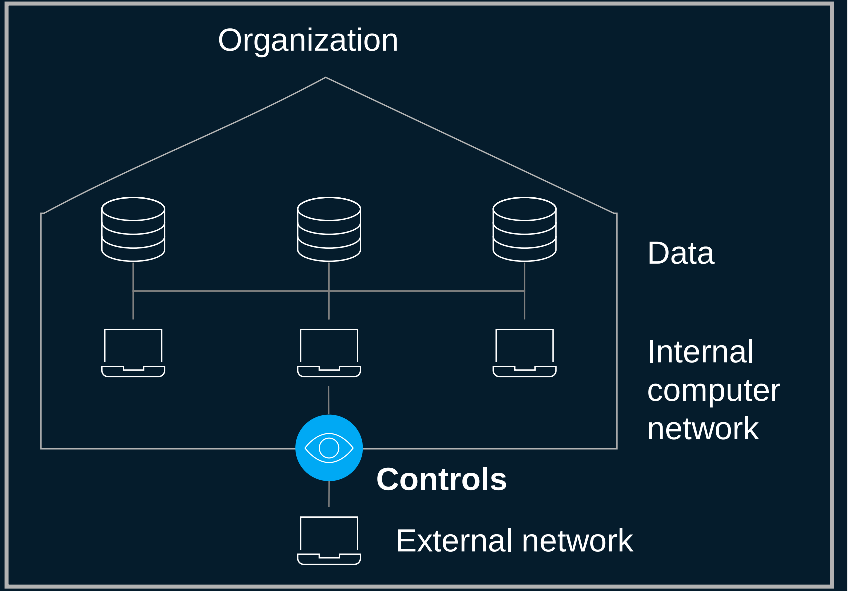
Source: McKinsey analysis

What are the most noteworthy technologies?

Zero-trust architecture assumes “zero trust” for more robust and secure data flow across technical systems

From: Traditional, perimeter-based architecture

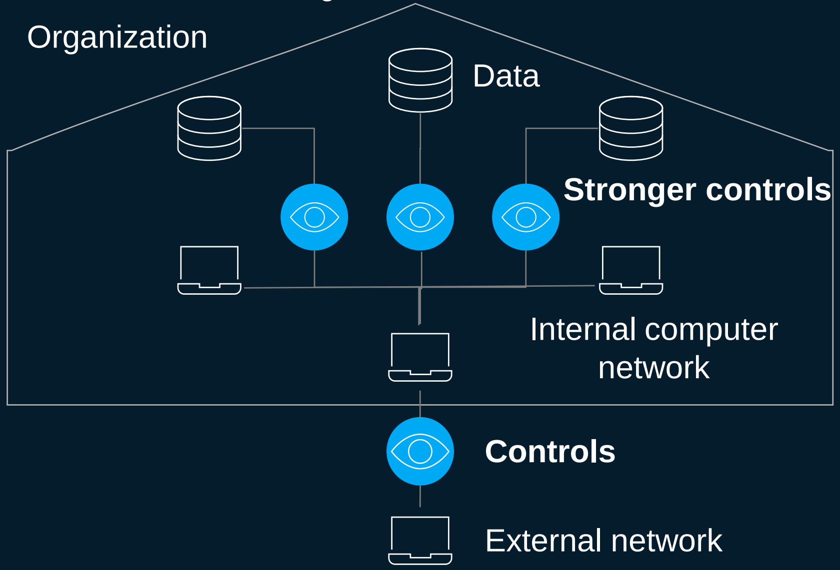
After users are verified and gain access past perimeter controls, **everything within the network is assumed safe**, which does not robustly protect against inner threats



To: Zero-trust architecture

The assumption is that **all entities**, within and outside the organization, **are not to be trusted**

- **Controls** (eg, identity and access management, network controls) are **set up for any interaction by an entity** within the network
- **Strength of controls** depends on **importance and risk level** of protected data and/or asset
- **Network is micro-segmented** to divide data and isolate attacks on data segments



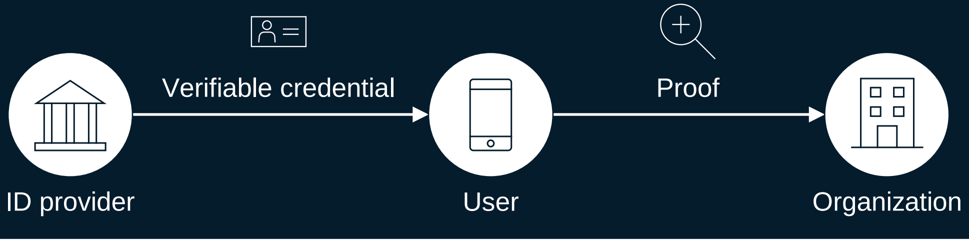
Benefits

- **Increased security and reduced risk** from increased controls across organizational network and customer data
- **Cost reduction** as losses from cyberattacks decrease
- **Increased visibility and understanding** of user access and traffic across the network from continuous monitoring
- **Upskilled workforce and streamlined technical stack** provide companies with stronger, faster technical capabilities and mitigate technical complexity, priming the company for incorporation of other cybersecurity technologies
- **Improved reputation** (due to fewer breaches in security and stronger technical stack), which can attract customers

Source: McKinsey analysis

What are the most noteworthy technologies? (continued)

Digital identity is enabling decentralization and new forms of verification – examples of innovation

	Self-sovereign identity (SSI)	**'Passwordless' identity**
Diagram	**Data flow**  	**Biometric verification**[1] 
Description	- Users **have control over their verified credentials** (attribute information to identify an individual); they can select the specific data for sharing (eg, name, password) and the sharing audience (eg, employers, healthcare provider)	- Users can verify and authenticate their digital identity without traditional alphanumeric passwords but with other forms of identifying information
Functionality	- Users interact directly with ID issuers and organizations without relying on an intermediary to facilitate data exchange - Data and user credentials are stored on a decentralized ledger (eg, blockchain) for easy access and verification	- Users can provide alternative identifying information, such as: — Biometrics (eg, facial scan, retinal scan, thumbprint, voice) — Devices and apps (eg, mobile phone, email) — Documents (eg, driver's license, passport)
Benefits	- **Increased individual control** over identity for **trusted transactions without an intermediary;** users themselves control what data they share and with whom from an interoperable and convenient identity source - **Improved security,** because decentralized data storage limits vulnerability to attacks	- **Alternative protections** against rising vulnerability attacks (eg, phishing, brute-force password cracking) - **Reduced inefficiencies** for the user (eg, too many passwords, lost password) - **Efficiency and convenience;** users can rely on streamlined identifying information, based on the level of risk associated with the system

[1] Diagram adapted from Alex Brown, "Passwordless authentication: A complete guide [2022]," Transmit Security, Jan 13, 2022.

Source: Expert input; McKinsey analysis

What are the most noteworthy technologies? (continued)

Privacy engineering governs data privacy protection, while XAI builds trust in AI models

	Privacy engineering	**Explainable AI**
Description	• Design techniques used to enable the practice governing implementation, operations, and maintenance of privacy • Broadly, these technologies support the strategic reduction of privacy risks, resource allocation, and implementation of privacy controls	• **AI-related techniques combining social science and psychology** to enable people to understand, appropriately trust, and effectively manage emerging AI technologies • Types of “explainability” differ based on the explanation objective (eg, explaining how the model works, clarifying why a model input led to its output, and providing additional information needed for people to trust a model and deploy it)
Benefits	• **Increased safety and control over data** for customers, employees, and organizations, resulting from additional controls and protective measures • **Easier process to implement privacy changes,** because the technologies form a privacy infrastructure that can facilitate privacy updates from the continually evolving regulatory landscape	• **More fair algorithmic outputs** given that XAI technologies can help mitigate bias in the data, model, and other processes • **Increased transparency, confidence, and reliability in AI models,** improving organizational performance, reputation, and relationships • **Improved efficiency and effectiveness across AI model pipeline,** due to greater understanding of model data, inputs, outputs, and algorithms

Source: Alejandro Barredo Arrieta et al., “Explainable artificial intelligence (XAI): Concepts, taxonomies, opportunities and challenges toward responsible AI,” *Information Fusion*, Volume 58, June 2020; Katherine Miller, “Should AI models be explainable? That depends,” Stanford University Human-Centered Artificial Intelligence, Mar 16, 2021; McKinsey analysis

What industries could be most affected by the trend?

Digital-trust technologies could affect all industries leveraging digital technology via **reduced risk**

Information technology and electronics and **financial services** are leading adoption, followed by industries managing highly sensitive and regulated data (eg, healthcare, retail)

Industry affected[1]	Impact from technology trend
 **Information technology and electronics**	• Decreased losses and mitigated risk, because more secure systems (from ZTA and privacy engineering) prevent cyberattacks • Improved software solutions and AI model development and deployment via embedded protocols and controls from privacy engineering and XAI • Enhanced customer experiences and reduced customer friction (eg, easier verification, log-in, etc) through easier, wider options for digital identification • Support of Web3 and metaverse technologies such as digital avatars and blockchain-supported decentralized storage for SSI
 **Financial services**	• Decreased losses and mitigated risk where digital identity verification is crucial for transactions • Pressure on regulators to increase compliance related to digital identity and data sensitivity • Support for decentralized-finance (DeFi) applications (eg, verification for crypto loans)
 **Healthcare systems and services; pharmaceutical and medical products**	• Value created by privacy engineering that balances protection of sensitive healthcare data with development of new uses for these data • Improved secure access to patient medical records; ZTA controls strength of protection, and digital identity can enable a single, unified data source • Advanced development of AI models for healthcare diagnostics, drug design, and treatment, due to greater understanding from XAI
 **Consumer packaged goods and retail**	• Improved secure access to sensitive customer data, enabled by ZTA controls and digital identity • Advanced development of AI models to improve the customer journey and increase revenue, based on greater customer understanding from XAI • Stronger brand reputation, as the technologies encourage stakeholder trust

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[1] Not exhaustive; focused on industries leading business adoption.

Source: McKinsey analysis

What industries could be most affected by the trend? (continued)

Digital-trust technologies could affect all industries leveraging digital technology via **reduced risk.**

The following industries also demonstrate high value-creation potential from digital-trust technologies.

Industry affected	Impact from technology trend
 **Aerospace and defense**	• Prevent data breaches that could threaten national security and classified information
 **Education**	• Protect students’ digital identity and data while ensuring access to educational resources
 **Media and entertainment**	• Protect intellectual property and media content across a fragmented industry value chain dependent on flows of consumer and sensitive data
 **Public and social sectors**	• Enable expansion of digital service opportunities • Secure and verify digital identity in addition to privacy engineering to protect citizen data
 **Telecommunications**	• Build digital-identity services on next-generation networks to expand their offerings • Enable enhanced customer experience • Ensure security of 3rd-party partners on their networks • Apply ZTAs and privacy engineering to internal systems and processes

Source: McKinsey analysis

What should leaders consider when engaging with the trend?

Zero-trust architecture

Long-term effort with incremental progress

Effective and full-fledged ZTA, privacy engineering, and XAI cannot be implemented immediately; for reliable results, organizations should gradually increase their controls and test them

Performance efficiency and scalability

Added authentication steps (eg, secure communications using VPN and public key infrastructure [PKI]) can slow daily work and network efficiency; this can vary based on the frequency of controls and size of the network

Privacy engineering

Inherent tension between privacy and fairness

Privacy and fairness can conflict: privacy approaches could restrict collection of personal data, while fairness approaches would collect personal data to detect bias

Digital identity

Nascent ecosystem

SSI has relatively few standards available, and Web3 is a rapidly growing space

Various dependencies

Progress depends on use of existing standards and infrastructures (eg, data regulations) and on development of rising technologies; registering alternative verified credentials can also be a complex process

Concerns over privacy of biometric data

Control, storage, and use of biometric data is a debated topic regarding privacy and ethics

Explainable AI

Lack of standardization

Deciphering the “black box” of large AI models to provide a meaningful explanation is challenging and depends on the task; resulting solutions could face new or unaddressed risks and need to balance privacy, fairness, accountability, responsibility, transparency, and ethics

Overarching risks and uncertainties

Implementation complexity will be significant given resource requirements, talent scarcity, lack of shared taxonomies, coordination challenges across multiple parties, and required shifts in organizational norms and practices needed to achieve effective deployments

Compatibility challenges will be encountered when updating or migrating technologies and integrating them with legacy systems or with an abundance of fragmented point solutions

Evolving regulations involving digital trust and privacy have become a prominent topic, as past standards (eg, on data privacy and data permanency) conflict with these technologies; regulatory measures to reconcile these differences and define newer areas will influence the direction of digital trust

Tensions between privacy and fairness can arise, for example, tension between the avoidance of excessive collection of demographic data and the need for that data to assess and mitigate bias

Lack of standardization and widely accepted best practices for how or when to use trust architecture techniques across industries will continue to be a challenge

Source: McKinsey analysis

Who has successfully created impact with trust architectures and digital identity?

Zero-trust architecture	A **Latin American oil and gas company** with a small IT estate began maturing its capabilities before establishing a ZTA rollout plan; rollout of the security update occurred on a system-by-system basis, targeting high-risk assets first, with the first full ZTA proof of concept implemented 1 year following rollout start date
Self-sovereign identity	**BankID** is a digital-identification service providing users in Sweden a single source of ID through their mobile phones; with BankID, users can make payments, participate in financial services, log in to government platforms, and access their medical records.
Passwordless identity	**Apple** has been working toward passwordless sign-ins, such as with Touch ID (ie, thumbprint) and Face ID (ie, facial recognition); As of May 2022, numerous technology companies and service providers, including Google and Microsoft, are working with the FIDO Alliance and World Wide Web Consortium to support passwordless sign-in standards

Source: Company websites; McKinsey analysis

What are some topics of debate related to the trend?

Development of digital trust depends on other trending technologies and the overall ecosystem, raising questions about its path forward.

1 **Stakeholder expectations**

How are the expectations of customers, employees, and communities changing in terms of data (especially privacy), transparency and outcomes of analytics, and technology security and resilience?

As new technologies seek to personalize the user experience, stakeholders will expect a balance between privacy (a priority that calls for not collecting demographic data) and fairness (a priority that can use demographic data to test for and correct biases). In one study, 97% of people surveyed expressed concern that businesses and the government might misuse their data.[1]

2 **Data and privacy regulation**

How do regulators reconcile past standards with rising technologies that have inherent conflicts?

Existing data privacy regulations can be at odds with emerging Web3 technologies. For example, the “right to be forgotten” from the General Data Protection Regulation in the EU enforces people’s right to have their data deleted. Storing data on the blockchain, however, creates the potential for an immutable ledger from which past data cannot be “deleted.”

3 **Risk area identification**

Where are companies typically most exposed to digital and analytics risk?

Improperly-decommissioned legacy systems, breaches to 3rd-party partners, and poorly configured database links, for example, are vulnerabilities that hackers can exploit. The right risk-management approach will require companies to define a mature enterprise-risk framework and conduct formal, holistic risk assessments tailored to their individual systems.

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[1] Theodore Forbath et al., “Customer data: Designing for transparency and trust,” *Harvard Business Review,* May 2015.

Additional resources

Knowledge centers

[McKinsey Risk and Resilience Practice]

[McKinsey Technology: Cybersecurity]

Related reading

[Getting to know—and manage—your biggest AI risks]

[Derisking digital and analytics transformations]

[Cybersecurity trends: Looking over the horizon]

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McKinsey Technology Trends Outlook 2022

Web3

August 2022

What is the tech trend about?

