McKinsey & Company

McKinsey Technology Trends Outlook 2022

Future of bioengineering

August 2022

What is the trend about?

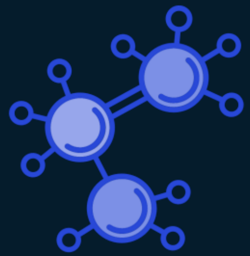
Focus for tech trend

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]

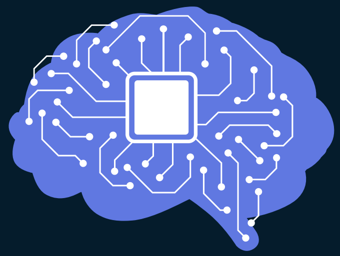
Biomolecules

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



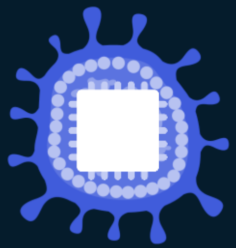
Biosystems

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)

[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

[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?

$0.8T–$1.3T

Forecast global impact, 2030–40

Sustainable and cruelty-free alternatives to traditional food options

Benefits | Risks and uncertainties

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