Report overview

Future of bioengineering

August 2022

What is the trend about?

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]

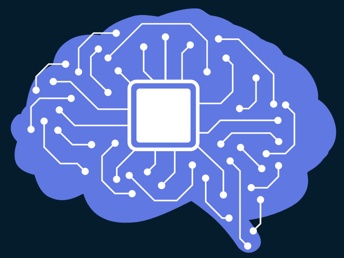
Focus for tech trend

Biomolecules

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

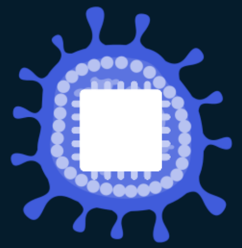
Biosystems

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)

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

Source: Michael Chui, Matthias Evers, James Manyika, Alice Zheng, and Travers Nisbet, "The Bio Revolution: Innovations transforming economies, societies, and our lives," McKinsey, May 13, 2020

Why should leaders pay attention?

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

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 and/or 2 emissions

>$400 million
Investment in cultivated meat in the first half of 2021, projected to increase rapidly

Potential 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 biology-related industries

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

What are the noteworthy technologies?

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

Non-exhaustive

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
	Bio-better	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 non-exhaustive. They were selected based on their combination of innovation, business adoption, and impact.

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

What is the notable potential impact of bioengineering technologies across industries?

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**

Industry affected[1]	Impact from technology trend
 **Healthcare and pharmaceuticals**	**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)
 **Consumer goods**	**Creation of sustainable, cost-effective, and higher-quality** materials and production processes for consumer goods, such as clothing, accessories, shoes, beauty, and packaging
 **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
 **Energy and utilities**	**Shift toward cleaner energy sources**, such as biofuels
 **Materials**	**Advancements in sustainable, cost-effective, and higher-quality** biomaterials and production processes

[1]Non-exhaustive, focused on industries where technology has widespread applications with mature adoption.

Source: Expert interviews; McKinsey analysis

What are examples of disruption in healthcare and pharmaceuticals?

$0.5–1.3 trillion

Forecast global impact, 2030–40

Increasing healthcare solutions that will treat or even prevent previously uncurable diseases

Benefits | Risks & 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, reproduction)

Personalized treatments

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

Genomic risk from therapies (eg, viral-vector gene therapy, DNA-based gene therapies) due to the permanence in altering DNA; long-term health effects are also still being investigated

Ethical concerns

Deep ethical and morality concerns on the extent of modifying genes and its cascading effects on human personality and behavior, as well as impact on future generations

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

What are examples of disruption 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 & uncertainties

Examples of technologies

Drop-in

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

Bio-replacements

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

Bio-better

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

Bio-replacements 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 are examples of disruption in agriculture?

Benefits | Risks & 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 the 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 are examples of disruption in energy and utilities and in materials?

Benefits | Risks & uncertainties

$200B–300B

Forecast global impact, 2030–40

Alternative, sustainable sources and processes for energy and raw materials

Examples of technologies

Drop-in

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

Bio-replacements

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

Bio-better

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%

Uncertainty around timing of impact

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

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

Scalability challenges

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

Source: McKinsey analysis

What should a leader consider when engaging with novel technologies?

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 bio-markets, which need to address challenges of consumer perception, safety, cost, and quality of end products

Lack of regulation due to nascency of markets

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

Source: McKinsey analysis

What are some notable topics of debate?

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, 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

Resources

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 & Company

McKinsey & Company

Future of clean energy

August 2022

What is this trend about? (1/2)

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**

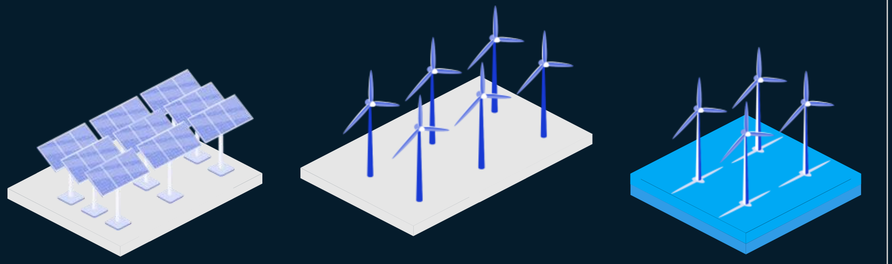
Power generation

Renewable energy

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

About 84% of global power demand, which is estimated to grow 3x 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

Biofuels and hydrogen-based fuels

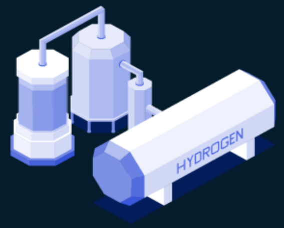
Sustainable fuels could **decarbonize high energy density requirements** of aviation, maritime shipping, and heavy freight

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)

Cost of producing decarbonized hydrogen (blue, using carbon capture; green, using renewable electricity) is **projected to beat conventional hydrogen** (gray, from natural gas) by 2030



Electrolyzers

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

Source: McKinsey analysis

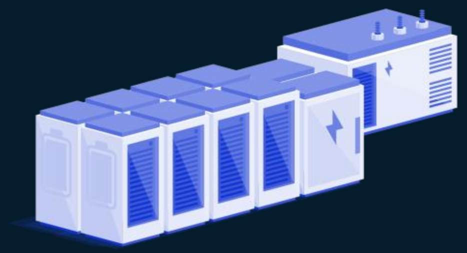
What is this trend about? (2/2)