Web3 includes platforms and applications that enable shifts toward a future, decentralized internet with open standards and protocols while protecting digital ownership rights, providing users greater data ownership and control over how their data is monetized, and catalyzing new business models

	Web2 (Current) *“Internet users (mostly) exchange their data for services based on TOS[1]”*	**Web3** *“Internet users own their data and shape the terms of its use”*
Highlights	Centralization where large platforms govern access and own the user data. Users have the “right to be forgotten” in some jurisdictions	**Disintermediation** with a shift toward individual ownership and control over data monetization, functionality, and value
Business model	Data monetization by tech platforms (eg, personalized ads, revenue sharing) where user audiences are often the “product” sold to advertisers	**Revenues are shared back to users and/or capital contributors** through smart contracts and decentralized autonomous organizations (DAOs)
Technical infrastructure	Centralized and aggregated services (eg, cloud computing services, security models, app stores) Private code, private data, cloud platform-based security models Accessible tools for building on the platform and services	**Decentralized** databases and software programs (eg, smart contracts) **Open-source code**, public immutable data, public-private key cryptography, and composability (ie, ability to fork and integrate on top of existing projects) **Accessible tools** for building on the services but often in new languages and with Web3-specific components

[1] Terms of service.

Source: Expert input; McKinsey analysis

Why should leaders pay attention?

Web3 is based on a more **decentralized, community-governed set of protocols** that could represent a paradigm shift of authority and ownership to individuals with potentially far-reaching implications

Disruption of existing business models

Web3 enables the disintermediation of business models by encoding existing functionality into autonomous smart contracts. Web3 could offer wider economic opportunities (eg, decreased fees), moving the accumulation of value away from middlemen and toward users and suppliers

Rapid innovation through open protocols

Rapid innovation is unlocked by the open-source and modular nature of Web3, which allows for rapid development, testing, and scaling of applications, built by a global developer base. This composability and growing developer base could increase the level of innovation exponentially over time

Increased access and inclusion

Web3 is public and permissionless, meaning that everyone can access, create, and own information and assets, globally, without intermediaries

Opportunity to build new infrastructure

Web3 infrastructure is nascent; new applications require new tools and infrastructure to scale and meet expected service requirements (eg, development platforms needed to build Web3 internet services, middleware software, node infrastructure, etc)

Unified customer experience

Web3 enables a transition from omnichannel to unichannel, seamlessly integrating customers' digital identity across applications by leveraging a common decentralized blockchain data layer, as opposed to a siloed view of customers that is limited to an individual business's customer profile

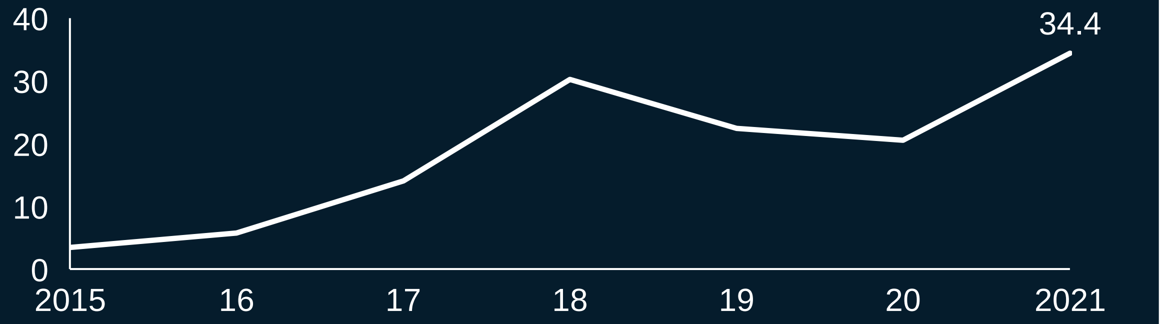
Source: Expert input; McKinsey analysis

Why is there enthusiasm for Web3?

Talent and investment have rapidly increased in the past year, with **continued expectations of long-term growth**

Talent

Number of developers contributing to Web3 projects,[1] 2015–21
thousands

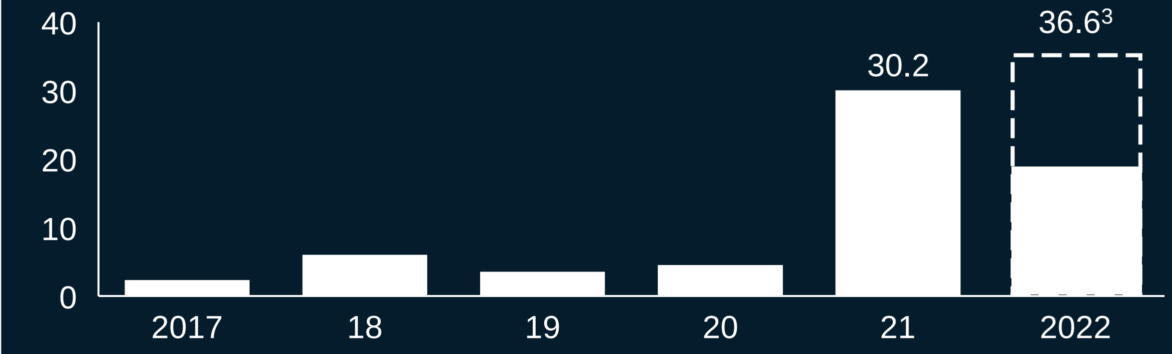


>34,000

Active Web3 developers in 2021

Capital

PE and VC investments[2] in Web3 deals, 2017–21
$ billion



~70% per year

Growth rate of PE and VC investments in Web3, 2017–22

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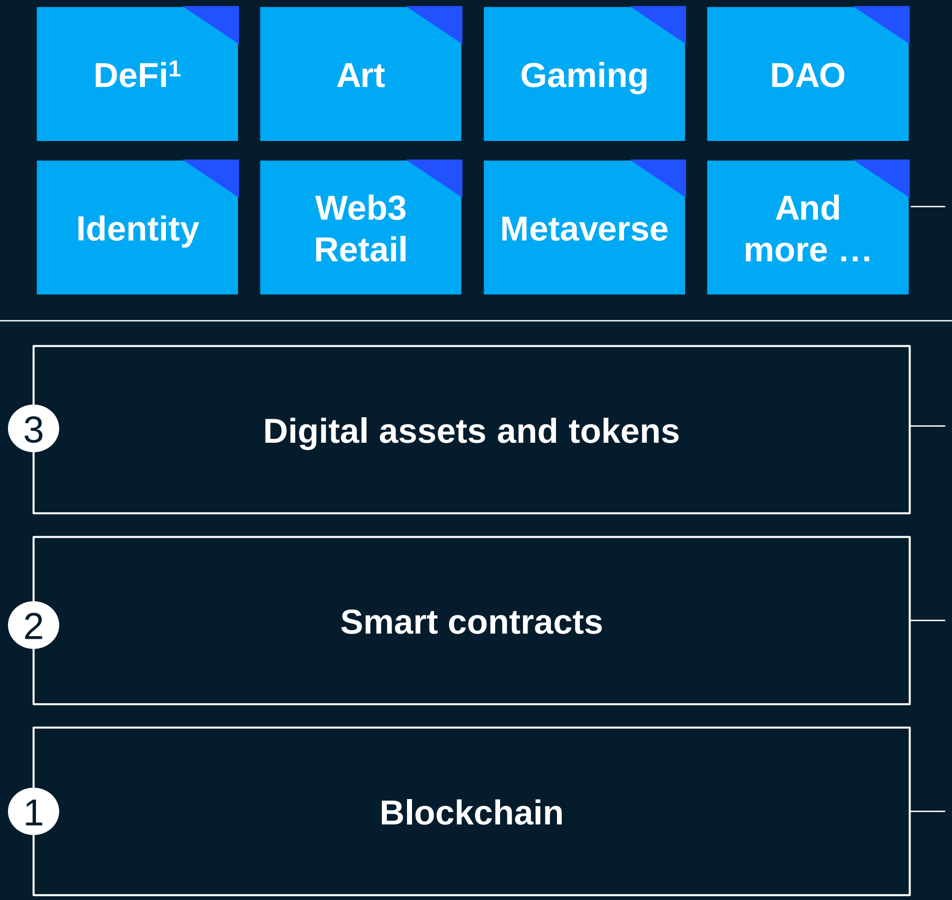
[1] Based on open-source repositories and code commits from GitHub.
[2] Private-equity and venture capital investments.
[3] Extrapolated from 2022-H2 investment figures of $18.3 billion (“What winter? Crypto VCs continue their spending spree,” *Fortune*, Jul 2022).

Source: Dovemetrics; Electric Capital; GitHub; PitchBook; The Block Research

What are the most noteworthy technologies and areas of interest?

Web3 can be decomposed by its foundational technologies and applications



Web3 applications and use cases

Applications and use cases built on top of Web3 technologies, including notable use cases in decentralized finance (DeFi), entertainment (art and gaming), and retail, among others

Connection of these virtual experiences is sometimes referred to as the metaverse

Web3 technologies

Digital assets: Digitally native intangible items such as native cryptocurrencies, governance tokens, stablecoins, NFTs,[2] and tokenized assets

Smart contracts: Software programs established in immutable code on a blockchain, which are automatically executed when specified conditions (such as terms agreed on by a buyer and seller) are met

Blockchain: Digitally distributed, decentralized data ledger that exists across a network of computers. These computers work together to facilitate the recording and confirmation of transactions

[1] Decentralized finance.
[2] Nonfungible tokens.

Source: Expert input; McKinsey analysis

What industries are beginning to adopt and shape Web3?

Many use cases across industries are being identified and built, especially as the tech infrastructure improves

● Details on following pages

Media and entertainment: Gaming

Web3 enables interoperability across games, digital assets facilitating new gaming experiences, and play-and-earn business models in which in-game rewards (eg, NFTs) are distributed with different utilities and value

Media and entertainment: Digital art and media

Creation and ownership of digital media (eg, artworks, video content)—sold as NFTs—allow new business models and creative possibilities while providing artists with more control and, in some cases, ongoing perpetual royalties

Retail

Retailers are using Web3 technologies to create new offerings, devise new modes of customer engagement (eg, ecosystem loyalty programs, access to unique experiences), assure the authenticity of goods, tap into new royalty-based revenue streams, accept novel payment methods (such as “stablecoins”), and track and orchestrate logistics across loosely coupled global supply chains

Financial services

DeFi is an ecosystem of applications that could autonomously perform similar services to traditional financial institutions, albeit with very different levels of protection, and where the traditional revenues are handed back to users or liquidity providers of these applications. Many are governed through token-based distributed governance systems. Other areas of financial services exploring Web3 applications include payments, asset management, and some areas of capital markets

IT and electronics

Innovators will use Web3 to create decentralized, peer-to-peer networks, enable social-media users to create and sell their content, enable stronger user control of digital identity, and lay the groundwork for the adoption of metaverse platforms

Industries leading adoption include **financial services, media and entertainment, retail, and information technology and electronics**

Emerging industries include blockchain-based identity,[1] logistics, carbon markets, and public sector

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[1] For more information about digital identity, see “Trust architectures and digital identity,” McKinsey, Aug 2022.

Source: Expert input; McKinsey analysis

What are the examples of business disruption that Web3 could cause?

Media and entertainment: Gaming

Web3 represents a new business paradigm in the gaming industry's revenue models: from pay-to-play[1] and free-to-play[2] today to play-and-earn[3]

Innovations

Incentives for players in a play-and-earn model where players earn in-game digital assets (eg, NFTs, in-game tokens) while playing, and can easily monetize these rewards via peer-to-peer networks or exchanges

Distributed ownership opportunities, where players can realize true ownership of in-game assets, with long-term potential for interoperability across different Web3-enabled games and metaverse

Community-based development where the player community can share feedback with developers and vote to change some in-game dynamics or codevelop game patches and updates

Different business model for gaming companies through digital-asset sales, secondary-market royalties (eg, for NFTs), and value exchange channels (eg, dedicated marketplaces)

Potential risks and uncertainties

High barriers of entry due to up-front investment (eg, in-game NFT and/or token purchases) and knowledge of existing Web3 tools (eg, self-custodial wallets) to start playing games

Low-fidelity gaming experience of present NFT games relative to traditional Web2 gaming, largely attributable to nascency of industry

Incentive-driven player base, such that player retention is at risk if rate of earnings decline**,** absent other incentives (eg, compelling gameplay)

Controversy in the traditional gaming community, where lack of understanding of Web3's value proposition and skepticism toward increasing monetization models is driving backlash

Nascency of infrastructure, in particular related to transaction costs, throughput, and security, to access and play the game reliably

Regulatory uncertainty on asset classification of in-game NFTs and digital assets, and of play-and-earn new business models

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[1] With pay-to-play, accessing the game costs money.
[2] With free-to-play ("freemium" model), players do not have to pay for game access but usually pay in-game.
[3] With play-and-earn, playing earns rewards: players become owners of in-game items and earn rewards in cryptocurrency.

Source: Expert input; McKinsey analysis

What are the examples of business disruption that Web3 could cause? (continued)

In retail, engagement channels and data ownership will shift away from business-centric to consumer-centric

Retail

Innovations

New model for consumer data ownership and access, which could enable greater control for users (eg, anonymous identity with permissioned data sharing)

New channels and methods for customer acquisition, engagement, and retention (eg, community-based retention models, Web3 loyalty programs, Web3 marketing through airdrops, etc)

New product categories to express brand identity in digital native form (eg, Web3 native items, digital twins of physical products)

New digital environments for customer engagement, potentially connected across different Web3 channels (eg, metaverse)

New value exchange models for global commerce (eg, stablecoins)

Provable authenticity and record of ownership for digitally native goods

Potential risks and uncertainties

Unclear long-term viability of specific digital assets and communities, coupled with (unwanted) volatility of digital asset markets

Immature user experience and security for digital goods to assure ownership and trusted transfer of assets (eg, self-custodial wallets)

Considerations on how to retain control over brand identity as new platforms and experiences proliferate in public permissionless infrastructure

Evolving regulatory environment for consumer protection and personally identifiable information building from early implementations notably in Europe (GDPR[1]) but expanding to many other jurisdictions

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[1] The EU's General Data Protection Regulation.

Source: Expert input; McKinsey analysis

What are the examples of business disruption that Web3 could cause? (continued)

Financial services

Web3 offers the promise of decentralization and potential disintermediation throughout financial services, offering better price and generating cost efficiencies

Innovations

Greater cost efficiency through employing smart contracts whose programmable logic determines automated decisioning and disbursement (eg, in decentralized lending, swaps)

Interest revenues and trading fees returned to users (eg, depositors, liquidity providers, lenders) instead of flowing back to the central enterprise

Broader investor base and enhanced liquidity for traditionally illiquid or inaccessible investment assets (eg, fractionalized commercial real estate)

Greater transparency of transactions since all ownership and transaction data reside on, and are potentially discoverable on, the blockchain

Low credit risk and delinquency in applications such as DeFi lending that entail overcollateralization requirements and automatic liquidations

Facility for providing always-on financial services (24/7), such as lending, trading, derivatives, mortgage, and insurance

Risks and uncertainties

Unsettled regulatory picture, including unclear classification of assets and jurisdictional authority

Limited or absent consumer protections (eg, for funds held in custody), including irreversibility of any fraudulent transactions

Immature user experience, often with poor interface design and lacking seamless integration with traditional financial services (eg, onboarding, funds transfer)

Security concerns, including the compromise and collapse of some nascent projects in DeFi, wallet theft, and poor AML/KYC[1] controls

Nascent technology, lacking traditional data privacy when using open, permissionless distributed ledgers and reliant on software (smart contracts) and data (oracles) that are not yet battle-tested at scale

[1] Antimoney laundering/know your customer.

