NATO OTAN
Science & Technology Organization (STO)

Biotechnology & Human Enhancements

Briefing paper 6/9

Biotechnologies use biological processes, genetics, cells or cellular compounds to develop new products. These can be applied for medical interventions, novel materials and manufacturing processes, and human enhancements (through biomimetics). Potential applications include the integration of robotics or neural interfaces with Artificial Intelligence (AI) into humans. While development is still early, this technology could prompt another revolution similar to the information age.

Implications

Economic Implications – Synthetic biology and biotechnology advances bring economic implications and potential disruptions. Agriculturally, developments may increase food yields and crop resilience, and reduce environmental impacts. For healthcare, personalised treatments and medications, new diagnostics and regenerative methods may become ubiquitous, while the production of biological products (hormones, enzymes, antibodies, vaccines) could become cheaper. Novel bio-manufactured materials and chemicals provide alternative, environmentally-friendly routes to synthesise energetics, propellants, and plasticisers.

Military Implications – Military use of biotechnologies applies to human enhancements across cognitive, physical and social performance benchmarks, and synthetic-biology military products (e.g. smart textiles, living sensors or power systems). New materials with advanced properties could facilitate more lightweight and durable armour or better chemical, biological, radiological, and nuclear (CBRN) defences. Advances in trauma medicine, psychological treatments and regenerative medicine are particularly important for sustaining soldiers' capabilities. Synthetic and physiological enhancements could revolutionise future soldiering.

Societal Implications – Biotechnology applications are driving society-wide benefits. Biofuels are a promising source of energy, environmental sensors may allow rapid detection of harmful chemicals, and genetically modified organisms have many applications, bringing medical benefits. Potential unintended consequences and the ethical, moral, and legal risks of altering biology are significant. Existing inequalities may be exacerbated by limited access to enhancements. Equally, privacy concerns, consent to the use of genetic information, and ethical research practices must be safeguarded.

Key Technology Areas

Genetics and Bioengineering – Genetic engineering and synthetic biology are driving efforts to enhance human performance and create functional (bio)materials. CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats), for instance, is now an established gene-editing tool. Gene reading, writing and editing (as well as bioengineering, and biomanufacturing processes and products) are expected to become more accessible over the coming decades. Biotechnology applications are increasingly replacing oil refining to produce commodity chemicals, including energetics and propellants. Up to two-thirds of the world's most commonly used chemicals could eventually be synthesised from renewable resources.

Bioinformatics and Biosensors – Bioinformatics describes the analysis of biological systems through large-scale data collection on the interactions between components of that system. Areas of interest include CBRN biological sensors, medical treatment monitoring and computational biology. New biosensors that measure biological or biochemical phenomena (immunological, pressure, thermal, etc.) have contributed to the volume of data available, as sensors have become cheaper and more accessible. Technologies for human physiological monitoring are already commercially available, and advanced sensor packages will mature in the medium term.

Cognitive, Physical and Social Enhancements – Cognitive enhancement is a key human application of biotechnology, requiring advances in brain-machine interfaces and understanding of the brain. Novel neurological and psychiatric treatments are expected to emerge from research, particularly for PTSD or cognitive recovery. Additionally, enhancement of strength, endurance, pain and fatigue tolerance has been a long-standing military goal. There is also significant research around modelling and simulating social dynamics to counter disinformation, cognitive, and hybrid warfare campaigns.

Technology Convergence

Artificial Intelligence and Quantum – Advances in biomimetic technology applications will enable the development of other biotechnology and human enhancement technologies, such as new biological agents that are designed and created molecule-by-molecule or cell-by-cell. These developments would greatly expand our ability to tailor-make pharmaceuticals or (synthetic) organic replacement parts or inspire new advanced computing approaches.

Materials, Energy and Electronics – Novel materials and manufacturing offer synthetic biology with improved properties and biomanufacturing opportunities. Additionally, biomanufactured fuels from renewable organic molecules may soon be a viable alternative to fossil fuels, while genetic engineering is enabling a class of living sensors with new capabilities, either integrated into biocomputing frameworks or in place of both active and passive sensing systems.