Power storage

Energy storage
Battery technologies, recycling, second use, long-term storage, e-mobility, 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% to 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? (1/2)

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

~3.3x

Increase in global 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 (SBTs)** toward 1.5–2.0°C goals, growing by ~3x from 2020 and representing a market cap of ~$23 trillion

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 Climate Change Report 2019),* CDP, 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? (2/2)

Energy tech

Renewable energy

>80%

Share of 2050 **global power demand** that could be generated by renewable energy, with solar PV generating ~60% and onshore windmills generating ~20%

Sustainable fuels

~75%

Share of renewable energy in transport that will come from sustainable fuels by 2030; transportation makes up ~20% of global emissions today

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: Are companies ready for climate change (CDP Climate Change Report 2019),* CDP, 2019; *SBTI progress report 2021*, Science Based Targets, June 2022; McKinsey analysis

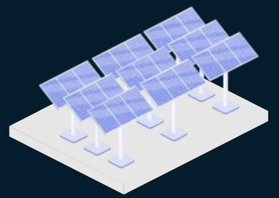
What are the most noteworthy technologies? (1/2)

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** (i.e., vs coal)

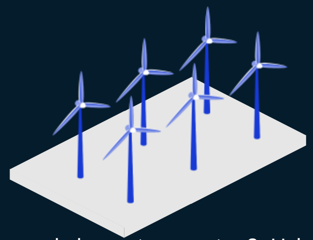
Advancements in 3rd-gen solar PVs are primarily **manipulating semiconducting materials** (organics[1] and perovskites[2]) at nano-scale to achieve higher efficiencies



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**

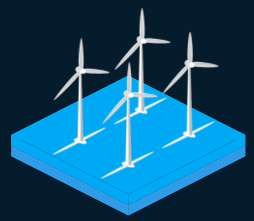
Offshore plants (expected by 2025) face engineering challenges (eg, marine infra-structure); onshore turbines face nontechnical limits[3]



Offshore wind generation

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

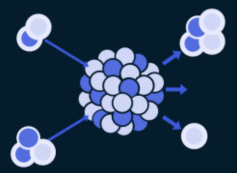
Current global shift from single-turbine pilots to multiturbine projects is expected by 2025+



Nuclear fusion

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

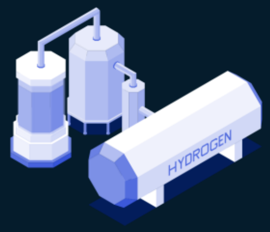
Fusion power research is nearing a close, driven by advancements in materials research and AI, with commercial launch of a nuclear fusion plant expected in the next decade[3]



Sustainable fuels
Biofuels and H_2-based fuels

Hydrogen

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 by-product of the process being oxygen (ie, zero carbon emissions)

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 chokepoints, land use, view, birds, shadows, etc. 4. More mature technologies include water electrolysis and steam reforming of biomethane/biogas with(out) 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, Oct 2021; McKinsey analysis

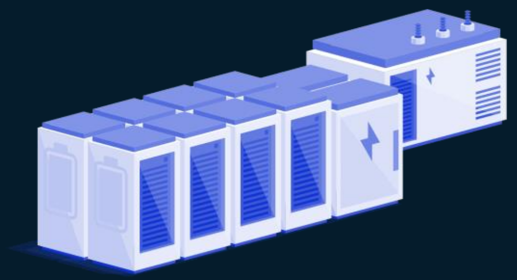
What are the most noteworthy technologies? (2/2)

Energy storage
Battery tech, recycling, 2nd use, long-term storage, e-mobility, 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 having issues with their high self-discharge rate

Other solutions (ie, long-duration 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 renewables cause in the energy and utilities industry?

Technology	Capabilities required
Solar photovoltaics (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;** e.g., augmented integration of distributed renewable energy resources and reduced reliance on fossil fuels

Source: "Global Energy Perspective 2022," McKinsey, April 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

8x
Growth in annual solar PV capacity installations (GW per year) from 2020 to 2030 in a 1.5ºC pathway

5x
Growth in power generated via onshore wind energy from 2016 to 2030

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

What disruptions could hydrogen cause in the energy and utilities industry?

Technology	Capabilities required
Hydrogen	**Drastic reductions in production costs, coupled with infrastructure development** (to enable adoption), are required to scale hydrogen production across a wider set of applications
Electrolyzers	**Lower production costs 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

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

Source: "Global Energy Perspective 2022," McKinsey, April 2022

Key disruptions enabled

~28%

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

5x

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 (e.g., 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 are some implications of clean energy technology in other industries?

Other industries are experiencing **second-level implications** of clean-energy tech, primarily focused on **energy-efficient operations**, **cost-effective solutions**, the need to **meet changes in resource demand**, and **shifting value pools**.

