SYNTHETIC BIOLOGY

WILL IT HELP US SURVIVE OR DESTROY US?

The Futures Literacy Company

Since DNA sequencing and synthesis have become increasingly cheap, synthetic biology is seen by many of its proponents as an attempt to design life according to the needs of humanity. The field has the potential to have a huge impact on society, the economy, the environment and even life on earth. Its applications have expanded into almost every major industry. Bioengineered products have been rapidly infiltrating our lives for some time now, and it is very likely that by 2030 we will be eating, dressing, using or being treated with one of these products.

Compared to more established genetic modification techniques, many aspects of synthetic biology are now entirely novel. Despite this, the value of the synthetic biology market reached around $10bn in 2021 and could grow to $37-100bn by 2030. In contrast, McKinsey research suggests that around 400 bioengineering applications, almost all of which are already feasible, could generate $2 to $4 trillion per year between 2030 and 2040.

Research areas include, but are not limited to, the analysis of the structure and function of biological molecules that translate into organismal functions and dynamics. In addition, scientists are applying engineering principles to understand and influence pathways, connections and interactions in biological systems. A third area is the replication or improvement. Another area of research uses DNA and RNA as carriers for information storage and data processing. Work is also underway on innovative interfaces that connect living organisms to computers.

The potential benefits of synthetic biology are many. Here are some of them:

- Reducing the impact of human land use on biodiversity;
- Bioremediation of contaminated industrial sites;
- Use of synthetic alternatives to products currently derived from plants and animals;
- The restoration or conservation of genetic diversity and conservation of endangered species;
- The development of new and/or more effective therapies and vaccines and diagnostic methods;
- Easier detection of contaminants;
- Faster resolution of shortages of of key materials.

However, it is important to remember that new trends in biotechnology also mean new risks. If we do not prevent them in time, they can have disastrous consequences for us humans and the planet as a whole. That is why, as in the case of artificial intelligence, we must act here and now.

WHAT NEW OPPORTUNITIES DOES BIOENGINEERING OPEN UP?

WHAT RISKS DOES SYNTHETIC BIOLOGY POSE AND CAN WE CONTROL THEM?

HOW WILL BIOENGINEERING AFFECT HEALTH, THE ENVIRONMENT, PRODUCTION PROCESSES AND PRODUCTS?

SYNTHETIC BIOLOGY ACHIEVEMENTS

Biological innovation today focuses on four areas:

- **biomolecules: mapping, measurement and engineering of molecules,**
- **biosystems: engineering of cells, tissues and organs,**
- **biomachines: the interface between biology and machines,**
- **biocomputing: using cells or molecules, such as DNA, for computing.**

Genome sequencing and gene synthesis are getting cheaper and faster.

A new class of programmable DNA modification systems is being researched and many improved gene editing tools are being developed.

Researchers are developing a new mobile eDNA sampler that can collect material in the environment and autonomously detect pathogens or invasive species.

The efficacy and scope of CRISPR therapies are being tested. Therapies are being developed for cancer, eye diseases and chronic infections. Scientists have already used genome editing to correct inherited retinal diseases.

Clinical trials of personalised mRNA vaccines for many cancers are underway.

Artificial intelligence and machine learning are greatly accelerating drug discovery, have enabled new molecular research, provided the ability to predict protein structure and custom design molecules from scratch, and generate new chemical compounds.

Dozens of projects are currently underway to create molecular robots - nanomachines based on DNA or proteins.

Programmable nanorobots built from living tissue (xenobots) are able to move and cooperate for 10 days without food, and will be able to be used for environmental clean-up and in medicine.

Biosensors that can detect biological weapons and harmful chemicals and the presence of specific DNA sequences.

Biological computers that are created from genetically modified strains of bacteria that can sense and respond to various chemicals.

Research is underway to determine whether laboratory-grown blood cells (already successfully transfused to a patient) last longer in the body than donated blood cells.

Renewable chemicals are being generated through synthetic biology. Reverse-engineered organisms are used in closed industrial settings to produce fuels, for example.