Source: Expert input; McKinsey analysis

What are some broader uncertainties affecting Web3 adoption?

Nonexhaustive

Evolving regulation as authorities choose approaches to governing issues such as consumer and investor protection, asset classification (eg, security, commodity, currency) and its implications, legality, and enforceability of blockchain-based contracts, accounting and tax standards, capital provisioning, accountability mechanisms, and know-your-customer and antimoney-laundering standards

User experience and value proposition of Web3 alternatives compared with incumbent systems (which also are continuing to evolve) are often either poor, unclear, or poorly understood

Ecosystem infrastructure is nascent and will continue to mature as business models (eg, merchants accepting digital loyalty tokens) and value chains (eg, creation, trading, and secure storage of NFTs) are tested and refined or discarded

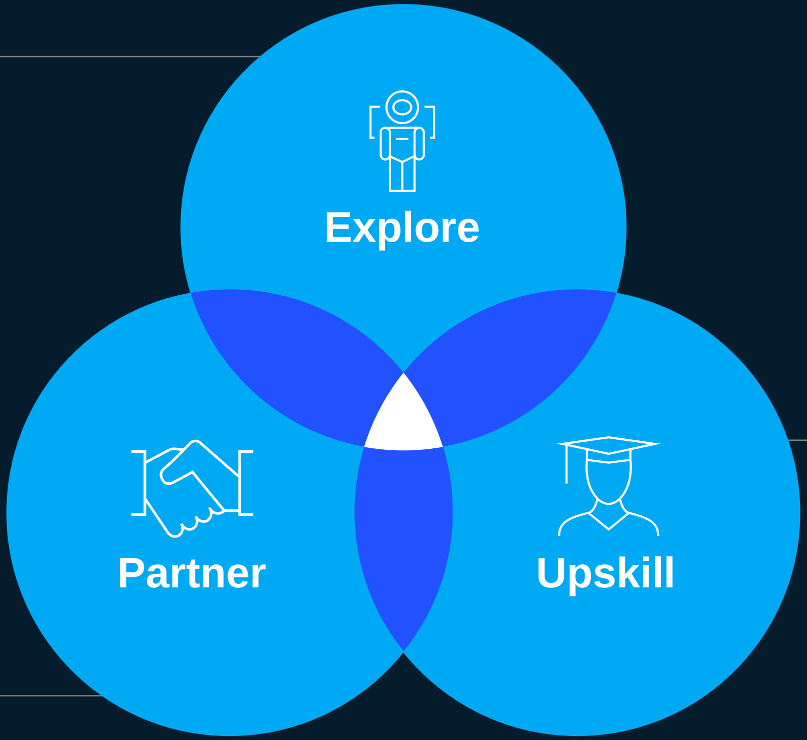
Consumer protection is increasingly becoming a focal point for regulators, especially during times of failure of several nascent Web3 projects (eg, the FTC's Consumer Protection Data Spotlight of June 2022 found that consumers lost $575 million from January 2021 to March 2022 as a result of bogus cryptocurrency investment opportunities)

Robustness of new technologies that depend on code (eg, smart contracts) or data (eg, oracles) is improving but has experienced some notable failures. The composability of underlying Web3 code can perpetuate vulnerabilities

Sustainability differences among Web3 platforms—relative to conventional alternatives—are shifting, given the high-energy consumption of older proof-of-work-based systems and the enhanced efficiency of alternatives such as proof-of-stake-based systems

Source: McKinsey analysis

How can leaders begin engaging with Web3?



Reevaluate your business model, value chain, and industry ecosystem to understand where Web3 disruption may happen. Likewise, keep an eye out for the rise of new competitors and business models in industries leveraging Web3 (eg, stablecoins, cryptocurrency payments) that will challenge the status quo

Partner with Web3 players to facilitate entry into new services and product offerings (eg, branded assets with NFT creator studios, Web3 gaming experiences)

Upskill workforce, from leadership to developers, on Web3 and its applicability to the organization's relevant applications. Start experimenting on small pilots and scale as teams learn by doing

Source: Expert input; McKinsey analysis

Who are industry players leveraging Web3 with impact?

Industry	Example	Description
 **Financial services**	**USDF consortium and Figure**	**USDF:** a consortium of FDIC-insured banks—**aims to promote the adoption and interoperability of a bank-minted stablecoin** in the form of tokenized deposits (as opposed to the fully reserved model) to facilitate the compliant transfer of value on blockchains. This stablecoin will run on the Figure network, a public blockchain
 **Media and entertainment: Gaming**	**Nike acquisition of fashion-gaming company RTFKT to enter Web3 and the metaverse**	**RTFKT**—a creator-led studio that uses the latest in game engines, NFT, blockchain, augmented reality, and other technologies to create one-of-a-kind sneakers and other digital artifacts—is widely regarded as a metaverse-native fashion brand that merges culture and gaming. **Nike** acquired the company in late 2021; earlier that year, RTFKT had a valuation at $33 million
 **Retail**	**Aura Blockchain Consortium for tracking and tracing**	**The Aura Blockchain Consortium** (including, among others, LVMH, Prada, Richemont) **is a not-for-profit, collaborative industry initiative that enables tracking and tracing for luxury goods.** Using a universal private blockchain, it has the goal of enhancing customer service by enabling consumers to access details of a luxury product's entire supply chain, product history, and authenticity. Members pay licensing fees and a fixed fee per product to track and trace any product with an NFT, attached to the product through a QR code or RFID tag

Source: Company websites

What are some controversial topics regarding Web3?

Nonexhaustive

Source: McKinsey analysis

1 Reliability and sustainability

Which Web3 business models and value chains will emerge as technically reliable, scalable, and commercially sustainable?

Business models must show they can produce more value for users than existing systems, achieve uptake beyond an enthusiastic cohort of early adopters, and overcome volatile periods. They must also satisfy evolving regulations for consumer protection, asset classification, and know-your-customer standards

2 Patterns of adoption

Given Web3's nascency and rapid development, what will unlock mainstream adoption? As a cultural phenomenon, how will patterns of Web3 adoption vary among different populations?

In order to become mainstream, Web3 tech needs to improve in terms of scalability, reliability, and security, with accessible developer tooling and improved user experience for consumers. Adoption across geographies will differ depending on a variety of factors, including government regulations, public interest in an open internet, and access to adequate connectivity

3 Enterprise architecture integration

How will Web3 ecosystems coexist and interconnect with enterprise system architectures and with hyperscale Web2 platforms?

Interoperability of platforms will be necessary for users to transfer assets (eg, enabling the transfer of avatars between different virtual worlds). This interoperability is a stark departure from the centralized business models of many web 2.0 businesses

4 Regulating trust

How will regulatory action influence trust in Web3 and affect potential future innovation?

Insufficient clarity around regulatory frameworks on Web3 technologies may contribute to reduced trust among users and developers. At the same time, Web3 may address a growing need for empowerment of the individual across data, functionality, and value, enhancing the trust of users and developers in the Web3 fundamentals

5 New models and the metaverse

How will the Web3 and immersive-reality trends influence existing models for accessing and building systems on the internet and come together to enable new experiences in the metaverse?

As the Web3 trend blends with others, new propositions and platforms will emerge. The metaverse, for example, could leverage tech trends like immersive reality and advanced connectivity to enhance and enable innovative user experiences in Web3 environments. Future use cases of open learning, working, entertaining could take place here

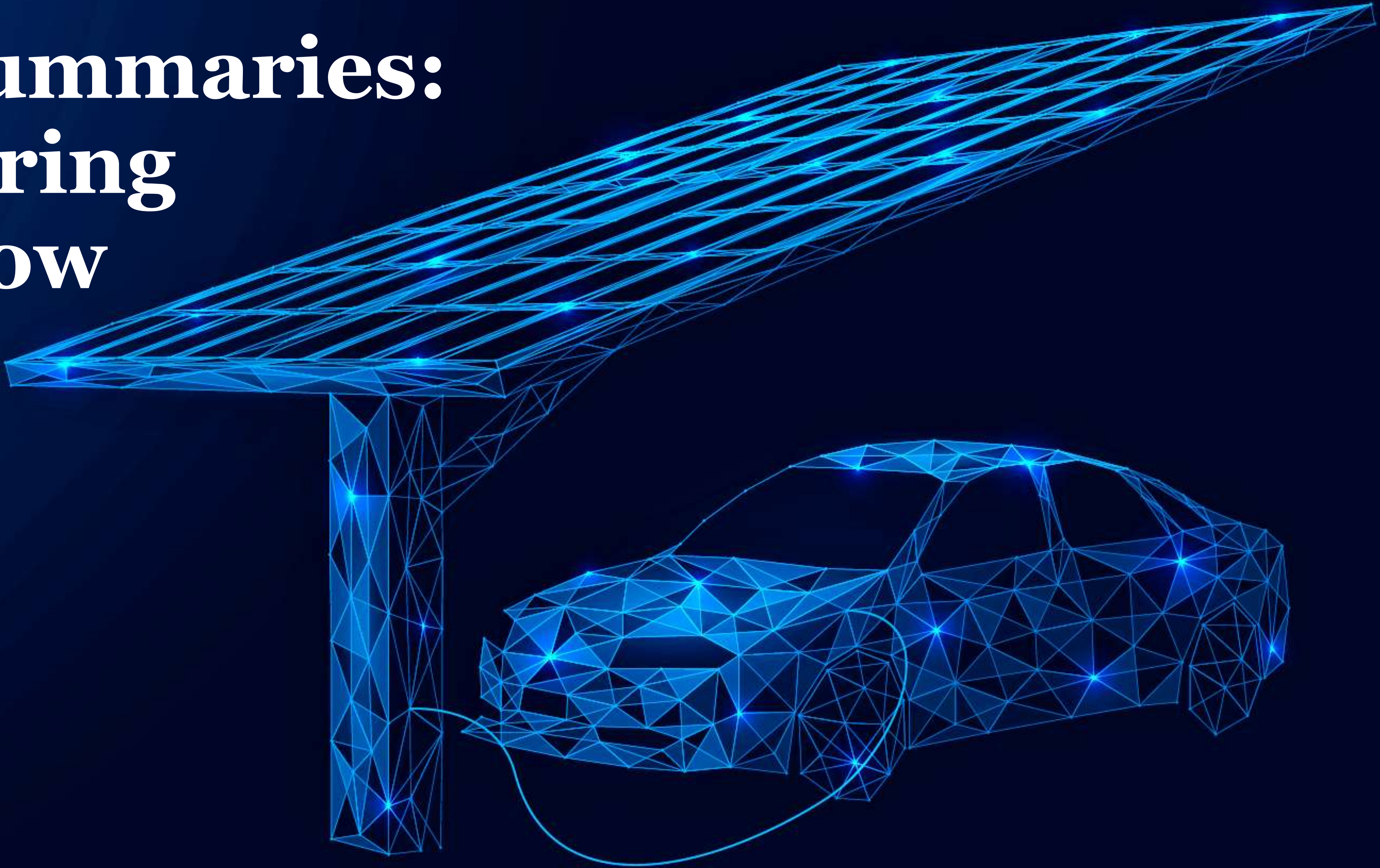
Additional resources

McKinsey Blockchain & Digital Assets

McKinsey Metaverse

Telecom’s future in the Web3 era: José María Álvarez-Pallete López

Trend summaries: Engineering Tomorrow



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McKinsey Technology Trends Outlook 2022

Future of bioengineering

August 2022

What is the trend about?

☐ Focus for tech trend

From the cellular level to complex living systems, **the future of bioengineering** reflects the convergence of biological and information technologies to transform business and society

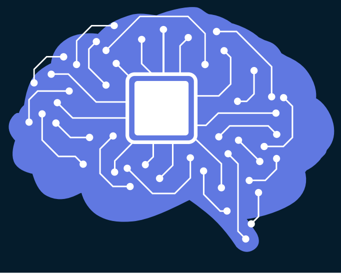
It is defined by 4 arenas: biomolecules, biosystems, biomachine interfaces, and biocomputing; in recent years, **biomolecules** and **biosystems** have experienced widespread developments[1]

Biomolecules

Mapping and engineering intracellular molecules (eg, DNA, RNA, proteins) related to the study of omics (eg, genomics, proteomics)

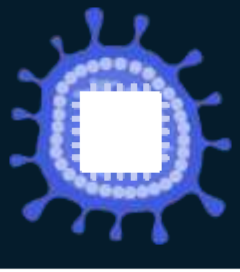
Biosystems

Mapping and engineering complex biological organizations, processes, and interactions (eg, cells, tissues, and organs)



Biomachine interfaces

Connecting nervous systems of living organisms to machines



Biocomputing

Using cells and cellular components for computation of information (eg, storing, retrieving, processing data)

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[1] Technologies featured are a selection of growing and promising technologies but are not exhaustive of all technologies in the field.

Source: "The Bio Revolution: Innovations transforming economies, societies, and our lives," McKinsey, May 13, 2020

Why should leaders pay attention?

Across industries, efforts in the development and adoption of bio-related technologies are increasing

400

Number of scientifically feasible use cases with implied economic impact across multiple industries identified

78%

Share of top global revenue-generating companies with some level of sustainability commitments related to scope 1 or 2 emissions

>$400 million

Investment in cultivated meat in the first half of 2021, projected to increase rapidly

These efforts could unlock transformative new capabilities, with a strong impact on scope and scale

Providing new business opportunities

$2T–$4T

Forecast annual global impact of bioengineering in 2030–40

Addressing global issues

45%

Share of global disease burden that could be addressed

Transforming production processes

60%

Share of world's physical outputs that could be made using biological means

Shifting investment focus

30%

Share of private-sector R&D that could be spent in bio-related industries

Source: "The Bio Revolution," May 2020; CDP Worldwide; PitchBook; S&P Capital IQ; Science Based Targets Initiative; McKinsey analysis

What are the most noteworthy technologies?

Across biomolecules and biosystems, several technologies have recently made significant progress

Nonexhaustive

Topic	Technology[1]	Description	Benefits	Example
Omics	**Viral-vector gene therapy**	Permanent replacement of poor-functioning genes to treat genetic diseases, where modified viruses act as drug-delivery vehicles of genetic sequences	Treats previously uncurable diseases Can address diseases before they are symptomatic	Treatment for cystic fibrosis
	mRNA therapy	Temporary use of synthetic mRNA translated into protein to compensate for missing or mutated genes	Offers temporary alternative to gene therapy that aids gene expression without risk	COVID-19 vaccine
Tissue engineering	**Cultivated meat**	Meat made by taking a small sample of animal cells and growing them in a controlled environment, emulating conventional meat qualities	Combines attributes of animal meat and plant-based meat with strengths in taste, food safety, animal welfare, and worker welfare	Cultivated chicken meat for consumption
Biomaterials	**Drop-in**	Materials that replace fossil-fuel-derived chemicals with biochemicals without changing existing production processes	Create cost-effective materials with minimal production disruption Offer more environmentally friendly alternatives to traditional chemicals with carbon emission reduction	Bioethanol-based polyethylene
	Bio-replacements	Materials using biochemicals that provide similar quality and cost but have better environmental impact than traditional chemicals	Improve sustainability but require complex value chain changes Minimize regulatory hurdles with low entry barriers	Vegan leather made from mushrooms
	Biobetter	Materials with new combinations of properties developed from unique biochemical synthesis	Improve sustainability Offer strong quality and technical performance	Bio-based optical films

[1] Technologies are nonexhaustive; they were selected based on their combination of innovation, business adoption, and impact.

Source: “The Bio Revolution,” May 2020; expert interviews; McKinsey analysis

What industries are most affected by the trend?