Industry affected	Implications of technology trend
Materials	**Recycling batteries to extract valuable metals** for manufacturing; **reusing and reprocessing second-life batteries** for use in vehicles or grid operations (eg, provide reserve energy capacity for a utility to maintain reliability at lower costs)
Mining	**Decarbonizing operations via sustainable fuels and green electricity,** especially as demand for raw materials (e.g., copper for electrification, lithium and cobalt for batteries) grows >10x
Oil and gas	**Decarbonizing upstream operations** and **exploring alternative low-carbon technologies and shifting value pools** (e.g., hydrogen) by leveraging strengths in access to capital and operational expertise

Source: McKinsey analysis

Who has succeeded in driving impact through leveraging this tech trend?

Industry	Case example
 **Energy 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
 **Materials**	**Redwood Materials, a battery-recycling company** that partnered with Panasonic and Tesla, is creating a **circular supply chain** that **recycles and redistributes materials** from **end-of-life vehicle batteries, grid storage batteries,** and scrapped cells (from the manufacturing process); it is also focusing on **EV battery recycling**, for which it recently announced partnerships with Ford and Volvo

Source: Company websites; Science Based Targets initiative

What are some uncertainties or unlocks required in order to achieve clean-energy disruptions?

Non-exhaustive

Renewables

Cost-efficient manufacturability is required to accelerate scaling of solar 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 (e.g., 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 (e.g., EV battery pack currently is 30–40% of total EV cost) are expected 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 notable topics of debate in clean- energy technology?

Non-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 (e.g., 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 environ-mental 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

What does it take for leaders to succeed?

The stakes are high for companies

Value at risk

- Challenges in attracting and retaining talent
- Delisting by OEMs due emissions intensity
- Capital dries up, capital costs increase
- Supply scarcity for low-carbon materials

30–50%

Share of corporate profits at stake from external engagement (eg carbon tax)

What it takes to win

Capturing full upside opportunity

- Revenues from EVs and low-carbon products
- Purposeful decarboni-zation investments
- Increased valuation due to sustainable business
- More loyal, excited, and productive employees

6x

Growth in sustainability products (eg, low-carbon products)

To capture the full value, companies must approach sustainability as a strategic pivot and true transformation that requires leadership and dedication from top management

Source: McKinsey analysis

Additional resources

McKinsey Publications

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

Insights on the net-zero transition

Innovate to net zero

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

McKinsey & Company

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 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?

Every business is as strong as its supply chain, 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

8×

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

[1]Electric vehicles
[2]Internal combustion engine

Source: McKinsey analysis

What are the noteworthy technologies?

ACES

Autonomy

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

Connected vehicle

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

Electrification

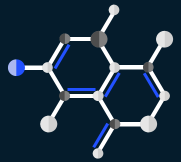
- Digital twin
- Lithium-ion battery (LIB)
- Beyond LIB
- Battery analytics
- Hydrogen fuel cells
- Hybrid propulsion

Smart mobility

- Transportation demand management (TDM)

Hardware | Software/AI

Adjacent tech



Lightweight technologies

- Advanced composites
- Advanced ceramics
- Metamaterials
- Nanomaterials

Value chain decarbonization

- Green primary materials
- Parts and materials circularity

[1]High-definition maps and simultaneous localization and mapping.
Source: McKinsey analysis

What are the 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

[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 are some disruptive solutions enabled by mobility tech advancements?

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

	Crewed	Uncrewed
Passenger transport	Vertical takeoff and landing (VTOL) air taxis (crewed and uncrewed) Wingless multicopters (crewed and uncrewed) Supersonic/hypersonic air transport	Vertical takeoff and landing (VTOL) air taxis (crewed and uncrewed) Wingless multicopters (crewed and uncrewed)
Transport of goods	Conventional air freight with novel propulsion	Unmanned aerial vehicles, such as freight or delivery drones Unmanned traffic management systems

[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 are some implications of the future of mobility across industries?

Among the **most affected industries** are automotive, logistics, telecom, and aviation

Industry affected	Implications of technology trend
Automotive	• **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)
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
Telecom	• **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 • **Security pressure** as in-vehicle systems and connected infrastructure are more exposed to security threats • **New opportunities for telcos to monetize value-added services** (eg, by combining core connectivity with vehicular technologies and real-time mobility data)
Aviation	• **New modes of aerial transportation** of passengers and goods, expanding aviation use cases • **Novel propulsion** drastically changing unit economics

Source: McKinsey analysis

What are some implications of the future of mobility across industries? (continued)

Diverse stakeholders across industries are experiencing **2nd-level 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
Basic materials	Change in material usage patterns (eg, steel for new powertrain types) and increased demand for sustainable materials (eg, green steel, green aluminum)
Energy utilities	Need for more generation capacity and for reinforcement of transmission and distribution networks to meet increased demand for electricity from EVs
High tech	Increased demand for solutions enabling, supporting, and integrating technological advancements across ACES
Financial services and insurance	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
Urban infrastructure and transit	Improved efficiency of public transport from dynamic shuttle services and pooled e-hailing; changes in city infrastructure from sustainability-focused regulation promoting smart mobility

Source: McKinsey analysis

What are some function-specific and industry use cases stemming from the future of mobility?