Organs-on-chips (OoCs), systems containing engineered or natural miniature tissues grown inside microfluidic chips to better mimic human physiology.

Genome sequencing and gene editing are used in a precision fermentation process that results in microbes designed to create synthetic products such as oils and plant-based meat substitutes.

CRISPR technology has increased the levels of omega-3 fatty acids in plants, created apples that do not turn brown, a drought-resistant variety of rice and mushrooms that can withstand shocks during transport. The first CRISPR-edited tomatoes have appeared in Japanese shops. Some modified varieties of soya, corn and potatoes have long been on the market.

There are already projects and companies producing and selling lab-grown, slaughter-free meat. Technologies are being developed to increase the scale of production and reduce its cost.

SYNTHETIC BIOLOGY ACHIEVEMENTS

Several companies are developing biological, durable biofilms and coatings to repair nicks, scratches and cracks. They are also producing particles, microbes and materials for a variety of applications, including transferring touch to the surfaces of smartphones, screens or skin.

Work is underway to optimise mycelial skin yields and develop new proteins for biomaterials.

China is conducting dozens of gene-editing experiments to create new breeds of super pigs resistant to disease and adapted to climate change.

Experiments are underway with specially designed mosquitoes to reduce the spread of deadly diseases such as dengue, yellow fever and the Zika virus. Scientists are also working on a weakened form of malaria--causing Plasmodium parasites that will not cause disease in humans, but will cause the body to produce antibodies.

Compounds derived from synthetic biology produce improved ingredients for skincare products. Biosynthesis has created squalene (a key antioxidant), biofermented microalgae for anti-ageing products, or alguronic acid, a glycoprotein (a biofermented exopolysaccharide isolated from brown seaweed).

Scientists are working on several projects to improve photosynthesis. In 2022, modified soybean plants showed a 20% increase in yield due to an improved photosynthetic system.

Using the CRISPR gene editing tool, scientists have discovered how to speed up tree maturation.

The use of human DNA for data storage is already technically possible.

Scientists have created a synthetic bacterium capable of swimming by inserting seven proteins into it. With minimal genetic information, the spherical synthetic bacteria are thought to be the smallest mobile life forms to date.

It has been possible to create a ‚complete' human embryo without the use of sperm, ova or uterus, which did not result from conception but from stem cell transformation.

New embryo genetic testing techniques to generate the entire genome of an embryo and calculate the likelihood of certain ailments before in-vitro treatment. It is possible to determine whether an embryo has the right number of chromosomes and to review risk assessments for heart attacks, certain cancers and diabetes. It is also possible to calculate scores and optimise for other genetic traits, such as height and intelligence.

Biopolymers such as polysaccharides, proteins and lipids can be used to produce edible films or coatings. Companies are also designing biodegradable and edible seaweed-based packaging.

Scientists used zeolite as a catalyst to break down various polymer molecules. Most of these could be converted into usable propane. This offers a new solution for the mass recycling of plastics.

Synthetic fabrics designed from DNA of living organisms, based on microbially fermented materials from mycelium.

Scientists are using synthetic biology to produce synthetic organisms capable of producing huge amounts of vegetable oil and nut trees that can be grown indoors, using only a fraction of the water that nut trees normally need, while producing twice as many nuts.

Synthetic wombs are already being used successfully in scientific experiments.

Today, home tests can determine the genetic composition of the microbiome.

Genetic research is being conducted to repurpose psychedelics as a treatment for depression and PTSD.

SYNTHETIC BIOLOGY ACHIEVEMENTS

A platform is being developed to help patients determine which medicines they should take - depending on their genetic data.

Acellular meat created from organic molecules that contain no living (or once living) material in the final product.

Scientists are using neural networks to develop new segments of human genomes. The aim is to create an artificial human genome that will enable DNA testing without violating the privacy of any individual.

Actions to diversify genomic research and include genes from continents other than North America and Europe.