Healthcare, including pharmaceuticals and fitness, is the leading industry in adoption of bioengineering, especially in development of new medical treatments

Other industries scaling adoption are r**etail, consumer goods, agriculture, energy and utilities, and materials**

Industries affected[1]	Impact from technology trend
 **Healthcare systems; pharmaceuticals and medical products**	**Advancements across healthcare, pharmaceuticals, wellness and fitness, and biological sciences** for improved understanding of health conditions and diseases (eg, diagnosis, monitoring), treatment, patient outcomes, and scientific discovery Ethical and long-term health concerns around use of novel and innovative technologies on humans (eg, impact of germ line gene editing on future generations)
 **Agriculture**	**Increased access and shift to more sustainable and cruelty-free food sources** through cultivated meat **Potential economic disruption across supply chain for food** Ethical and long-term health concerns associated with unconventional production of food sources
 **Chemicals**	**Advancements in sustainable, cost-effective, and higher-quality** biomaterials and production processes
 **Consumer packaged goods**	**Creation of sustainable, cost-effective, and higher-quality** materials and production processes for consumer goods, such as clothing, accessories, shoes, beauty products, and packaging

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[1] Nonexhaustive; focused on industries where technology has widespread applications with mature adoption.

Source: Expert interviews; McKinsey analysis

What disruptions could the trend enable in healthcare systems and services and in pharmaceuticals and medical products?

$0.5–$1.3 trillion

Forecast global impact, 2030–40

Increasing number of therapies, including those that can treat or even prevent previously uncurable diseases

🟦 Benefits 🟥 Risks and uncertainties

Examples of technologies

Viral-vector gene therapy

As of Feb 2022, there are 8 FDA-approved therapies, with 25 in late-stage development and another 120 in Phase II trials, and growing work on more therapies

mRNA therapy

As of 2022, there are ~130 RNA assets in the pipeline, with a predicted 40% annual growth rate for ~1,800 RNA assets by 2030

Expected outcomes

Treatment for monogenic and polygenic diseases

Treatment for ~10,000 diseases caused by a single gene (eg, sickle cell anemia, hemophilia, inherited blindness, immune deficiencies) and diseases caused by a combination of genes (eg, cardiovascular, neurodegenerative, metabolic, reproductive)

Personalized treatments

Bespoke treatments using genetic data to identify risk of certain diseases (eg, COVID-19, HIV) and to provide targeted treatment

Novel cancer treatment

Treatments addressing all stages of cancer (from screening to treatment to cure), especially cancer linked to genes (eg, BRCA1 and BRCA2 for breast cancer)

Aging prevention

Anti-aging therapies that eventually assist with tissue repair, longevity, mental cognition, and physical capabilities

Health risks

Long-term health effects are also still being investigated

Ethical concerns

Ethical and moral concerns about potential unintended side effects of modifying genes, and when applied to embryos/germ lines, its impact on future generations

Source: “The Bio Revolution,” May 2020; expert interviews

What disruptions could the trend enable in consumer goods?

$200B–$800B

Forecast global impact, 2030–40

Improving production processes for sustainability and cost-effectiveness while maintaining end-product quality

Adding new capabilities to products

🟦 Benefits 🟥 Risks and uncertainties

Examples of technologies

Drop-in

Sustainability-oriented clothing lines leveraging biochemicals (eg, biomass waste streams) can be implemented with minimal disruption

Bioreplacements

Biotech textiles (eg, mushroom leather, spider silk) are growing among apparel manufacturers

Biobetter

Cosmetics can be produced more easily, with new qualities, and personalized to individuals' skin microbiomes

Expected outcomes

🟦 Reduced carbon footprint

Production can utilize sustainable processes, such as leveraging biomass waste to synthesize materials

🟦 Alternative renewable resources

Difficult-to-access or costly materials can be derived from bio routes (eg, using fermentation-based manufacturing to extract complex natural fragrances)

🟦 Personalization in beauty and cosmetics

Technologies offer advancements in omics and biomaterials to better cater to individual customer needs

🟥 Disruption in value chain

Bioreplacements can cause complex disruption in the value chain; vegan leather is often a popular topic of debate on its widespread implications (eg, economy and consumer perception) beyond environmental impact

Source: "The Bio Revolution," May 2020; expert interviews; McKinsey analysis

What disruptions could the trend enable in agriculture?

🟦 Benefits

🟥 Risks and uncertainties

$0.8T–$1.3T

Forecast global impact, 2030–40

Sustainable and cruelty-free alternatives to traditional food options

Examples of technologies

Cultivated meat

Lab-grown meat, such as beef, poultry, and seafood, can be produced and harvested

Expected outcomes

🟦 Sustainable, accessible food source

Production techniques are more accessible, environmentally friendly, friendly to animal welfare, and friendly to worker welfare

🟥 Consumer acceptance and unknown long-term health impact

Consumer perception is crucial for adoption of cultivated meat; producers need to strengthen confidence in safety and nutritional value, which varies depending on meat type; novel processes may use ingredients with unknown long-term health effects

🟥 Economic disruption and scale

Cultivated-meat adoption could disrupt existing agricultural value chains if society decides to adopt alternative foods broadly

🟥 High prices and limited variety

As a relatively nascent product, cultivated meat is priced higher than traditional meat and has limited variety; as the industry scales, consumer prices should decrease (with reduced production costs), and product variety is expected to increase

🟥 Limited regulatory approval

Singapore is currently the only country to approve sales of cultivated meat

Source: “The Bio Revolution,” May 2020; expert interviews; McKinsey analysis

What disruptions could the trend enable in chemicals, materials, and energy?

$200B–$300B

Forecast global impact, 2030–40

Alternative, sustainable sources and processes for materials and energy

🟦 Benefits 🟥 Risks and uncertainties

Examples of technologies

Drop-in

Environmentally friendly replacements for popular fossil-fuel-derived chemicals (eg, polyethylene, plastics)

Bioreplacements

Biofuels, alternative renewable-energy sources (eg, oil from genetically engineered microbes), and raw materials

Biobetter

Novel biotech films that deliver unique material properties (eg, opacity, oxygen/water permeability)

Expected outcomes

🟦 **Sustainability and reduced carbon footprint**

Biomaterial-based production processes can lead to reductions in carbon footprint by as much as ~50%

🟦 **Increased source material optionality**

Incorporation of biogenic carbon into the materials value chain provides wider material sources and novel production methods; when coupled with carbon capture, this can also result in carbon-negative products

🟥 **Uncertainty around timing of impact**

Current solutions are not cost-competitive with existing fossil-fuel technologies

🟥 **Scalability challenges**

Bio-based solutions are not necessarily scalable to the extent of full replacement of fossil fuel

Source: McKinsey analysis

What should leaders consider when engaging with the trend?

Benefits

Opportunity to address global challenges through improved/enhanced healthcare solutions and accelerate environmental impact through renewable-energy sources, and more

Novel sustainable production practices that are more environmentally friendly than traditional methods while often being cost-effective

Risks and uncertainties

Nascent biomarkets, which need to address the challenges of consumer perception, safety, cost, and quality of end products

Lack of regulation due to nascency of markets, along with existing regulations on genetically modified organisms

Ethical concerns about the extent of modifying living systems, such as human genes

Source: McKinsey analysis

What are some topics of debate related to the trend?

With its cross-disciplinary innovations and potential cross-cutting impact, bioengineering ventures into interconnected areas of debate

1 Risk and bioethics

How should we use bioethics to determine the appropriate extent for genome editing?

- **Biology** is **self-replicating and self-sustaining;** it **lacks boundaries**; due to gaps in knowledge and interconnections among the biological sciences, experimentation could lead to unintended, potentially harmful consequences
- Some gene therapies and other methods (somatic gene editing) are generally viewed as appropriate for treating rare diseases; other **gene methods that could affect future generations** (germ line gene editing) are contentious
- Likewise, different values and principles can influence different perspectives on **ethical use and misuse in bioengineering**, such as editing human traits, dubbed “playing God”

2 Changes to existing daily life

How does cultivated meat fit within existing diets? Is it vegetarian, vegan, kosher, etc?

- Cultivated meat can benefit welfare for animals and human workers (eg, it's cruelty free), which makes it a more ethical as well as sustainable option
- However, cultivated meat is an unprecedented and nuanced area for dietary restrictions (eg, some consider it to still be an animal), and individual consumers make take a different stance; in the future, cultivated meat could receive standardized certifications (eg, cruelty-free, kosher) to facilitate consumer decisions

3 Outlook

What will shape the long-term impact and implications of bioengineering technologies?

- Varying perspectives debate **timeline, type and scale of impact,** and **level of disruption** (eg, regulatory changes) in society and the economy
- Based on their execution, these technologies could **reinforce or widen socioeconomic disparities** due to unequal levels of technological access
- Alongside the digital debate on **privacy and consent**, these topics also touch on debates related to **individual personal biological information** (eg, ancestry, hereditary traits)

Source: Expert interviews; McKinsey analysis

Additional resources

Related reading

The Bio Revolution: Innovations transforming economies, societies, and our lives

The third wave of biomaterials: When innovation meets demand

Cultivated meat: Out of the lab, into the frying pan

Inside the fact-based report on biological science that reads like science fiction

How could gene therapy change healthcare in the next ten years?

COVID-19 and cell and gene therapy: How to keep innovation on track

Viral-vector therapies at scale: Today’s challenges and future opportunities

McKinsey Technology Trends Outlook 2022

Future of clean energy

August 2022

What is this trend about?

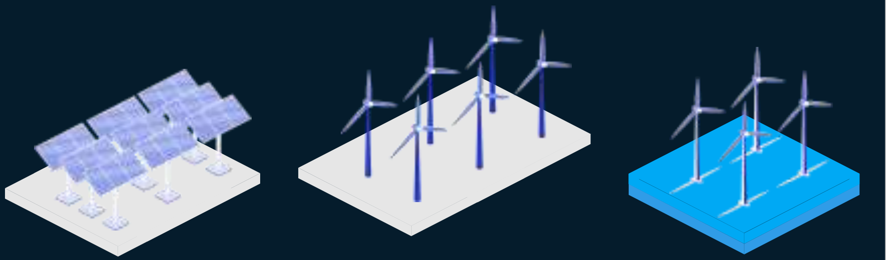
The clean-energy future is a trend toward **energy solutions that help achieve net-zero emissions** across the energy value chain, from **power generation** or production to **storage** to **distribution**

Power generation

Renewable energy
Solar photovoltaics (PV) and thermo-solar, wind, geothermal, nuclear

About 84% of global power demand, which is estimated to grow 3× by 2050, **can be met using renewable energy**

Solar photovoltaics are expected to cover **~60%, onshore wind** power generation to cover **~20%,** and **offshore wind** power generation to cover **~4%**



Sustainable fuels
Including biofuels

Sustainable fuels could **decarbonize high-energy-density requirements** of aviation, maritime shipping, and heavy freight

Demand growth rate is expected to outpace that of fossil fuels

Limited capital is required to transition; these “drop-in” fuels do not require upgrading existing engines

Hydrogen (H_2)-based fuels
Production of hydrogen as an energy source

Producing decarbonized hydrogen (blue, using carbon capture; green, using renewable electricity) is projected to **cost less than producing conventional hydrogen** (gray, from natural gas) by 2030

Electrolyzers’ **critical role** in **unlocking demand for green hydrogen** is that they reduce the cost of production

Source: McKinsey analysis

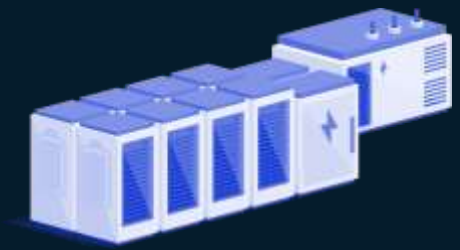
What is this trend about? (continued)

Power storage

Energy storage
Battery technologies, battery recycling/second use, long-term storage, gravity-based storage, etc

Stationary storage system

Long-duration energy storage technologies are expected to drive **~20% of renewables adoption,** enabling ~2.4 gigatons (Gt) of renewables abatement; **short- to mid-duration storage** is expected to **expand renewables penetration from 30–80%,** indirectly enabling up to ~6 Gt of abatement



Power distribution

Energy optimization and distribution

Smart grid

Advanced, intelligent electric grid system could provide real-time insights and control for the distribution grid

Increasing AI applications across smart grids could leverage big data's potential (eg, improving accuracy of demand predictions)

EV[1] charging infrastructure (EVCI)

EVCIs compete primarily on charging time and cost, with wide ranges in both: charge times range from ~8 hours to just 10 minutes, and prices range from €7,500 to €110,000

[1] Electric vehicle.

Source: McKinsey analysis

Why should leaders pay attention?

Overall trend

Significant near-term value at stake

~$2.4 trillion

Annual capital spending required in 2031–35 for the net-zero transition: $1.2 trillion in power generation, $1 trillion in the power grid, and $200 billion in energy storage in the NGFS[1] Net Zero 2050 scenario

Bolder environmental regulation

~20%

Increase of climate-related laws and policies since 2020 in China, EU, and US[2]

Increasing power demand

~3.3×

Increase in global electric power demand in a 1.5°C scenario by 2050

Increasing corporate commitment

>1,000

Number of companies that in 2021 **set science-based targets** toward 1.5–2.0°C goals, growing by ~3× from 2020 and representing a market cap of ~$23 trillion

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[1] Network for Greening the Financial System.
[2] Current number of policies is 11 in China, 17 in US, and 48 in EU.

Source: *Major risk or rosy opportunity: Are companies ready for climate change?,* CDP Worldwide, 2019; “Nuclear fusion market could achieve a $40 trillion valuation,” Bloomberg, Dec 28, 2021; *The net-zero transition: What it would cost, what it could bring*, McKinsey, Jan 2022; *Global energy perspective 2022*, McKinsey, Apr 2022; McKinsey analysis

Why should leaders pay attention? (continued)

Energy tech

Renewable energy

>80%

Share of 2050 **global power demand** that could be generated by renewable energy, with solar PV generating ~43%, onshore windmills generating ~26%, and offshore windmills generating less than ~7%

Sustainable fuels

3.3×

Growth in sustainable fuels until 2035, driven primarily by road transport, reaching 290 Mt in the Further Acceleration scenario, while aviation plays an increasingly important role thereafter

Nuclear fusion

>$4 billion

Investment across 35 nuclear fusion projects, focused on tackling engineering challenges

Energy storage

~30% CAGR

Growth in battery demand by 2030, driven mainly by electrification of mobility applications, which account for >90% of 2030 demand

Energy storage

30–60%

Decrease in battery prices expected by 2030; however, offering bespoke battery solutions to fulfill segment-specific requirements presents profitable opportunity

Source: *Global energy perspective 2022*, McKinsey, Apr 2022; "Unlocking growth in battery cell manufacturing for electric vehicles," McKinsey, Oct 2021; *Major risk or rosy opportunity,* CDP Worldwide, 2019; *Science-based net-zero: Scaling urgent corporate climate action worldwide*, Science Based Targets initiative, June 2022; McKinsey analysis

What are the most noteworthy technologies?