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
Energy utilities	• Vehicle-to-grid systems (in which EVs return excess electricity back to the grid or throttle their charging rate)
High tech	• Software/AI solutions for simultaneous mapping and localization, object detection, driving strategy • Hardware for autonomous vehicles (eg, lidars, cameras)
Urban infrastructure and transit	• 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 and insurance	• Personalized insurance rates based on driving patterns from connected-vehicle data • New insurance use cases for autonomous vehicles (eg, insurance for vehicle intelligence)
Entertainment	• Novel ways of engaging a passenger during commute

Source: McKinsey analysis

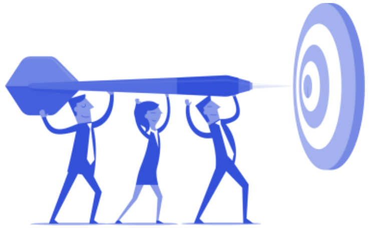
Who has succeeded in driving impact through leveraging these technologies?

Industry	Mobility technology	Example company	Disruption caused by technology
 **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**	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**	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)
 **Energy 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
 **Basic materials**	Lightweight materials	**General Motors** **Caltech** **Boeing** **UC Irvine**	**Efficient aviation**: "Microlattice" metal, codeveloped by Boeing, Caltech, GM, and UC Irvine, is reported to be 100× lighter than Styrofoam but strong enough to be used in structural components of airplanes[3]
 **High tech**	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

[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: Company websites

What should a leader consider when engaging with mobility technologies?



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 in the transition to uncrewed and autonomous mobility

Tech and infrastructure maturity, given that novel modes of transportation still must improve features (eg, batteries with sufficient range for air mobility use cases)

Customer perception challenges from impact on daily routines in terms of noise and visual aesthetics

Equipment and infrastructure costs of new modes of transportation and freight

Regulation shifts during development of mainstream certification framework for licensing, maintenance, and operating requirements

Privacy and security concerns across algorithms and workflows enabling mobility—most notably data risks

Source: McKinsey analysis

What are some notable topics of debate concerning the future of mobility?

Ground transportation | Air mobility

1	**Market penetration 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 smart 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

Articles

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

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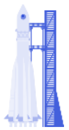
Future of Space Technologies

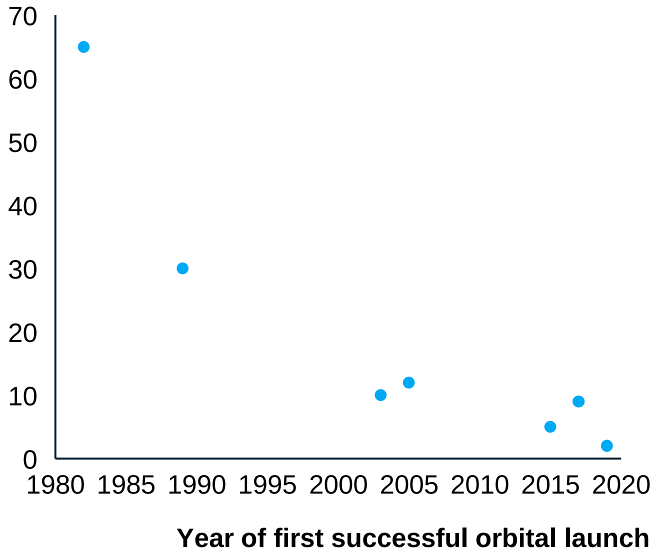
June 2022

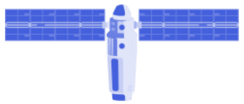
[Future of space technologies] What is this trend about?

By moving down the cost curve, use cases have been unlocked that were previously cost-prohibitive

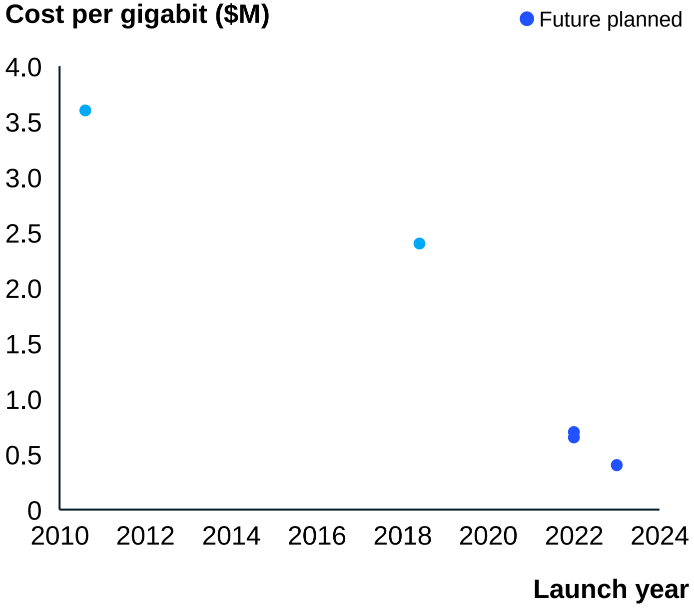


Heavy launch[1]





GEO Communication satellites[1]



1. Satellite lifetime not factored into cost per gigabit. Figures reflect estimates only (based on analysis using publicly stated information and expert estimates). Launch years reflect actual or planned per company announcements.

Source: Company websites; public press; expert interviews; Center for strategic and international studies; McKinsey analysis

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 for cost efficiency** has been the **reduction of Size, Weight, Power and Cost (SWAP-C)** of satellites and launch vehicles…
3. …which has **led to architectural shifts**: e.g., from individual, **large GEO** satellites to **smaller, distributed LEO satellites**

[Future of space technologies] Why should leaders pay attention?