A Chinese researcher edited embryos created from the egg of a healthy woman and the sperm of a man with HIV infection. Healthy twins were born, becoming the first known case of gene-edited babies.

Over the past decade, China has quietly established a scaled-up national programme to collect, sequence and store its citizens' genetic data, which allows the government to continuously monitor its citizens. The prosecution of criminals is cited as the main benefit of genetic testing.

Researchers are building the first ever comprehensive map of all 37.2 trillion human cells in the body.

The researchers used a machine learning model to generate new mutations of natural enzymes that allow bacteria to break down plastics found in drinks bottles and most consumer packaging. The enzyme, named FAST-PETase, could work on an industrial scale to clean up landfills, for example.

Incomplete knowledge of how nature works

This makes it very difficult to apply the design, testing and learning cycles used in conventional engineering to the production of synthetic biological materials.

Complex ethical issues

Increasing concerns and challenges about the moral and social implications of the development of synthetic biology when new techniques, such as genetic surgery or the creation of organoids grown from human stem cells will become publicly available. Increased tensions over decisions to allow or preventing the editing of human reproductive cells.

Environmental risks

Organisms produced using synthetic biology and released into the environment can have unknown, unintended and potentially irreversible effects on ecosystems. The modified organism may compete with species native to the ecosystem or affect the environment through the movement of genes or genetic material between organisms.

Potential risks to human health

New allergens, resistance to new antibiotics or carcinogenic effects of synthetic biology products are possible. There is also a potential risk that synthetically modified organisms will create new pathogens or toxins or increase the virulence or quantity of known pathogens or toxins.

Access to resources

Particularly access to specialists in the field and capital, can increase the likelihood and speed of new discoveries or slow them down.

Geopolitical conflicts

The geopolitical race for dominance in synthetic biology research and achievements is already underway. China is developing a vast domestic biotechnology ecosystem, which can give it a strategic advantage in research, testing and development of new products.

In the absence of a global framework to regulate bioengineering, we can expect geopolitical conflicts to arise from the use of new biotechnology-based technologies.

As bioengineering technologies advance, it is necessary for governments to work together on a common vision for the future, as well as on harmonised policies and regulations.

Bioengineering research costs

Are still very high, although the prices of components, equipment and materials continue to fall.

Regulatory and policy uncertainty

Given the rapid growth of this field, there is a need to develop regulatory initiatives aimed at mitigating risks and standardisation initiatives - aimed at creating interoperability in biosystem modelling and DNA design standards.

Biohacking

Low barriers to entry open the door to potential abuse with potentially fatal consequences. Some biological technologies are relatively cheap and accessible. Commercial CRISPR gene editing kits are sold relatively cheaply online.

Genetic data protection

Concerns about privacy and the use of private genetic data without appropriate consent are common, considering that the basis for advances in synthetic biology relies on data from our bodies and brains. Protecting genetic privacy will become increasingly challenging and will require proper regulations and safeguards.

Fair distribution of benefits

Similar to other modern technologies, there is a significant risk that developed countries will be the main beneficiaries of the development of synthetic biology, bypassing developing countries.

Storing the genome

According to estimates, there may not be enough space to store human genomes by 2025.

DNA for research

Due to the rapid development of synthetic biology, there is an increasing need for a larger quantity of anonymized DNA sequences for research purposes.

Disruptions in conventional production

In the near future, disruptions in traditional agri-food production, textiles, and the development of pharmaceuticals might arise.

Innovation pace

While the pace of innovation is fast, transitioning research beyond the laboratory takes time.