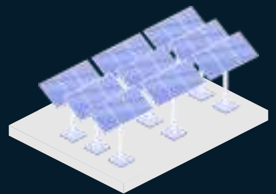
Renewable energy

Solar PV and thermo-solar, wind, geothermal, nuclear

Solar photovoltaics (PV)

Maturity in tech has **driven down costs below costs of traditional fossil fuels** (ie, vs coal)

Advancements in 3rd-generation solar PVs are primarily **manipulating semiconducting materials** (organics[1] and perovskites[2]) at nano-scale to achieve higher efficiencies



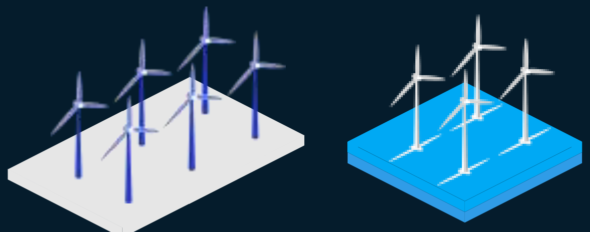
On- and offshore wind generation

Wind power plants with larger rotors, blades, and height are better suited to **harvest lower wind speeds at higher altitudes**

Offshore plants (expected by 2025) face engineering challenges (eg, marine infra-structure); onshore turbines face nontechnical limits[3]

Wind turbines **mounted on floating structures** allow **power generation in water depths where bottom-mounted structures are not feasible**

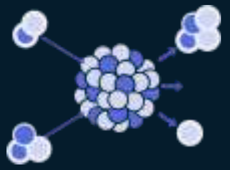
Current global shift from single-turbine pilots to multiturbine projects is expected by 2025 or later



Nuclear fusion

Fusion is the **process of combining atoms** under high temperatures and pressure **to release clean energy**

Fusion power research is could yield commercially-viable plant within a decade, driven by advancements in materials research and AI, with commercial launch of a nuclear fusion plant expected in the next decade[3]



H_2-based fuels

Production of hydrogen as an energy source

Primary methods for hydrogen production are gray/brown (unsustainable, being replaced), blue (affordable, lower-carbon alternative), and green (zero carbon emissions) hydrogen[4]

Electrolyzers

Electrochemical energy conversion technologies convert water into green hydrogen (sustainable energy source), with the only byproduct of the process being oxygen (ie, zero carbon emissions)

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[1] Use of organic electronics for light absorption and charge transport. [2] Hybrid (organic-metallic) semiconductor material composition tweaked to absorb broader light spectrum. [3] Including transportation and infrastructure choke points, land use, view, birds, shadows, etc. [4] More mature technologies include water electrolysis and steam reforming of biomethane/biogas with or without carbon capture and utilization/storage. Others include biomass gasification/pyrolysis, thermochemical water splitting, etc.

Source: Andy Ridgway, “Why the promise of nuclear fusion is no longer a pipe dream,” *BBC Science Focus*, Dec 3, 2021; Philip Ball, “The chase for fusion energy,” *Nature*, Nov 17, 2021; *The global fusion industry in 2021*, Fusion Industry Association and UK Atomic Energy Authority, Oct 2021; McKinsey analysis

What are the most noteworthy technologies? (continued)

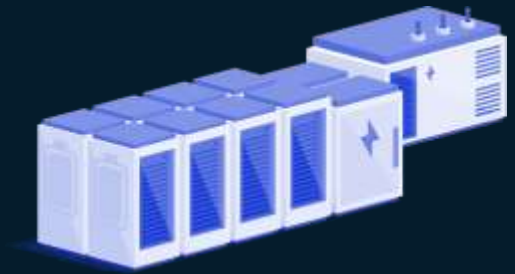
Energy storage

Battery tech, recycling, second use, long-term storage, gravity-based energy storage, etc.

Battery storage system

Lithium-ion batteries' price declined >90% in past decade, and they can only shift energy for **<8 hours** without becoming very expensive and incurring issues with their high self-discharge rate

Other solutions (ie, long-duration energy storage, gravity-based energy storage) are **required for weeks or months of storage**



Energy distribution

EV-charging infrastructure (EVCI)

Extensive networks of stations boost the accessibility and **speed of recharging EV batteries**

EVCI hardware includes grid and site electrical upgrades, on-site energy storage, and charger unit

EVCI software and services include energy management, electrical installation, operations and maintenance, and customer apps

Smart grid

A smart grid is an advanced, intelligent electric-grid system that can provide real-time insights and control for the distribution grid

Source: McKinsey analysis

What disruptions could renewable energy enable in the electric power, natural gas, and utilities industry?

Technology	Capabilities required
Solar PV	Cost-efficient manufacturability with improved stability/reliability would **accelerate scaling of solar panels** globally
On- and offshore wind generation	Ability to generate power efficiently **in low-wind scenarios** could unlock new sites for wind energy
Long-duration energy storage	**More efficient energy storage capabilities are required,** given increased solar and wind power generation; often, power demand and supply don’t match simultaneously, especially in “off seasons” when solar or wind farms produce little energy
Smart grid	**Changes to grid operation and infrastructure** to **optimize supply-side responses to demand in real time;** eg, augmented integration of distributed renewable energy resources and reduced reliance on fossil fuels

Source: *Global energy perspective 2022*, McKinsey, Apr 2022; McKinsey analysis

Key disruptions enabled

Net-zero power

Targets set by developed economies for 2040 and by emerging economies for 2050

80–90%

Share of 2050 global energy mix to be sourced from renewable generation

8×

Growth in annual solar PV capacity installations (gigawatts per year) from 2020 to 2030 in a 1.5ºC pathway

5×

Growth in power generated via onshore wind energy from 2016 to 2030

Access deep-water regions

Ability to access new sites (where water depth is ≥60 meters) for development of offshore wind parks by not requiring solid foundation

What disruptions could hydrogen enable in the electric power, natural gas, and utilities industry?

Technology	Capabilities required
Hydrogen-based fuels	**Drastic reductions in production costs, coupled with infrastructure development** (to enable adoption), are required to scale hydrogen production across a wider set of applications **Lower production costs of electrolyzers must be paired with higher efficiency** to improve hydrogen density, purity, lifetime, etc **Dispatchable electrolyzers** will allow for the **integration of more intermittent renewable energy** sources in the system

Additional enablers include greater regulatory clarity, government decarbonization commitments,[1] and deployment of transport and storage infrastructure

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[1] About 40 countries already have dedicated hydrogen strategies in place (eg, French government's target of 10% green hydrogen use in industry for 2022 and 20–40% for 2027).

Source: *Global energy perspective 2022*, McKinsey, Apr 2022

Key disruptions enabled

~28%

Share of final energy consumption could be met by green hydrogen by **2050**

5×

Growth in hydrogen demand by 2050, driven primarily by road transport, maritime, and aviation

~0.5 Gt

Carbon abatement by 2030, reaching 2.5 Gt by 2050, which is particularly critical for some hard-to-abate sectors (eg, iron and steel production, chemical and refining, long-haul trucks, cargo ships)

~65%

Share of hydrogen supply mix coming from green hydrogen by 2035—and up to ~80% by 2050

What other industries are most affected by the trend?

Other industries are experiencing **implications** of clean-energy tech, primarily focused on **supporting the clean-energy transition**, meeting **changes in resource demand**, and **shifting value pools**

Industry affected	Implications of technology trend
Metals and mining	**Growing demand for specific raw materials** (eg, copper for electrification, lithium and cobalt for batteries)
Oil and gas	**Decarbonizing upstream operations** and **exploring alternative low-carbon technologies and shifting value pools** (eg, hydrogen) by leveraging strengths in access to capital and operational expertise
Construction and building materials	**Constructing additional transmission and distribution infrastructure** to enable the delivery of electricity generated by renewable sources to where it is demanded
Chemicals	**Increasing demand for chemicals needed for the production of renewables** (eg, silicon for the development of photovoltaic cells)
Public and social sectors	**Prioritizing clean energy on governments' agendas** by providing greater **regulatory clarity**, government **decarbonization commitments, investment incentives**, among other actions

The construction industry is involved in **decommissioning fossil-fuel assets** (eg, coal mines, fossil-fuel power plants) and **environmental remediation of industrial sites** and infrastructure for the energy and utilities, oil and gas, and mining sectors

Source: McKinsey analysis

Who has successfully created impact with clean-energy technologies?

Industry	Case example
 **Electric power, natural gas, and utilities**	**Ørsted, a Danish energy company,** committed to **reducing greenhouse-gas emissions from energy production by 96%** from 2006 to 2023 through building >**1,000 offshore wind turbines**, **reducing** offshore wind **technology costs by >60%** since 2012, and **reducing coal consumption by 82%** in power stations since 2006 by switching to sustainable biomass, among other actions. Ørsted also divested its oil and gas business to focus on expanding its international renewable energy operations
	Iberdrola, one of the world's largest utilities (by market cap), aims to **reduce all emissions 43% by 2030** (from 2017) and **achieve carbon neutrality** in Europe by 2030 and globally by 2050; key actions include **drastically increasing renewable capacity** and increasing investments in **smart grids** and **green hydrogen** for industrial use

Source: Company websites; Science Based Targets initiative

What uncertainties must be resolved for the trend to achieve scale?

Not exhaustive

Renewables

Cost-efficient manufacturability is required to accelerate scaling of solar-power and wind generation tech

Higher capacity, stability, and reliability are needed in solar PVs and on- and offshore wind generation plants

Supply chain risks persist amid global economic uncertainties

Hydrogen production

Significant cost reductions in green hydrogen production (eg, electrolyzers) are needed to scale

Higher production efficiency in electrolyzers is crucial to improve hydrogen density, purity, and lifetime

Hydrogen use is currently confined to a few sectors, pending wider applications

The **slow pace of infrastructure development** inhibits adoption

Electrification

High production costs (eg, EV battery pack currently is 30–40% of total EV cost) are expected to drop as consumer demand accelerates by 2030, unlocking economies of scale

Current limited distribution of EV-charging infrastructure needs scaling to accelerate EV adoption

Energy storage/smart grids

Long-duration energy storage technologies remain under R&D, requiring major leaps in the short run and continuous innovation in the long run to optimize costs and storage duration

Smart grids face integration, costly installation, and deployment challenges that require further research investments

Overarching uncertainties include supply chain risks amid global economic uncertainties, as well as insufficient regulatory clarity on decarbonization commitments, renewable-energy requirements, and uncertain carbon pricing

Source: McKinsey analysis

What are some topics of debate related to the trend?

Not exhaustive

	1. Will traditional renewables be outpaced by newer technologies?	**2. Is it feasible to switch to 100% renewable energy?**	**3. Will business opportunities in clean tech continue to grow?**
Supportive view	• Solar and wind renewables are **“battle tested,”** with **clear business case and cost advantage** • Solar and wind **capacity is expanding** • Solar and wind **costs are decreasing** every year	• The long-term **cost** of renewable energy is **competitive or lower** than today’s energy sources • Solar, wind, and geothermal **capacity is expanding** every year • Fossil fuels have both **environmental costs and national security** risks in some countries	• **The global consensus** is for clean energy, with initiatives beyond investing (eg, emission penalties, mine shutdowns) • **B2C market is growing** as consumers increasingly favor sustainable products • **B2B market is growing** as businesses are anticipating sustainability regulations and seeking energy and cost savings
Opposing view	• **Hydrogen** is attracting significant investments and already has commercialized use cases • **Nuclear** power could become more attractive, thanks to new yet untested designs that would reduce environmental and national-security risks • **Fusion** power may or may not become scalable in the foreseeable future	• Most renewable energy sources are intermittent; therefore, **storage systems remain a bottleneck** • In some **countries,** 100% renewable energy is **more difficult to achieve,** since it depends on one’s resources • **Political forces** and incumbent players **may stifle** the transition	• Many tech projects remain **costly in terms of capital expenditures** and bear high execution risks • Some technologies will prove to be more effective than others; **not all clean tech will remain** viable • In **2006–11**, a **clean-energy bubble burst**

Source: McKinsey analysis

Additional resources

Knowledge centers

Insights on the net-zero transition

Innovate to net zero

Related reading

Global energy perspective 2022

The net-zero transition: What it would cost, what it could bring

An AI power play: Fueling the next wave of innovation in the energy sector

Decarbonizing the world’s industries: A net-zero guide for nine key sectors

Failure is not an option: Increasing the chances of achieving net zero

McKinsey Technology Trends Outlook 2022

Future of mobility

August 2022

What is the trend about?

Mobility is undergoing its **“second great inflection point”**—a shift toward autonomous, connected, electric, and smart (ACES) technologies

This shift promises to disrupt markets while improving **efficiency and sustainability** of land and air transportation of people and goods

Mobility is defined by several arenas across 4 disruptive dimensions of mobility **(ACES) and adjacent technologies** that enable more sustainable and efficient transportation

ACES

Autonomous technologies

Automated systems with sensors, AI, and analytical capabilities able to make independent decisions based on the data they collect

Connected-vehicle technologies

Equipment, applications, and systems that use vehicle-to-everything communications to address safety, system efficiency, and mobility on roadways

Electrification technologies

Solutions replacing vehicle components that operate on a conventional energy source with those that operate on electricity

Smart mobility solutions

Hardware and advanced digital/analytics solutions enabling use of alternative forms of transportation (eg, shared-mobility solutions) in addition to or instead of owning a gas-powered car

Adjacent technologies

Lightweight technologies

Incorporation of new materials (eg, carbon fiber) and processes (eg, engine downsizing) to boost fuel efficiency and improve transportation sustainability

Value chain decarbonization

Technical levers to abate emissions from materials production and end-to-end manufacturing process and increase use of recycled materials across the value chain

Source: McKinsey analysis

Why should leaders pay attention?

Physical supply chains are vital to many industries, and today transportation is at a major inflection point, as mobility ecosystems are **simultaneously affected by regulation, shifting consumer preferences, and technology disruption**

1. Regulation is enabling a mobility revolution

Carbon targets and subsidies

50%

Amount by which emission targets for 2030 could be tightened by the EU

Urban access regulation

150+

Number of EU cities with access regulation for low-emission vehicles and pollution emergencies

2. Consumers are accepting new mobility solutions

Alternative ownership models

2/3

Portion of US consumers expecting their use of shared mobility to increase in next 2 years

Greener attitude

60%

Year-over-year increase in inner-city trips with shared bikes and scooters (136 million trips in 2019)

3. Technology disruption is happening at an unprecedented pace, and availability challenges remain

Autonomous driving

8x

Increase in average annual investments in autonomous vehicles over past 5 years

Connectivity

6 months

Length of delays in some recent vehicle launches due to software integration issues

Electrification

1:1

Cost parity for small EVs[1] with ICE[2] today, with fuel-cell parity expected by 2030

Smart mobility

50%

Portion of miles traveled with shared transportation modes expected by 2030

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[1] Electric vehicles.

[2] Internal combustion engine.

Source: McKinsey analysis

What are the most noteworthy technologies?

ACES

Autonomy

- Radar and camera
- Lidar
- Steer/brake/shift-by-wire
- HD maps plus SLAM[1]
- Object detection
- Driving strategy

Hardware | Software/AI

Connected vehicle

- Infotainment
- Vehicle-to-infrastructure (V2I) connectivity
- Cybersecurity

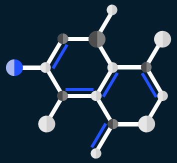
Electrification

- Digital twin
- Lithium-ion battery (LIB)
- Beyond LIB
- Battery analytics
- Hydrogen fuel cells
- Hybrid propulsion

Smart mobility

- Transportation demand management (TDM)

Adjacent tech



Lightweight technologies

- Advanced composites
- Advanced ceramics
- Metamaterials
- Nanomaterials

Value chain decarbonization

- Green primary materials
- Parts and materials circularity

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[1] High-definition maps and simultaneous localization and mapping.