>$1.0T[1] estimated 2030 market

~7-10%+ growth expected in commercial products and services, driven by growth in Earth observation, positioning/navigation (e.g., GPS)

~3-5% growth expected in global demand

Increased participation globally

>**1,400 companies** involved in the new space industry, from gov. to startups, which are expected to grow from 600+ today to 1,000+ in 2030

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

Significant cost reductions

Disruptions such as space mining and commercial human spaceflight **depend on drastically reducing launch and return-to-Earth costs**

New business models

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

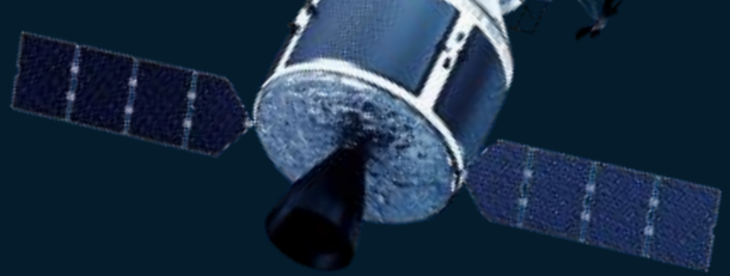
Increased focus on software

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

1. Estimated market size (Source: Various market reports (NSR, Grand View, Mordor, The Space Foundation Space Report Q2 2020), US federal budget requests and projections, Bank of America, Morgan Stanley, press search)

2. 1.5oC 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,

[Future of space technologies] What are the most noteworthy technologies? (1/2)



NON-EXHAUSTIVE

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

Satellites

Application of new technologies

Higher computing power leveraging consumer processor tech[2] across distributed satellite networks to support data collection from increasingly high resolution sensors

Less expensive, higher resolution sensors: conduct observation of their targets (e.g., Earth, planets, etc.); typically passive observation in several spectrums (e.g., optical, infrared, etc.), and active sensors (via radar)

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

In aggregate, new technologies are providing **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 cubesat architectures (built using standard dimensions; Units or “Us” of 10X10X10cm) used as extendable “building blocks

Shift from job-shop to assembly line: increased demand (for proliferated constellations) and investment in facilities is changing 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 enable new players to enter the market

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

Architectural shift

LEO constellations

Low Earth Orbit (LEO) satellites orbit close to Earth’ atmosphere (altitude 300–2000km)

Proliferation in number of active satellites - ~4.1k in 2021 vs. ~2.7k in 2020[1] – with a focus mega constellations using of smaller satellites

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

To learn more about this tech, see the Connectivity trend

1.Evangela Rodgers, “With satellite internet, network capacity is key,” Viasat, September 2021
2.Katja Lenz, “Smartphone technology provides satellites with increased computing power”, German Aerospace Center (DLR), June 2022

[Future of space technologies] What are the most noteworthy technologies? (2/2)

NON-EXHAUSTIVE

Other emerging technologies will build on the transformation the sector has undergone in previous decade

Communications

Laser comms

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

Potential to increase data transfer speeds[1] by 100X-1,000X (as opposed to traditional radio frequency)

Ability to emit laser to very specific locations (both to satellites in space and ground stations on Earth) **mitigates coverage overlap and interference**[2]

Digital capabilities

Edge computing & AI

With the growing launch of satellites and space crafts for activities such as Earth observation, **higher volumes of data will be collected**, hence the **need for edge computing**

Edge computing allows for the **processing of 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 spacecrafts at higher speeds for longer distances, enabling deep space exploration[3]

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 the 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, capabilities and reduce replacement costs.

E.g., Orbit Fab developed e2e refueling service 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: raising the orbit or changing the inclination of a satellite

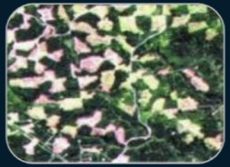
End of life disposal: pulling space debris to re-enter Earth's atmosphere for disposal (reducing collision risks)

1. Stew Magnuson, *"Laser communications to thwart jamming, interception" National Defense*, November 2014
2. Daniel Baird, *"Bonus - LCRD: Your Questions Answered | NASA's The Invisible Network Podcast"*, NASA, April 2022
3. As opposed to current chemical and solar electric propulsion technologies suffer from significant energy inefficiencies

[Future of space technologies] What are the examples of disruption that a technology could cause? (1/2)

Enabled by remote sensing

Advancements in applications of Earth Observation data

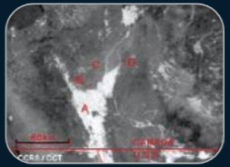


Forestry

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

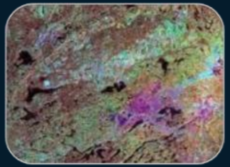
Compliance monitoring (farming practices)

Land cover & use

Routing/logistics planning (e.g., seismic activities, urban expansion, resource extraction)

Target detection

Damage delineation

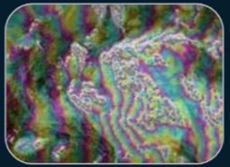


Geology

Mapping (e.g., structural, terrain, geologic unit)

Exploration/exploitation (e.g., mineral, sand, and gravel)