OPPORTUNITIES ARISING FROM CURRENT RESEARCH

- New opportunities for healthcare, pharmaceuticals, agriculture, food and beverage production, beauty, chemicals, sustainable development, energy, and material production
- Improving or replacing many materials currently used in production processes with their substitutes created using synthetic biology – from fuels and raw materials, through materials and products, to consumer goods such as electronics or clothing
- Faster and cheaper genome sequencing or gene synthesis, next-generation programmable DNA modification systems, and tools for genome editing, leading to new genetically targeted therapies and drugs, new diagnostics and treatments for cancers, rare diseases, eye diseases, chronic infections, as well as rapid detection and diagnosis of pathogens, and vaccine production, including mRNA-based approaches
- Biosensors capable of detecting biological weapons, harmful chemicals, and specific DNA sequences
- Xenobots for environmental cleanup, unblocking veins, and other operations, early detection of cancer, or targeted drug delivery
- The use of CRISPR-edited probiotic bacteria in the treatment of infections, especially those resistant to antibiotics
- Greater precision in treatment through new methods of controlling cell therapy
- New techniques for preventing, and even reversing, age-related diseases
- Synthetic wombs and biobags
- Gene surgery (fixing errors in biological code), including optimizing children for genetic traits
- Optimization of recreational drugs based on the unique genetic profile
- Increased drug safety through the use of organ-on-a-chip (OoC) systems that mimic the functions, processes, and physiological reactions of organs
- Targeted therapies and genetic enhancements using molecular robotics, enabled by the programming of DNA and robots
- Limiting the spread of deadly infectious diseases through specially designed organisms
- New therapies based on research into the human microbiome
- Artificial blood
- Better understanding of the fundamental principles of life and the ability to design it through the development of the simplest form of life - organisms, cells with minimal genetic information
- Accelerated drug discovery through the use of artificial intelligence and machine learning
- Faster protein and drug assembly through quantum computing, and new discoveries based on the quantum nature of enzymes, DNA, viruses, etc.
- New, simple forms of neural networks created from biological material (biological computers)
- Storing data in human DNA with the ability to recover it for thousands of years
- New products based on precise fermentation processes and platforms
- Lab-grown meat
- Leather and biomaterials derived from fungi and proteins

OPPORTUNITIES ARISING FROM CURRENT RESEARCH

- Acellular meat created from organic molecules that do not contain living material
- Synthetic dairy from synthetic cow's milk, grown through the artificial reproduction of proteins in casein and whey
- Products utilizing durable biofilms and coatings in construction, cosmetics production, and electronics
- Smart biopolymers for the food industry
- Plant varieties that also store carbon to improve soil health
- Increased crop yields, reinforcement of natural plant defense mechanisms, enhanced nutritional value, accelerated ripening, and extended freshness through improved photosynthesis and CRISPR
- New breeds of animals resistant to diseases and adapted to climate change
- Creating new materials and products using microbial, cellular, and enzyme engineering as-a-service
- New possibilities for capturing carbon dioxide, recycling plastics, and improving biodiversity
- Improving plastic recycling by breaking them down into propane or utilizing natural enzyme mutations
- Environmental DNA (eDNA) as an early warning system for potential disease outbreaks or for reconstructing ancient ecosystems
- Sequencing ancient genomes and new discoveries related to human evolution, longevity, and resilience through insights into the human genome

TRENDS

Current changes that could positively [↗] or negatively [↘] affect the future of synthetic biology.

- ↗ Decrease in costs and an increase in the pace of bioengineering research
- ↗ Development of ecosystems supporting research and the utilization of achievements in synthetic biology in leading world economies
- ↗ Rise in the number of standards and regulations aiming for sustainable development in this field
- ↘ Global competition for dominance in synthetic biology leading to increased environmental, health, and human life threats
- ↗ Increased utilization of synthetic biology advancements in agriculture, medicine, and industry, particularly in the agri-food, pharmaceutical, and chemical sectors
- ↘ Acceleration in the development of modern biological weapons
- ↗ Rising demand for biotechnologists, molecular biologists, bioengineers, etc., leading to an increase in the popularity of studies in these fields
- ↗ Growth in the use of artificial intelligence and machine learning in synthetic biology research

ANTI TRENDS

Factors of change that mat disrupt currently observed trends in a way that can be either beneficial [↗] or detrimental [↘] to the development of synthetic biology.