Source: McKinsey analysis

What are the most noteworthy technologies? (continued)

▮ Hardware ▮ Software/AI

	Tech cluster	Technologies	Description
ACES	**Autonomous**	Radar and camera	Sensor with algorithms to automatically detect objects, classify them, and determine the distance from them
		Lidar	Range detection system relying on light travel time measurement
		Steer/brake/shift-by-wire	Electrical or electromechanical systems for vehicle functions traditionally achieved by mechanical linkages
		HD maps plus SLAM	Simultaneous mapping and localization solution to map out unknown environments
		Object detection	Perception technologies used for behavior planning, route planning, motion planning
		Driving strategy	Solutions integrating hardware and software components in a full-stack autonomous vehicle
	Connected vehicle	Infotainment	In-vehicle infotainment solutions (eg, augmented reality, voice recognition, and gesture control)
		V2I connectivity	Software and hardware enabling vehicle-to-infrastructure (V2I) connectivity
		Cybersecurity	Security solutions to protect connected cars and commercial vehicles against cyberattacks (eg, encoding)
	Electrification	Digital twin	Real-time virtual model of a system or process mirroring key attributes of the existing power infrastructure
		Lithium-ion battery (LIB)	Advanced battery technology that uses lithium ion as a key component of its electrochemistry
		Beyond LIB	Sodium-ion (Na-ion) and potassium-ion (K-ion) batteries, which might solve the resource issues facing LIBs
		Battery analytics	Intelligence to extend battery life, improve manufacturing, unlock end-of-life markets, prevent safety hazards
		Hydrogen fuel cells	Propulsion system where energy stored as hydrogen is converted to electricity by the fuel cell
		Hybrid propulsion	Propulsion system including several propulsion sources used either together or alternately (eg, fuel–electric)
	Smart mobility	Transportation demand management (TDM)	Solutions optimizing use of locally available transportation resources to incentivize transition to more efficient and sustainable modes of commuting
Adjacent tech	**Lightweight technologies**	Advanced composites	Polymer matrix composites with unusually high strength or stiffness (eg, carbon fiber)
		Advanced ceramics	Advanced composites such as carbon-fiber-reinforced plastics, which could substitute for steel
		Metamaterials	Materials measuring 10–100 nanometers in at least 1 dimension (eg, graphene or carbon nanotubes)
		Nanomaterials	Engineered materials that have properties not found in nature and that can modify wave properties
	Value chain decarbonization	Green primary materials	Green steel, carbon-reduced production technologies, green aluminum, and green plastics[1]
		Parts and materials circularity	Reuse, refurbishment, remanufacturing of modules or parts, and recovery of high-quality materials from end-of-life vehicles and other products to enable low-carbon vehicle production

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[1] Green steel is made with mass balancing or innovative technology. Carbon-reduced production technologies include using direct reduced iron (DRI) and an electric arc furnace (EAF). Green aluminum is made with more widespread use of renewable electricity in smelters and multiple technology innovations flushing out most of the residual production emissions over the next decade. Green plastics include those made from bio-based feedstock and electrified production assets.

Source: McKinsey analysis

What disruptions could the trend enable?

Ground transportation

	With driver	Autonomous
Passenger transport	Advanced driver assistance systems (ADAS), ie, autonomy level of L2 and below[1] Dynamic shuttle services/ pooled e-hailing Peer-to-peer mobility (including car sharing)	Autonomous vehicles (eg, Level 3 or higher autonomy,[1] robo-taxis) Hyperloop
Transport of goods	Same-day delivery Trucking marketplace[2]	Autonomous trucks Last-mile delivery solutions (eg, last-mile robots on road or sidewalk)

Air mobility

<table>
<tr><th></th><th>Crewed</th><th>Uncrewed</th></tr>
<tr><td rowspan="2">Passenger transport</td><td colspan="2">Vertical takeoff and landing (VTOL) air taxis
Wingless multicopters</td></tr>
<tr><td>Supersonic/hypersonic air transport</td><td></td></tr>
<tr><td>Transport of goods</td><td>Conventional air freight with novel propulsion</td><td>Unmanned aerial vehicles, such as freight or delivery drones
Unmanned traffic management systems</td></tr>
</table>

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[1] Autonomy is categorized across level of supervision needed: L1 is execution of steering and acceleration/deceleration; L2 is monitoring of driving environment; L3 is fallback performance of dynamic driving tasks; L4 is system capability (ie, driving modes).

[2] With AI to manage logistics networks and fleet parks.

Source: McKinsey analysis

What industries are most affected by the trend?

Among the **most affected industries** are automotive and assembly; aviation, travel, and logistics; and telecommunications

Industry affected	Implications of technology trend
Automotive and assembly	• **Changing pockets of growth** as a revolution in urban mobility creates a shift from personal ownership to shared vehicles (global vehicle sales volume is at best projected to remain constant through 2030) • **Exploration of new mobility verticals** and **operating models** to take part in the novel mobility solutions arena • Drastic **increase in OEM market entrants** after decades of primarily mature-player presence • **Increased investment in tech R&D and ecosystem partnerships** (revenues from ACES may account for 1/5 of OEM value pool by 2030)
Aviation, travel, and logistics	• Improvements in **operational setup**, with higher asset utilization, increased flexibility, improved safety • **New business models**, as asset ownership may shift from small carriers to large integrators • **Shift of volume from rail to road** as cost advantage shifts to longer distances with autonomous trucks • Improved **efficiency of public transport** from dynamic shuttle services and pooled e-hailing
Telecommun-ications	• **Significant pressure for higher bandwidth** as mobility fuels exponential growth in data traffic and for **global coverage** to meet the need for vehicles to be connected everywhere, at all times • **New opportunities for telcos to monetize value-added services** (eg, by combining core connectivity with vehicular technologies and real-time mobility data)
Aerospace and defense	• **New modes of aerial transportation** of passengers and goods (eg, aerial autonomy for freight delivery, small size VTOL enabling air taxis) which will expand aviation use cases • **Novel propulsion** drastically changing unit economics • **Security pressure** as in-vehicle systems and connected infrastructure are more exposed to security threats

Source: McKinsey analysis

What industries are most affected by the trend? (continued)

Diverse stakeholders across industries are experiencing **second-order implications** of novel transportation technologies. Disruption is primarily driven by **macroeconomic impact**, changes in **resource demand patterns**, novel **modes of transportation,** and changes to vehicle **ownership models**, as well as **shifting value pools**

Industry affected	Implications of technology trend
Metals and mining	Change in material usage patterns (eg. steel for new powertrain types) and increased demand for sustainable materials (eg. green steel, green aluminum)
Electric power, natural gas, and utilities	Need for more generation capacity and for reinforcement of transmission and distribution networks to meet increased demand for electricity from EVs
Information technology and electronics	Increased demand for solutions enabling, supporting, and integrating technological advancements across ACES
Financial services	Change in claims portfolio (eg. impact of increasing car safety with ADAS and autonomous-vehicle systems)
Oil and gas	Change in demand for gasoline and diesel once EVs reach critical scale
Retail	Novel modes of delivery with airborne drones
Public and social sectors	Changes in city infrastructure from sustainability-focused regulation promoting smart mobility Revisions to land-use planning (eg. autonomous vehicles and shared mobility reducing the need for parking lots)

Source: McKinsey analysis

What are some use cases for the technologies that drive this trend?

Function-specific use cases

Function affected	Technology use case
Transportation of goods	• Autonomous trucks in long- haul supply chain • Freight drones for last-mile delivery • Supply chain optimization solutions enabling same-day delivery • Trucking marketplaces for efficient freight management
Transportation of people	• Novel mobility services such as robo-taxis • Purpose-built vehicles with longer durability (eg, designed specifically for shared mobility)

Industry use cases

Industry affected	Technology use case
Electric power, natural gas, and utilities	• Vehicle-to-grid systems (in which EVs return excess electricity back to the grid or throttle their charging rate)
Information technology and electronics	• Software/AI solutions for simultaneous mapping and localization, object detection, driving strategy • Hardware for autonomous vehicles (eg, lidars, cameras)
Public and social sectors	• Mobility-as-a-service for integrated commuter experiences across public transit, ride sharing, and micromobility • Congestion pricing (ie, dynamic pricing based on traffic)
Financial services	• Personalized insurance rates based on driving patterns from connected-vehicle data • New insurance use cases for autonomous vehicles (eg, insurance for vehicle intelligence)
Media and entertainment	• Novel ways of engaging a passenger during commute

Source: McKinsey analysis

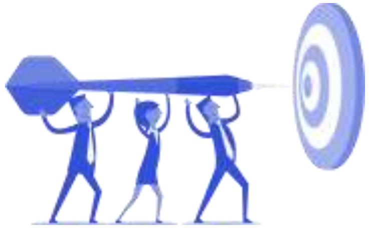
Who has successfully created impact with these technologies?

Industry	Mobility technology	Example company	Disruption caused by technology
 **Aviation, travel, and logistics**	Autonomous trucks	**UPS** **TuSimple**	**Environmental benefits and fuel savings:** TuSimple partnership with UPS North American Air Freight has delivered >13% fuel savings,[1] with potential to lower customers' freight costs significantly
 **Automotive and assembly**	Advanced driver assistance systems	**BMW**	**Safer driving:** BMW's Driving Assistance package cut property damage claims 27%, bodily injury claims 37%, and collision claims 6%[2]
 **Telecom-munications**	Connected vehicles	**Deutsche Telekom**	**New revenue streams:** DT is actively codeveloping connected-vehicle solutions in partnership with OEMs and identifying new customer connectivity needs (eg, Wi-Fi hotspot within BMW ConnectedDrive)
 **Electric power, natural gas, and utilities**	Electrification of vehicles	**E.ON**	**Business diversification:** In 2016, E.ON established a business unit to expand EV-charging infrastructure in the EU, signaling a strategic focus on e-mobility
 **Information technology and electronics**	Smart mobility	**The Routing Company**	**Dynamic public transit:** TRC offers an on-demand vehicle routing and management platform for cities to power the future of public transit
 **Metals and mining**	Lightweight materials	**General Motors** **Caltech** **Boeing** **UC Irvine**	**Efficient aviation**: "Microlattice" metal, codeveloped by Boeing, Caltech, GM, and UC Irvine, is reported to be 100x lighter than Styrofoam but strong enough to be used in structural components of airplanes[3]

[1] Savings achieved when operating in the optimal long-haul operating band of 55–68 miles per hour. | [2] Package includes forward collision and lane departure warnings, autobraking, and adaptive cruise control.
[3] In the case of the Boeing 787-9, which burns approximately 5,400 liters of fuel per hour, a 10–12% improvement in fuel economy amounts to 540–650 liters saved per hour.

Source: McKinsey analysis

What should leaders consider when engaging with the trend?



Benefits

Cost savings from supply chain improvements

Market expansion from reaching new customer segments in otherwise unserviceable locations or with improved delivery speed

Sustainability as new modes of ground and air mobility prioritize electric, hydrogen-based, or hybrid propulsion

Risks and uncertainties

Safety and accountability concerns surround uncrewed and autonomous mobility technologies

Technology uncertainties about batteries with sufficient range to support more applications (such as air mobility) may hinder greater adoption

Customer perceptions of noise and visual impact remain in play

Equipment and infrastructure costs are factors for new modes of transportation

Regulation shifts will occur as mainstream certification frameworks are developed

Privacy and security concerns for underlying algorithms and workflows must be addressed

Source: McKinsey analysis

What are some topics of debate related to the trend?

🟦 Ground transportation 🟦 Air mobility

1 **Market penetration and timing of autonomy**

What share of vehicle sales will autonomous vehicles account for?

While autonomy offers significant benefits (eg, reduction in traffic deaths, improvements in fuel economy), widespread adoption may be hindered by safety concerns (eg, several high-profile accidents), data protection issues, high upfront costs (vehicles and infrastructure), and insufficient regulation

2 **Future of smart mobility in cities**

How will future-of-mobility trends shape cities?

Smart mobility reduces traffic congestion and air and noise pollution, and it improves safety, speed, and cost of travel; however, urban infrastructure plans are often criticized for imposing heavy investment requirements and creating security/privacy concerns

3 **Impact of shared mobility**

Will advancements in shared mobility deliver on hoped-for financial and environmental impact?

Shared mobility has not yet proved its long-term economic viability, as many operators struggle with profitability; further, shared mobility must prove its sustainability impact as a full replacement for private cars, with an associated shift away from private-vehicle ownership (rather than its primary role today as an extension of private vehicles, thereby increasing the vehicle fleet)

4 **Timing for new aerial modes of transport**

What scale will advanced air mobility achieve in the next decade?

While air mobility enthusiasts project that over the coming decade (or soon after), an electric aircraft could become a popular mode of transportation and a viable alternative to traditional taxis, few players have so far managed to bridge the engineering-to-scale chasm, overcome product and business model uncertainties, or bend customer perception challenges related to noise and visual aesthetics

5 **Sustainable and inclusive air mobility**

When should customers expect affordable advanced air mobility solutions?

Novel, subscale modes of aerial transportation with a premium price tag may become available to customers in the next decade, but the industry may take significantly longer to scale and bend the cost of a short-haul flight to the equivalent of a taxi ride

Source: McKinsey analysis

Additional resources

Knowledge center

McKinsey Center for Future Mobility

Related reading

Mobility’s second great inflection point

The future of mobility is at our doorstep

Advanced air mobility in 2030

Reimagining mobility: A CEO’s guide

The zero-carbon car: Abating material emissions is next on the agenda

McKinsey
& Company

McKinsey Technology Trends Outlook 2022

Future of space technologies

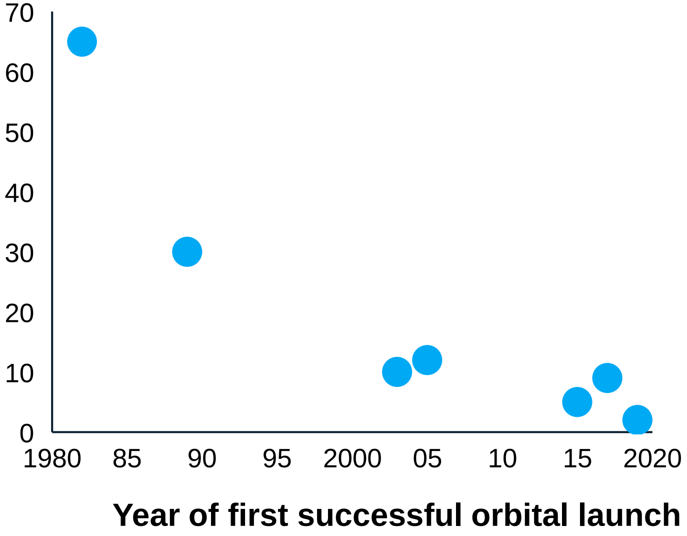
August 2022

What is this trend about?

Moving down the cost curve has unlocked use cases that were previously cost-prohibitive

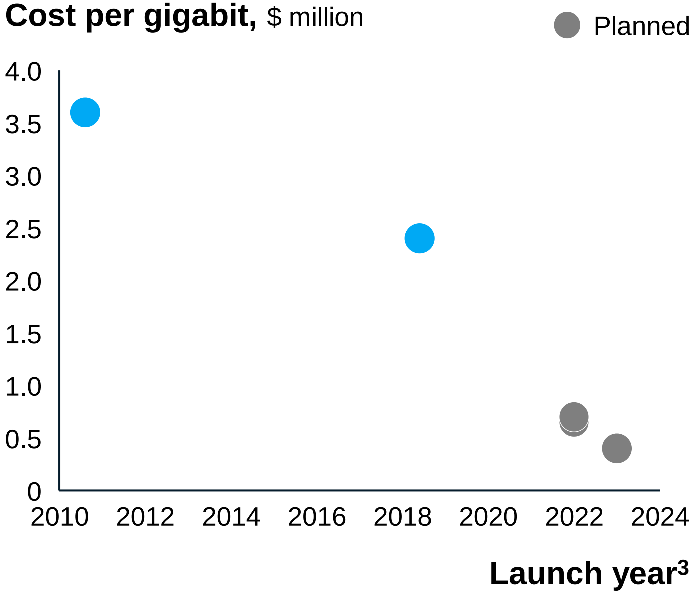
Heavy launch[1]

Cost per kg to low-Earth orbit (LEO), $ thousand



GEO[2] communications satellites[1]

Cost per gigabit, $ million



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1. Figures reflect estimates only, based on analysis using publicly stated information and expert estimates. Satellite lifetime not factored into cost per gigabit.
2. Geosynchronous equatorial orbit.
3. Launch years are actual or planned per company announcements.