Baseline infrastructure



Mapping

Planimetry/surface geometry

Digital elevation models

Baseline thematic/ topographic mapping

Oceans & coastal monitoring

Ocean pattern identification

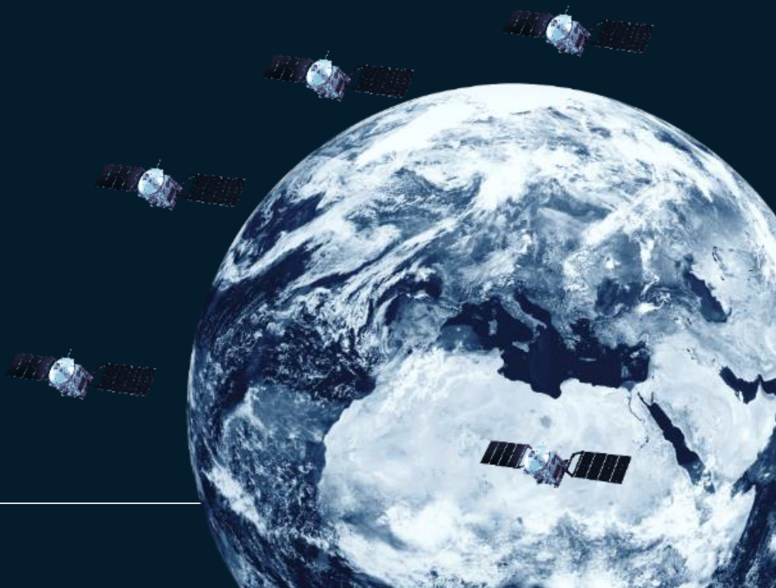
Storm forecasting Environmental evaluation (e.g., fish stock and marine mammal assessment, oil spills)

Sea & ice assessment

Tactical identification (e.g., detection, tracking, navigation)

Shipping/rescue routes

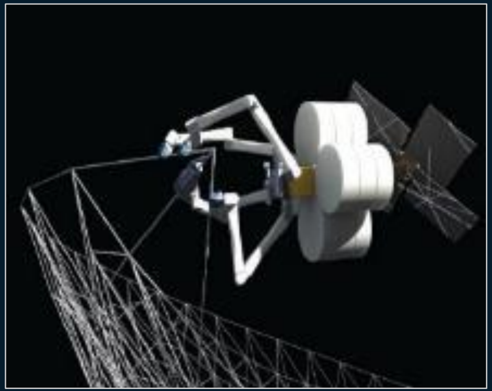
Global change monitoring (e.g., ice condition, pollution indexing)



[Future of space technologies] What are the examples of disruption that a technology could cause? (2/2)

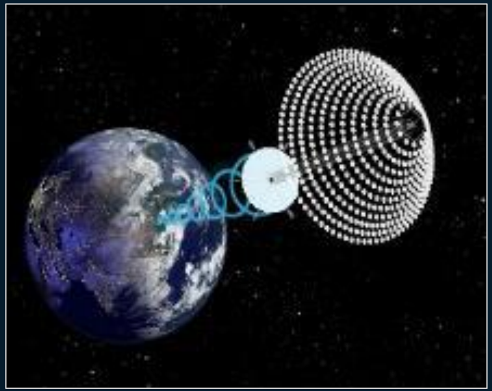
The future space economy and human spaceflight could be made up of activities not currently employed in space today, enabled by drastic launch costs reduction, AI applications in space, and power transmission advancements, etc.

Space economy



In-orbit construction & 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

Space mining

Mine asteroids and space objects for materials to return to earth

Scaling human spaceflight

Commercial tourism

Aims to scale paying customers to space for short experiences of zero-gravity and Earth views

[Future of space technologies] What industries are impacted by these technology developments?

Emerging applications and use cases are being built especially as costs decline and accessibility increases

Energy and mining

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.

Pharmaceuticals

Conducting experiments leveraging microgravity (e.g., protein crystallization) to improve pharmaceuticals

Telecom

Providing broadband internet to planes and remote areas, including emergency backup coverage

Automotive

Collaborating on lunar rovers, enabling autonomous driving and in-car entertainment

Transportation

Tracking moving shipping containers, providing positioning and navigation information, monitoring temperature of sensitive containers and road congestion

Consumer

Experimenting in space under specific aerodynamic conditions to inform design and manufacturing of sneakers, soccer balls, etc.

Finance

Leveraging commodities geolocation tracking (e.g., vessels) to inform trades

Insurance

Using radar satellite-based flood monitoring capability to inform risk management and tailor solutions

Tech

Developing in-space computing offerings

Media

Filming movies on International Space Station

Source: Press search, McKinsey's report on "The Role of Space in Driving Sustainability, Security, and Development" read more here

[Future of space technologies] Who has managed to successfully drive impact through leveraging this tech trend?