- ↘ Increase in the number of biological incidents, improper use of human genetic data, or an ecological disaster
- ↗ Pandemics
- ↘ Use of biological weapons
- ↘ Restrictive regulations or a ban on biological experiments
- ↗ Climate warming and the spread of new epidemiological threats
- ↘ Intensification of opposition to synthetic biology due to ethical concerns and safety
- ↘ Slow progress in research due to global economic slowdown, inadequate access to funding, social unrest, and armed conflicts
- ↘ Lack of appropriate ecosystems in democratic states
- ↘ Shortage of specialists
- ↘ Strong resistance from industries that could be most affected by the development of synthetic biology
- ↘ Weakening international research collaboration
- ↗ Technological advancement (e.g., in quantum computing) and an increase in the pace of research

CONCLUSIONS

For some time now, nothing has stirred more interest among scientists, philosophers, governments, and investors than synthetic biology. There is a wealth of scientific literature and much speculation about how this field might transform our entire way of life on Earth and even resurrect species that have long been extinct.

However, considering all the potential benefits and risks stemming from advancements in synthetic biology, scientists must first critically assess whether there is sufficient information available to enable the design of biological processes and turn biology into a predictive science. It's worth remembering that even the most well-known achievements in this field have arisen more from traditional methods, trial and error, rather than electronics-based engineering.

Moreover, we must not forget that cells possess innate abilities for mutation and evolution. Will we ever be able to predict the potential consequences of releasing genetically modified particles and organisms into nature? Given our current level of knowledge about nature, the answer is likely not anytime soon. So, are we willing to risk our health and existence for potential benefits?

In this context, we must also bear in mind that the potential advantages this field can offer to the world's leading powers, regardless of whether democratic societies eventually express a desire to halt research and development in synthetic biology, are unlikely to dissuade continued progress. Furthermore, if we decide that the potential benefits promised by research in this field may outweigh the associated risks to our existence, then we must promptly establish the necessary tools, regulations, well-prepared human resources, and ensure public acceptance while being fully aware of all these risks. Otherwise, the hopes tied to the positive impact of bioeconomy on our world may prove to be quite futile and short-lived. Leaving this field in the hands of those driven by profit-seeking commercial entities or major undemocratic military powers of this world appears to be quite perilous.

And let's not forget that the development of synthetic biology is already expanding the roster of agents that require attention. This increases the need for the development of detection, identification, and monitoring systems and the active building of countermeasures against chemical and biological threats.

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4CF is a strategic foresight and long-term strategy building consultancy. For almost two decades, 4CF has been helping its clients prepare for an uncertain tomorrow. The company has completed hundreds of projects for private companies, public and international institutions, including UNESCO, UNDP and WHO.

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4CF is at the forefront of global innovation and actively contributes to the development of cutting-edge foresight tools. The company's foresight experts have extensive interdisciplinary knowledge and experience. They are constantly refining the 4CF methodology and actively collaborate with leading international foresight centres.

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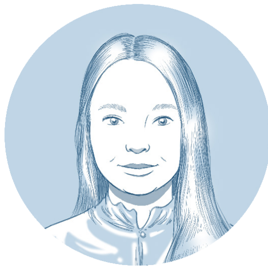

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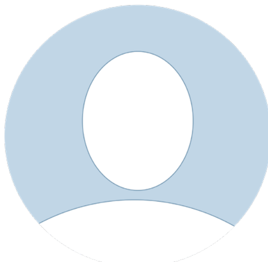

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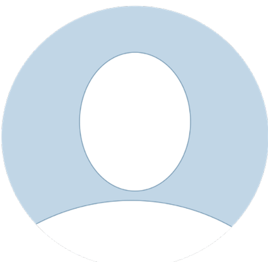

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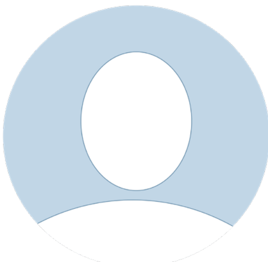

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