Source: Ryan Brukardt, Jesse Klempner, Daniel Pacthod, and Brooke Stokes, “The role of space in driving sustainability, security, and development on Earth,” McKinsey, May 2022

Key trends

① The **largest shift in space tech** over the past 5–10 years has been the **acceleration down the cost curve**, which is **increasingly unlocking new capabilities**, **use cases**, and **users** for space tech and satellite data and **scaling accessibility**

② One of the **drivers of cost-effectiveness** has been the **reduction of size, weight, power, and cost (SWaP-C)** of satellites and launch vehicles

③ SWaP-C reduction has **led to architectural shifts**, eg, from individual, **large GEO** satellites to **smaller, distributed LEO satellites**

Why should leaders pay attention?

>$1 trillion estimated market

>10% estimated annual growth by 2030 in the space market from a value of ~$447B today

~15% CAGR up to 2030 estimated for Earth observation information products, data analytics, data downlink, and space tourism and travel, all of which are expected to drive long-term demand[1]

Increased participation globally

>**1,400 companies** involved in the new space industry, from governments to start-ups, which are expected to grow from 600+ today to 1,000+ in 2030

New entrants are moving faster than legacy players by focusing on first-mover advantages and commercial opportunities

Significant cost reductions

Significant cost reductions are already occurring, and **further reductions in launch and return-to-Earth costs** could **enable even more disruptive applications**, such as space mining and commercial human spaceflight

New business models

New business models, including **vertical integration** required to meet increased demand, are driven by **movement toward value-added services,** given higher margins

Increased focus on software

Value-added services necessitate a higher degree of digital applications (eg, autonomous landing of launch vehicles, AI delivering real-time insights to clients)

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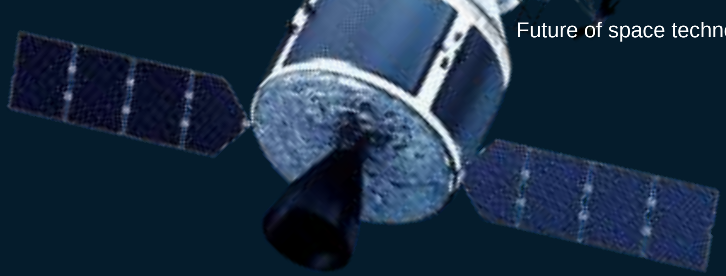
[1] "NSR's global space economy report projects $1.25 trillion in revenue by 2030," Northern Sky Research (NSR), January 2022.

Source: "The role of space in driving sustainability, security, and development on Earth," McKinsey, May 2022



What are the most noteworthy technologies?

Nonexhaustive

Technological advancements and the reduction of size, weight, and power of satellites and launch vehicles have contributed to cost-effectiveness, making new space applications more economically feasible

Satellites

Application of new technologies

Higher computing power leveraging consumer processor tech across distributed satellite networks to support data collection from increasingly high-resolution sensors

Less expensive, higher-resolution sensors that conduct observation of their targets (eg, Earth, planets), typically using passive observation in several spectrums (eg, optical, infrared) and active sensors (via radar)

Less costly, more efficient power systems using smaller, lightweight solar panels and more efficient batteries, allowing small (cube) satellites to have greater power availability for expanded missions

Greater capabilities in a smaller size, weight, and power (SWaP) package, enabling new missions

Industrialization of assembly

Design for modularity: Manufacturing approach that enables faster design, development, and assembly via cube-sat architectures (built using standard dimensions, ie, units of 10 × 10 × 10 cm) used as extendable building blocks

Shift from job shop to assembly line: In response to increased demand (for proliferated constellations) and investment in facilities, changes in satellite production from one-off, hand-built examples to a more industrial process

Democratization of production: Lower costs due to new manufacturing processes, including additive manufacturing and modular designs, enabling market entry of new players

Enabled a shift in architecture from individual GEO satellites to proliferated architectures in LEO

Architectural shift

LEO constellations

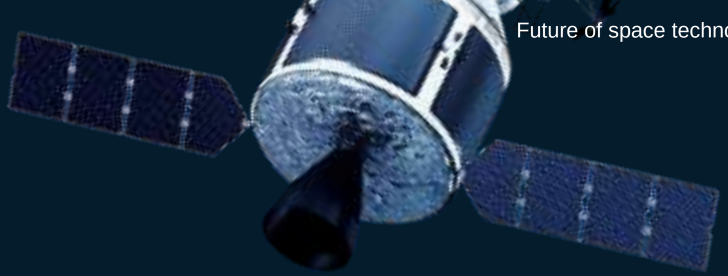
Low-Earth-orbit (LEO) satellites, which orbit close to Earth's atmosphere (altitude 300–2,000 km)

Proliferation in number of active satellites, from ~4,100 in 2021 to ~2,700 in 2020, with a focus on mega-constellations using smaller satellites

Pros: Increasingly dense coverage and capacity globally, lower latency, higher flexibility and revisit

To learn more about this technology, see "Advanced connectivity," *McKinsey Technology Trends Outlook 2022*, August 2022

Source: Evangela Rodgers, "With satellite internet, network capacity is key," Viasat, Sept 2021; Katja Lenz, "Smartphone technology provides satellites with increased computing power," German Aerospace Center (DLR), June 2022



What are the most noteworthy technologies? (continued)

Nonexhaustive

Other emerging technologies will build on the sector's transformation over the previous decade

Communications

Laser communications

Laser links would allow satellites to **communicate using pulses of light** for data transmission

Potential exists **to increase data transfer speeds** by 100x–1,000x vs traditional radio frequency

Ability to direct laser emitted to very specific locations (both to satellites in space and ground stations on Earth), which **mitigates coverage overlap and interference**

Digital capabilities

Edge computing and AI

With the growing launch of satellites and spacecraft for activities such as Earth observation, **higher volumes of data will be collected**, introducing a **need for edge computing**

Edge computing allows for **processing data closer to** the **point of collection** in the **cloud**, **leveraging AI and machine learning capabilities**, reducing latency, and saving bandwidth to deliver **near-real-time insights**

Deep-space exploration

Nuclear propulsion

Nuclear thermal/electric propulsion could propel spacecraft at higher speeds for longer distances, enabling deep-space exploration[1]

Technological advancements are optimizing performance and reliability while improving affordability to enable a cadence of more frequent launches

Currently in R&D; may carry safety risks, and most missions don't have a need for rapid transit that would justify it

Operations

In-orbit servicing

Satellite refueling/mods: Satellites refuel or modify satellites in orbit to extend mission lifetime and capabilities and to reduce replacement costs

Orbit Fab developed end-to-end refueling using its Rapidly Attachable Fluid Transfer Interface (RAFTI), a fueling port that can also be used as a drop-in replacement for existing satellite fill-and-drain valves

Orbit repositioning involves raising the orbit or changing the inclination of a satellite

Launch: Reuse of booster structures, engines, or otherwise, coupled with technology advancements (eg, material sciences, computer-aided design, 3-D printing) and increases in launch rate, are contributing to a reduction in operational costs and an increase in accessibility to space

End-of-life disposal is pulling space debris to reenter Earth's atmosphere for disposal, reducing collision risks

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[1] As opposed to current chemical and solar electric propulsion technologies, which suffer from significant energy inefficiencies.

Source: Stew Magnuson, "Laser communications to thwart jamming, interception," National Defense, Nov 2014; Daniel Baird, "LCRD: Your Questions Answered," The Invisible Network Podcast, NASA, Apr 2022

What disruptions could the trend enable?

Enabled by remote sensing

Advancements in applications of Earth observation data

Forestry

- Commercial forestry (inventory and mapping applications)
- Reconnaissance mapping
- Environmental monitoring

Hydrology

- Soil moisture estimation
- Flood mapping and monitoring
- Irrigation scheduling and leakage detection

Agriculture

- Crop type classification, condition assessment, yield estimation
- Mapping of soil characteristics and management practices
- Compliance monitoring (farming practices)

Land cover and use

- Routing/logistics planning (eg, seismic activities, urban expansion, resource extraction)
- Target detection
- Damage delineation

Geology

- Mapping (eg, structural, terrain, geologic unit)
- Exploration/exploitation (eg, mineral, sand, and gravel)
- Baseline infrastructure

Mapping

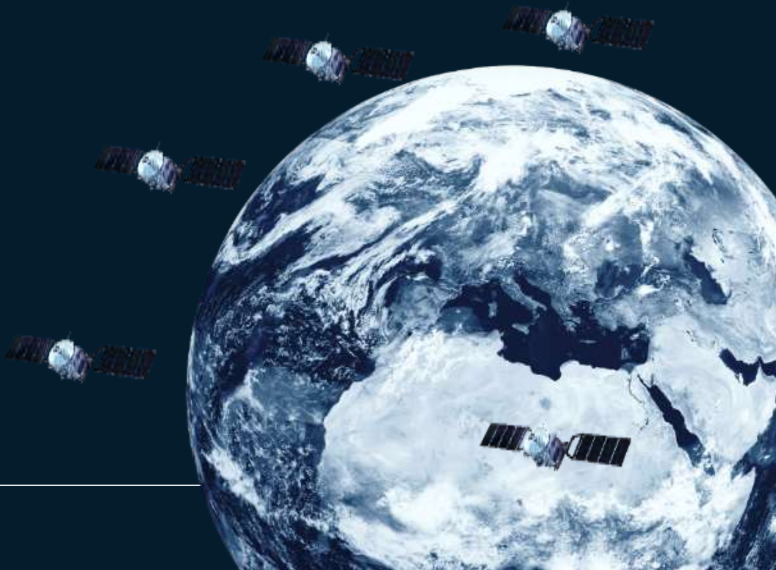
- Planimetry/surface geometry
- Digital elevation models
- Baseline thematic/topographic mapping

Oceans and coastal monitoring

- Ocean pattern identification
- Storm forecasting
- Environmental evaluation (eg, fish stock and marine mammal assessment, oil spills)

Sea and ice assessment

- Tactical identification (eg, detection, tracking, navigation)
- Shipping/rescue routes
- Global-change monitoring (eg, ice conditions, pollution indexing)



Source: McKinsey analysis

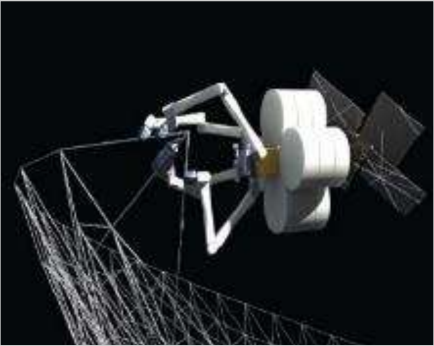
What disruptions could the trend enable? (continued)

The future space economy and human spaceflight could consist of activities not currently employed in space today, enabled by drastic reduction of launch costs, AI applications in space, and advancements in power transmission

Space economy

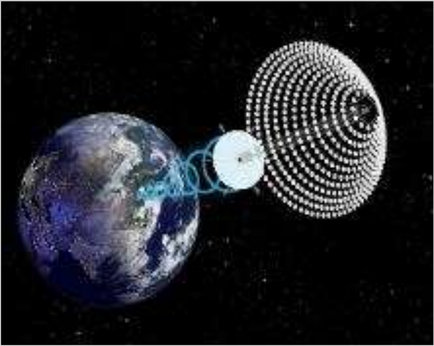
Space mining

Mine asteroids and space objects for materials to return to Earth



In-orbit construction and manufacturing

Seeks to capitalize on the benefits of zero gravity and supply future space travel



In-orbit power generation

Build space-based solar power generator leveraging 24/7 exposure to sunlight to offset emissions on Earth

Cislunar activity

Public- and private-sector exploration missions and development of infrastructure on the surface and in orbit

Scaling human spaceflight

Commercial tourism

Scale paying customers to space for short experiences of zero gravity and Earth views

Source: McKinsey analysis

What industries could be most affected by the trend?

While applications for space technologies are being developed across all industries, two are primarily impacted:

Telecommunications

Providing broadband internet to planes and remote areas, including emergency backup coverage

Aerospace and defense

Providing satellite imagery for navigation and monitoring to achieve security and intelligence objectives

Source: "The role of space in driving sustainability, security, and development on Earth," McKinsey, May 2022

Emerging use cases are being built across other industries, especially as costs decline and accessibility increases

Electric power, natural gas, and utilities

Monitoring methane emissions; informing development of sustainable energy services; providing imagery of mining sites

Agriculture

Monitoring soil, rainfall, and snow cover to inform irrigation plans, predictions of agricultural output, etc

Information technology and electronics

Developing in-space computing offerings

Automotive and assembly

Collaborating on lunar rovers; enabling autonomous driving and in-car entertainment

Aviation, travel, and logistics

Tracking moving shipping containers; providing positioning and navigation information; monitoring temperature of sensitive containers and road congestion

Financial services

Using radar satellite-based flood-monitoring capability to inform risk management and tailor solutions; leveraging commodities geolocation tracking (eg, vessels) to inform trades

Consumer packaged goods

Experimenting in space under specific space environment conditions to inform design and manufacturing of sneakers, soccer balls, etc

Pharmaceuticals and medical products

Conducting experiments leveraging microgravity (eg, protein crystallization) to improve pharmaceuticals

Who has successfully created impact with space technologies?

McKinsey deployed remote-sensing analytics to unlock new insights across industries

Case examples (nonexhaustive)

Ⓐ Field-level insights for agriculture input players

Used local agronomic data and various satellite imagery to inform marketing strategy, identify growth opportunities, match offerings to grower needs, adjust to changing conditions

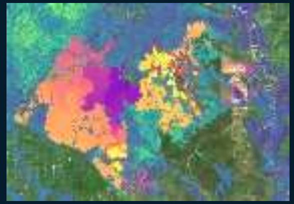
Ⓑ Vegetation detection for utility players

Optimized vegetation-trimming cycles around major utility grids by combining lidar and high-resolution optical images to map vegetation attributes

Ⓒ Commodity tracking and procurement

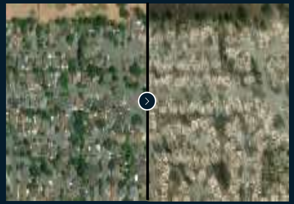
Helped companies that trade/process commodities to enhance their purchasing/trading activities through earlier insights on drivers of supply and demand (eg, by predicting and monitoring refinery shutdowns or port congestion)

Ⓓ Supply chain traceability and forest carbon



Helped consumer packaged goods (CPG) companies verify their zero-deforestation or sustainable-sourcing commitments by monitoring natural assets in key production areas

Ⓔ Building and construction detection



Supported NGOs and public organizations by tracking urbanization and building-level features (eg, to identify unreported property development or, in post-disaster relief effort, to identify damaged buildings via high-resolution satellite images

Ⓕ Oil and gas shale activity monitoring

Helped oil and gas companies monitor the life cycle of shale oil exploration and production, including drilling and fracking events

Source: McKinsey analysis

What are unresolved risks related to space technologies?