McKinsey deployed remote sensing Analytics to unlock new insights across industries

Case examples (not exhaustive)

A Field-level insights for Ag input players

Used local agronomic data and various satellite imagery to inform marketing strategy, identify growth opportunities, match offerings to grower needs, or adjust to changing conditions

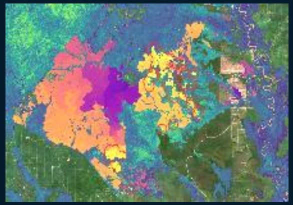
B Vegetation detection for utility players

Optimized vegetation trimming cycles around major utility grids by combining LiDAR and high resolution optical images to map vegetation attributes

C Commodity tracking and procurement

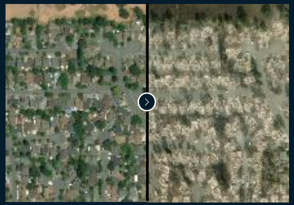
Helped companies that trade/process commodities to enhance their purchasing/trading activities through earlier insights on supply/demand drivers, e.g., by predicting/monitoring refinery shutdowns or port congestion

D Supply chain traceability and Forest Carbon



Helped CPG companies verify their zero deforestation/ sustainable sourcing commitments by monitoring natural assets in key production areas

E Building and construction detection



Supported NGOs/public organizations by tracking urbanization and building-level features, e.g. to identify unreported property development or in post-disaster relief effort by identifying damaged buildings via high resolution satellite images

F O&G shale activity monitoring

Helped O&G companies monitor the lifecycle of shale oil exploration/production in the North American Permian Basin to provide advanced information on drilling and fracking events

Source for deep-dives on each case: Remote Sensing Analytics

[Future of space technologies]
What are unresolved risks within space tech?

Cost efficiency

Cost-effectiveness of space technologies required for the scalability of space services and human spaceflight

Trade-off between more cost-effective (higher risk) commercial technologies vs. higher performance, more reliable, “space-qualified” technology

Careful risk assessment required on the importance of mission assurance/ accomplishment; e.g., extensive use of commercial tech in constellations increases the risk of satellites dying prematurely and adding to the space debris challenge

Governance

Governance of 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

Cyber risks

Growing risk and complexity of cyber threats

As dependency on space tech increases across different use cases, the potential damage resulting from exploitation of a cyber vulnerability increases

Proliferation of commercial players raises a question of whether all services will be well-protected from cyber risks

[Future of space technologies] What are some controversial topics within space tech?

NON-EXHAUSTIVE

1 Space militarization

How can leaders define rights and norms?

Governments recognize space as a warfighting domain (e.g., GPS-jamming, anti-satellite weapons) reflected by recent organizational changes (e.g., Space Commands in US, Japan, France, UK)

2 Legal conflicts between states

How can leaders define ownership and access rights?

A key need for the sector is **clarity of ownership rights for space properties and resources – e.g., 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 & traffic management

Should LEO have limits?

As more companies access space, there is **concern regarding space debris, space traffic management, and congestion**; e.g., ~27,000 pieces of debris in space, and what they might hit and when, are uncertain

Source: Press Clippings, IOP Conference Series: Materials Science and Engineering

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 & Company

McKinsey & Company

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)

Bio-based

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 to $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

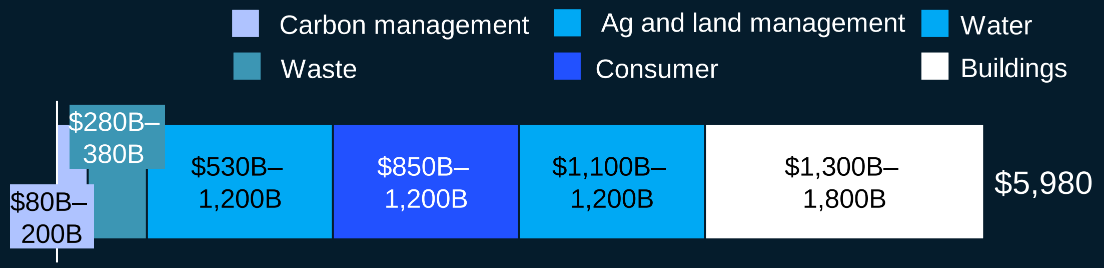
Macro level

90%

emissions 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



Micro level

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 dimensions of ESG[2]

First movers capturing value

50%

Faster growth in sustainable brands (eg, Unilever's Sustainable Living Brands vs the rest of the portfolio)

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 Climate Change Report 2019), CDP, 2019; McKinsey analysis

What is the willingness to pay the ‘green premium’?

End customers are ready to shoulder the load by paying ‘green premiums’ across various commodities and products

XX Evidence at scale XX Emerging evidence

2–15%

Transportation
Green container shipping

7–16%

Utilities
Green electricity

5–50+%

Chemicals
Green plastics (eg, bio-based, recycled)

14–38%

Automotive manufacturing
Electric vehicles

40+%

Consumer packaged goods (CPG), food
Plant-based meat alternatives

1–12%

Agriculture
Green fertilizers, methane inhibitors

9–15%

Oil and gas
Renewable diesel, biodiesel

0.5–3%

Mining and metals
Low-carbon aluminum

39%

CPG, nonfood
Average sustainably branded CPG

Source: “How much will consumers pay to go green?,” McKinsey, October 2012

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-materials 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)

Carbon capture use and storage (eg, capture of CO_2 directly from industrial emission sources[1])

Carbon removals

Nature-based solutions (eg, tree planting) and engineered carbon removal (eg, direct air capture, biomass to capture CO_2 during energy generation)

1. Excluding bioenergy with carbon capture and storage (BECCS), covered under carbon removals.

Source: McKinsey analysis

What industries are most affected by transition to net-zero consumption?

Industry affected	Implications from technology trend
Automotive	• Electrification of global fleet, slowly replacing oil-powered internal-combustion engine (ICE) 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)
Construction	• Novel building techniques (eg, insulation to lower space heating/cooling demand, electrification for small-carbon-footprint heating) • Increasing use of sustainable materials (eg, green steel, recycled plastics) • Change in materials usage patterns (eg, more scrap steel, less carbon-intensive materials)
Manufacturing	• Waste optimization programs and robust contamination prevention processes • Increased adoption of sustainable sourcing practices (eg, bulk purchases, supplier accountability) • Sustainability-optimized facility operations (eg, remote sensing for efficient electrification)
Logistics	• Fleet modernization (eg, electrification and/or vehicles with higher fuel efficiency) • Decarbonized fuels (eg, sustainable aviation fuel) • Fleet dispatch and travel route optimization for sustainability (eg, shift toward more rail) • Truck load optimization (eg, redesign of boxes, double stack pallets) • “Green corridors”— trade routes between major port hubs where zero-emission solutions are supported

Source: McKinsey analysis

What are some examples of industry-specific use cases stemming from sustainable end use? (1/2)

Technology	Industry example	Technology use case
 **CCUS**	**Chemicals**	**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 • Permanent sequestration of carbon[1]
 **Carbon removal**	**Oil and gas**	**Carbon sequestration** as an **extension of an enhanced oil recovery** (EOR) process • CO_2 EOR technology injects CO_2 into partially depleted oilfields to force out additional volumes of oil, with CO_2 being residually trapped and permanently stored
 **Green construction**	**Construction**	**New materials generation and design processes** through: • Improvement of resource efficiency (eg, energy-efficient buildings) • New sustainable products and green materials (eg, steel produced with hydrogen and electricity instead of coal) • Reuse of waste products (eg, recycled CO_2 in production of fresh concrete)

1. Subject to sustainable end-of-life disposal of plastic.

Source: McKinsey analysis

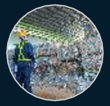
What are some examples of industry-specific use cases stemming from sustainable end use? (2/2)

Technology	Industry example	Technology use case
 **Natural capital and nature**	**Mining**	**Nature analytics** allowing companies with large-footprint activities to: • reduce impact on the environment (eg, swap out inputs, change production geographies, minimize large-footprint activity) • optimize offsets of irreducible footprint for biodiversity benefits **Solutions increased minerals production** for climate technologies
 **Sustainable agriculture and alternative proteins**	**Agriculture**	**Precision agriculture** addressing crop production emissions through: • improvements in cultivation practices (eg, improved seeding, optimal crop varieties, water management, methane inhibitors) • improvements in fertilization practices (eg, improved fertilization timing, variable-rate fertilization, reduced nitrogen overapplication) • reduction in irrigation needs (eg, from flood to drip or sprinkler)
 **Circular technologies**	**CPG**	**Circular economy** solutions and business models enabled by: • optimization of products (eg, material selection, product/packaging design) • Improved product and materials flows (eg, optimized reverse logistics) • Enhancements in recycling (eg, new material recovery technologies)

Source: McKinsey analysis

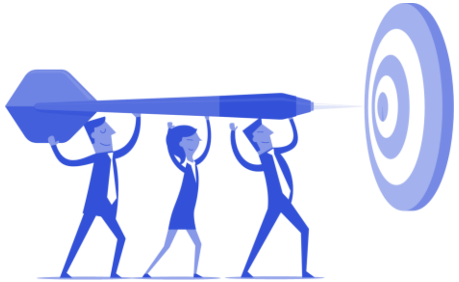
Who has managed to drive impact through leveraging sustainable consumption tech?

Sustainable end use technologies are already enabling climate impact across a variety of industries; today's main challenge remains scale

 **CCUS**	**Oxy 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 RunningTide and **kelp blue,** have introduced technologies that grow significant amounts of seaweed, seagrasses, and algae through artificial farming and pre-grown 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** to incentivize accelerated development of **permanent carbon removal** by guaranteeing future demand launched by Alphabet, Shopify, Stripe, Meta, McKinsey
 **Green construction**	**ArcelorMittal** is developing a series of **industrial-scale hydrogen projects for use in steelmaking** that will start to deliver substantial CO_2 emissions savings within the next 5 years
 **Natural capital and nature**	**IKEA** 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** and became a leader in blue ammonia/blue nitrogen production. Nutrien 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 Inc** 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

Source: Company websites

What should a leader consider to engage with clean technologies?



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 between all clean-energy ecosystem players

Risks and uncertainties

Commercialization pathways: Scale risk for nascent technologies (~50% of clean tech requires support to be cost-competitive)

Supply chain shortages: Challenges with steady inputs of hard-to-find input materials

Upfront and ongoing costs: Significant additional cost of decarbonization for production facilities and value chains (eg, green-steel production >40% more expensive than conventional)

Regulatory action: Alignment of standards across borders and regions

Changes in consumer behavior: Ability to share the cost of decarbonization with producers and governments (eg, willingness to pay "green premiums")

Source: McKinsey analysis

What are some controversial topics within sustainable end use technologies?

Overall | Land consumption | Materials 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?** An estimated capital spending of ~$9.2 trillion per year (an annual increase of as much as $3.5 trillion from today) 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?** Over 1/3 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 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. Further, 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 CCUS 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

McKinsey Platform for Climate Technologies

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

McKinsey
& Company

Report Conclusion