Cost-effectiveness

Space technologies must be cost-effective for space services and human spaceflight to be scalable

Trade-offs exist between more cost-effective (higher-risk) commercial technologies and higher-performance, more reliable “space qualified” technology

Careful risk assessment is required on the importance of mission assurance/ accomplishment (eg, extensive use of commercial tech in constellations increases the risk of satellites dying prematurely and adding to the space debris challenge)

Governance

Governance should encompass usage rights and space activities

Uncontrolled proliferation of all possible space concepts increases the risk of spectrum interference, physical collisions, etc

Governance mechanisms need to better define allocation of spectrum and orbit usage rights in order to accommodate the increasing number of players, satellites, and applications

Cyberrisks

Risk and complexity of cyberthreats are growing

As dependency on space tech increases across different use cases, the potential damage resulting from exploitation of a cyber vulnerability also increases

Proliferation of commercial players raises a question of whether all services will be well protected from cyberrisks

Source: McKinsey analysis

What are some topics of debate related to the trend?

Nonexhaustive

1 **Space militarization**

How can leaders define rights and norms?

Governments recognize space as a war-fighting domain (eg, GPS jamming, antisatellite weapons), as demonstrated by recent organizational changes (eg, space commands established in France, Japan, UK, US)

2 **Legal conflicts between states**

How can leaders define ownership and access rights?

A key need for the sector is to reach a **common understanding about access rights and usage of properties and resources** (eg, for Lagrange points, spectrum, and minerals found in space); such rights can help create a democratized setup whereby all can participate in the benefits of space

3 **Space debris and traffic management**

Should LEO have limits?

As more companies access space, **concern arises** regarding **space debris, space traffic management, and congestion** (eg, uncertainty about what the ~27,000 pieces of debris in space might hit and when)

Source: McKinsey analysis

Additional resources

Related reading

The role of space in driving sustainability, security, and development on Earth

The potential of microgravity: How companies across sectors can venture into space

The future of space: It’s getting crowded out there

Expectations versus reality: Commercial satellite constellations

Look out below: What will happen to the space debris in orbit?

McKinsey
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McKinsey Technology Trends Outlook 2022

Future of sustainable consumption

August 2022

What is the tech trend about?

Sustainable consumption centers on the use of goods and services that are produced with minimal environmental impact, using low-carbon and sustainable materials. Enabling technologies transform industrial and individual consumption to address environmental risks, including climate change

6 main patterns reflect enhancements in conscious consumption

Low carbon

Minimizing greenhouse-gas (GHG) emissions over life cycle of production, use, and disposal

Reduce, reuse, and recycle

Reusing materials previously used in a product or created as a manufacturing by-product

Biodegradable

Using materials that can be broken down into chemical constituents in ambient conditions (ie, landfill)

Waste conscious

Minimizing waste through optimized consumption (eg, of water, plastic)

Biobased

Prioritizing materials intentionally made from substances derived from living (or once-living) organisms

Nontoxic

Following processes that emit fewer chemicals and environmental pollutants during production and use

Consumption types

Industrial

- Industry (eg, mining, chemicals)
- Sustainable agriculture
- Public and industrial transport
- Commercial buildings

Individual

- Residential buildings
- Passenger transportation (eg, personal vehicles)
- Household consumption (eg, food)

Energy end use contributes to ~50% of GHG emissions, vs ~20% from energy supply and ~30% from non-energy-related emissions

Source: McKinsey analysis

Why should leaders pay attention?

At a macro level, **sustainability is no longer optional:** 90% emission reduction paired with emission removal is needed to avoid an environmental crisis, creating a $4 trillion–$6 trillion addressable market focused on industrial and individual end use by 2030

For companies, production of sustainable goods and services can support compliance with emerging regulations, create growth opportunities, and help attract talent

Macro level

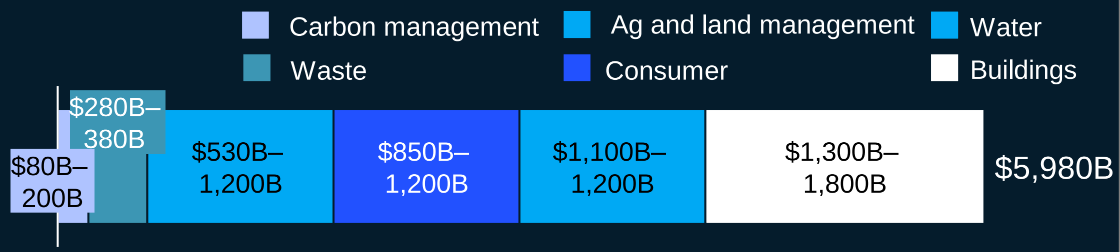
90%

GHG emission reduction required to comply with 1.5°C pathway[1]

$4T–$6T

global sustainability **addressable market by 2030** focused on industrial and individual end use

Global sustainability-addressable market



Micro level

Applying bolder sustainable-consumption regulation

30%–50%

corporate profits at stake (eg, from carbon pricing, sustainable-packaging and waste regulations)

Shifting customer expectations

≤50%

'green premium' customers are willing to pay for sustainably produced products and services across B2C and B2B sectors

Talent moving to sustainable companies

80%

millennials want to work for a company strong on sustainability and other ESG[2] dimensions

First movers capturing value

50%

faster growth in sustainable brands vs others (eg, Unilever's Sustainable Living Brands vs the rest of the portfolio)

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[1] The 1.5°C pathway refers to goal of holding global warming to 1.5°C above preindustrial levels through achieving net zero by 2050 and halving carbon emissions by 2030.
[2] Environmental, social, and governance.

Source: *Major risk or rosy opportunity: Are companies ready for climate change*, CDP Worldwide, 2019; McKinsey analysis

What are the most noteworthy technologies?

Many sustainable end-use solutions are past the initial proof of concept phase and innovating to become cost effective; the next economic battleground is to scale them over the next decades

Land consumption

Sustainable agriculture; alternative proteins

Micro-irrigation; vertical farming; hydroponics; plant-based and cultured meats; methane inhibitors; green fertilizers

Natural capital and nature

Technologies for restoration of forests and natural ecosystems; coastal vegetation; biodiversity; freshwater basins; etc

Raw-material consumption

Circular technologies

Design; production; recycling and reuse; waste management

Green construction

Energy and water efficiency; waste reduction; eco-friendly materials use (eg, green cement, green steel)

Sustainability enablers for hard-to-abate industries

Carbon capture use and storage (CCUS)

Capture of CO_2 directly from industrial-emission sources[1]

Carbon removals

Nature-based solutions (eg, tree planting); engineered carbon removal (eg, direct air capture, biomass to capture CO_2 during energy generation)

Electrification technologies

Electric heat pumps; electric propulsions for terrestrial and aerial vehicles (eg, magnetic levitation trains); electric arc furnaces for steelmaking; electrification of farm equipment

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[1] Excluding bioenergy with carbon capture and storage (BECCS), covered under carbon removals.

Source: McKinsey analysis

What industries are most affected by the trend at present?

Industry affected	Implications from technology trend
Automotive and assembly	• Electrification of global fleet, slowly replacing oil-powered internal-combustion-engine vehicles as costs, battery ranges, and charge times improve
Agriculture	• Digitally enhanced agronomy services (up- and downstream) for precision agriculture • Innovative agriculture technologies (eg, indoor, vertical farming, drip irrigation, GHG-focused animal breeding, gene editing to improve carbon sequestration of plants) • Alternative proteins (eg, plant or microorganism based, cultured)
Aviation, travel, and logistics	• Fleet modernization (eg, electrification, vehicles with higher fuel efficiency) • Decarbonized fuels (eg, sustainable aviation fuel) • Fleet dispatch and travel route optimization for sustainability (eg, shift toward more rail use) • Truck load optimization (eg, redesign of boxes, double stacking of pallets) • “Green corridors” (trade routes among major port hubs where zero-emission solutions are supported)
Construction and building materials	• Novel building techniques (eg, insulation to lower space heating/cooling demand, electrification for small-carbon-footprint heating) • Increased use of sustainable materials (eg, green steel, recycled plastics) • Change in material usage patterns (eg, more scrap steel, less carbon-intensive materials)
Pharmaceuticals and medical products	• Optimized manufacturing processes to improve energy efficiency and reduce water consumption • Substitute traditional single-use plastics for more sustainable, recycled materials for packaging
Public and social sectors	• Organizations can incentivize the market for sustainable goods and services and mandate shifts, boost innovation by securing funding, and deliver important initiatives to other parts of the economy

Source: McKinsey analysis

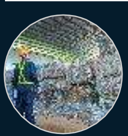
What industries could be most affected in the long term?

Industry affected	Implications from technology trend
Chemicals	Growing markets for recycled plastics and specialty plastics created from captured CO_2; conversion of CO_2 into polyurethane foam, displacing hydrocarbon that would otherwise come from fossil fuels
Oil and gas	Increasing adoption of carbon sequestration to support enhanced oil recovery (EOR); CO_2 EOR technology injects CO_2 into partially depleted oil fields to force out additional volumes of oil, with CO_2 being residually trapped and permanently stored
Metals and mining	Decarbonization of operations and offset of production activity effects on natural capital, as well as increasing production of the minerals needed for clean energy and other sustainable tech
Electric power, natural gas, and utilities	Variable demand for electric power based on sustainable consumption trends such as electrification
Consumer packaged goods	Circular economy solutions and business models enabled by product optimization (eg, material selection, product/packaging design); improved product and material flows (eg, optimized reverse logistics); and enhancements in recycling (eg, new material recovery technologies); as well as rising demand for products with legitimate sustainability attributes
Aerospace and defense	Designing and manufacturing aircrafts that rely more on sustainable fuels and increased energy efficiency
Information technology and electronics	Optimizing electric power consumption in data centers; powering data centers by renewable energy; and reducing waste across the consumer electronics value chain
Retail	Green product sourcing; in-house facility management (energy, water, and packaging waste minimization); appropriate management of customer returns/disposal of products
Real estate	Market shifts in response to changes in consumer preferences; urban planning; and infrastructure development
Telecommunications	Optimized energy consumption by upgrading to 5G, and networks operated with renewable energy

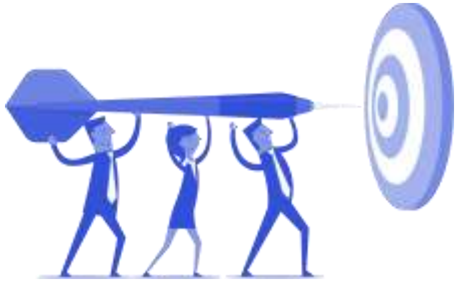
Source: McKinsey analysis

Who has created impact with technologies enabling sustainable consumption?

Relevant technologies are already enabling climate impact across a variety of industries; today’s main challenge remains scale

	**CCUS**	**Occidental Petroleum and Cemvita Factory** launched a pilot project for **conversion of captured CO_2 to bioethylene;** OxyChem can then use the bioethylene as feedstock, and resulting chlorovinyls are used in manufacturing of plastics, including foams and PVC pipes
	**Carbon removal**	Several start-ups, such as **Running Tide** and **Kelp Blue,** have introduced technologies that grow significant amounts of seaweed, seagrasses, and algae through artificial farming and pregrown seeds, using CO_2 to accelerate their growth; the plants are then **used to absorb CO_2 or converted into food sources** for fish and marine animals
		Frontier is an **advance market commitment** by Stripe, Alphabet, Shopify, Meta, and McKinsey, to incentivize accelerated development of **permanent carbon removal** by guaranteeing future demand
	**Green construction**	**ArcelorMittal** is developing a series of **industrial-scale hydrogen projects for use in steelmaking** that will start to deliver substantial CO_2 emission savings within the next 5 years
	**Natural capital and nature**	**IKEA Systems** includes **biodiversity and deforestation considerations** in its value chain partnerships (eg, supplier code of conduct), restricting business activities in areas of high conservation value and encouraging suppliers to follow the lead
	**Alternative proteins and sustainable agriculture**	**Nutrien** drastically **reduced upstream emissions in fertilizer production,** became a leader in blue ammonia/blue nitrogen production, and created one of the industry's first and broadest **carbon marketplaces for farmers**
	**Circular technologies**	The **Hong Kong Research Institute of Textiles and Apparel (HKRITA)** has partnered with **Gap** to develop **eco-friendly production processes and technology solutions**, with an initial focus on separation of spandex from used garments and denim decolorization for recycling

What should leaders when engaging with this trend?



Benefits

Operating savings in the long run: Cost-effective investments for rapidly scaling end-use-focused clean technologies (eg, green construction)

Early-mover advantage: Network benefits for companies that join climate tech ecosystems early

Incentives: Support or guarantees for new technology takeoff and increase in adoption (eg, green bonds, loan guarantees, decarbonization subsidies)

Transparent industry standards: Mature clean-energy standards in developed countries and global decarbonization commitments

Vibrant carbon markets: Rapidly growing global markets for CO_2 permits traded among clean-energy-ecosystem players

Source: McKinsey analysis

Risks and uncertainties

Commercialization pathways for climate tech mean they aren’t yet cost competitive with conventional tech

Availability of critical input materials might be insufficient

Upfront and ongoing costs to decarbonize production facilities and value chains are of concern (eg, green-steel production >40% more expensive than conventional)

Regulatory action and alignment of standards across borders and regions will be important

Changes in consumer behavior, compared with stated commitments, can affect sustainable consumption initiatives (eg, willingness to pay “green premiums”)

What are some topics of debate related to the trend?

⬜ Overall 🟦 Land consumption 🟦 Material consumption 🟦 Sustainability enablers for hard-to-abate industries

1 Capital reallocation to accelerate decarbonization

How will companies and governments mobilize capital flows in support of sustainable consumption?

Estimated capital spending of ~$9.2 trillion per year (an annual increase of as much as $3.5 trillion from 2022) is required for a global transition to a net-zero economy; ~85% of technologies needed to meet this target already exist, highlighting the importance of closing the capital funding gap to deploy these technologies across sectors and geographies

2 Consumer behavior shift

How will consumer mindsets and behaviors change? Where and how will they diverge or converge? What new behaviors and habits will become mainstream?

More than one-third of global consumers are ready to pay a green premium as demand grows for environmentally friendly alternatives; however, attitudes vary across generations, countries, and industries; relative importance of sustainability during the purchasing process will continue to increase

3 Feasibility of sustainable agriculture

Is global adoption of sustainable agriculture practices feasible?

Sustainable agriculture benefits the environment through helping maintain soil quality, reducing erosion, and preserving water; however, such practices are often hard to abide by for mass agriculture farmers, given implications for crop yields, particularly challenging in regions with food security concerns

4 Future of circular economy

To what extent will circular-economy practices (those favoring the comprehensive recovery and reuse of materials with minimal losses of quality) replace conventional practices?

Current momentum in circular technologies is generating a seismic shift across manufacturing industries globally; however, an attempt to reach a 100% recyclability rate might prove counterproductive if the price of recovery remains higher than the value of the materials recovered; furthermore, the existing regulatory landscape does not incentivize all ecosystem players to pursue a circular economy

5 Balance of decarbonization levers

What is an appropriate balance between carbon removal and other decarbonization levers?

CCUS is necessary in industries without other decarbonization alternatives and is already cost effective for some industrial processes; however, investments in carbon removals may divert funds and attention away from the critical business of reducing emissions, further propping up the fossil fuel industry

Source: McKinsey analysis

Additional resources

Knowledge center

McKinsey Platform for Climate Technologies

Related reading

The net-zero transition: What it would cost, what it could bring

Delivering the climate technologies needed for net zero

Decarbonizing the world’s industries: A net-zero guide for nine key sectors

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