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7. Biotechnology and Bioengineering

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Abstract:

This chapter focuses on the intertwined dimensions of biotechnology and bioengineering, broadening their working principle and groundwork applications in various fields like healthcare, agriculture, industry, environmental applications, etc. Biotechnology is a multidisciplinary field that encompasses both engineering and natural sciences to contribute towards human wellness. Currently, biotechnology has fueled the landscape of healthcare, agriculture and industrial sectors by the introduction of technologies such as Genetic engineering, Biofuels, Bioreactors and so on. Whereas, bioengineering brings together tools of engineering and applications of biology to create exceptionally economical and efficient products. It is used dynamically in designing medical devices, industrial instruments, agricultural tools and other tools in different areas to develop high standards of living. This chapter revolves around different concurrent problems that are addressed by these fields, including vaccine development, uncurable disease treatment and environmental safety. It also explores the latest methods and technologies that are futuristic advancements, such as 3-D bioprinting, wearable health devices and synthetic biology. By empowering multifaceted aspects of biotechnology and bioengineering, this chapter outlines their superficial role in the future progression of the world.

Keywords:

Biotechnology, bioengineering, healthcare, GM crops, biofuels.

7.1 Introduction:

Biotechnology encapsulates two major fields, engineering and natural sciences to develop a product or a service by utilizing living cells, organisms or a biological system. Karoly Ereky became the first one to coin the term ‘Biotechnology’ back in 1919. The main aim of biotechnology is to produce something viable by using biological systems or living organisms such as bacteria, yeasts, and plants. Biotechnology has various applications that can be applied in real life to accelerate environmental sustainability, healthcare development and even agricultural advancements. One such emerging technology is ‘Genetic engineering’. This technology involves the manipulation of gene sequences to obtain desired results. For example, the introduction of lipid-inducing genes from bacteria into microalgae for biomass production.

This can be widely used for different purposes as it can manipulate the characteristics of a particular organism. With a wide range of applications, biotechnology also comes up with constraints of ethical clearance around questionnaires involving applications of genetic modifications. Biotechnology involves laboratory research and development using bioinformatics to explore, extract, utilize, and produce valuable products from living organisms and biomass sources. This is achieved through biochemical engineering, enabling the creation, prediction, formulation, development, manufacturing, and marketing of high-value products aimed at sustainable operations.

Biomedical engineering or Bioengineering is a collaborative approach between principles of biology and engineering tools to produce practical, concrete, and financially feasible products.[5] Advancements in bioengineering over the years have seen the development of rapid disease-diagnostic devices, tissue-engineered organs, prosthetics, medical imaging technology and many more.[6] Recently, biomedical engineering has brought a potential outbreak in enriching ecological aspects of an area by implementing environmental modifications including slope protection, surface soil protection, and protecting watercourses and shorelines. Sub-disciplines of bioengineering include biochemical engineering. bioprocess engineering, genomics, environmental health engineering, biomimicry, bioprinting, system biology and many more depending on their boundaries of applications.[7] Several applications in diverse fields can be seen concerning bioengineering which aims to raise human standards of living by eliminating the possible solution-to-a-problem dilemma. Biological engineers generally strive to either replicate biological systems to develop products or to alter and manage biological systems.

7.2 Biotechnology:

Biotechnology is a broad discipline which cumulates biological applications with technology to produce technologies that aim to raise living standards of human life. Modern technology continuously thrive to combat serious rare disease illness, rapid environmental degradation, and to meet industrial and agricultural needs to develop and progress the productivity of essential products such as feed and food.[9] Biotechnology contributes towards various fields with specific technologies. Different branches of biotechnology leads to the contribution to distinctive fields. Such as Red biotechnology, also known as medical biotechnology, involves using biotechnological applications to improve medical and health care practices. Blue technology refers to the application of biotechnology in marine and aquatic environments. It explores the potential of marine organisms to develop new products and processes for a variety of uses. Grey biotechnology focuses on environmental applications of biotechnology, primarily in pollution control and waste management. Yellow biotechnology pertains to the use of biotechnology in the food industry, particularly focusing on food production, processing, and safety. White biotechnology, also known as industrial biotechnology, applies biotechnology to industrial processes. It aims to create more sustainable and efficient industrial practices. Gold biotechnology involves bioinformatics, the use of computational tools and techniques to analyze and interpret biological data. And, Green biotechnology, also known as agricultural biotechnology, involves the use of biotechnological techniques to enhance the efficiency and sustainability of agricultural practices. This branch focuses on improving crop yields, developing pest-resistant plants, and creating environmentally friendly agricultural processes.

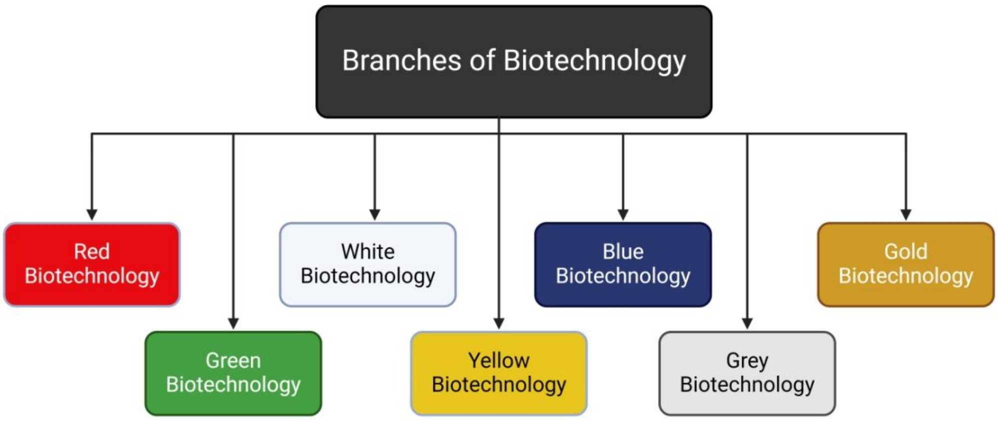

Figure 7.1: Different branches of Biotechnology

7.3 Applications of Biotechnology:

Applications of biotechnology are mainly directed to four major sectors including, healthcare, agriculture, industrial and environmental. Examples of such applications include beverage production (beer and alcohol) using fermentation techniques that are synthesized using microorganisms like yeast, waste management techniques, production of biological instruments, genetically modified crops and biotechnology also has its application in industrial waste treatment. [11] This innovative discipline harnesses cellular and biomolecular processes to create solutions that improve the quality of life and address global challenges.

The applications of biotechnology span across several domains, including medicine, agriculture, industry, and environmental management, each contributing uniquely to advancements in their respective fields. [12]

7.3.1 Medicine:

Modern biotechnology has diverse applications in areas such as antibody production, biopharmaceutical drug designing, pharmacogenomics, drug testing and genetic screening. Over the past few years, the inclusion of pharmaceutical biotech companies has been on the rise in the major medicinal fields including oncology, neurology and other rarely occurring diseases.[13]

Biotechnology has contributed to the production of small-molecule pharmaceutical drugs and biopharmaceutics which are biotechnology products itself. Also, modern biotechnology is responsible for the production of existing medicines relatively easily and cheaply.[14] It has enabled genetic testing of inherited diseases that allows early detection of diseases that are left undiagnosed over time until their severity grows. Insulin, which is widely used as a treatment option for diabetes was traditionally extracted from animal abdomen. Now, with genetically engineered bacteria insulin can be produced in large batches at a time in relatively lower capital. Biotechnology has also facilitated the development of new treatments such as gene therapy which are widely used in the treatment of diseases like cancer, thrombosis, and hemophilia.

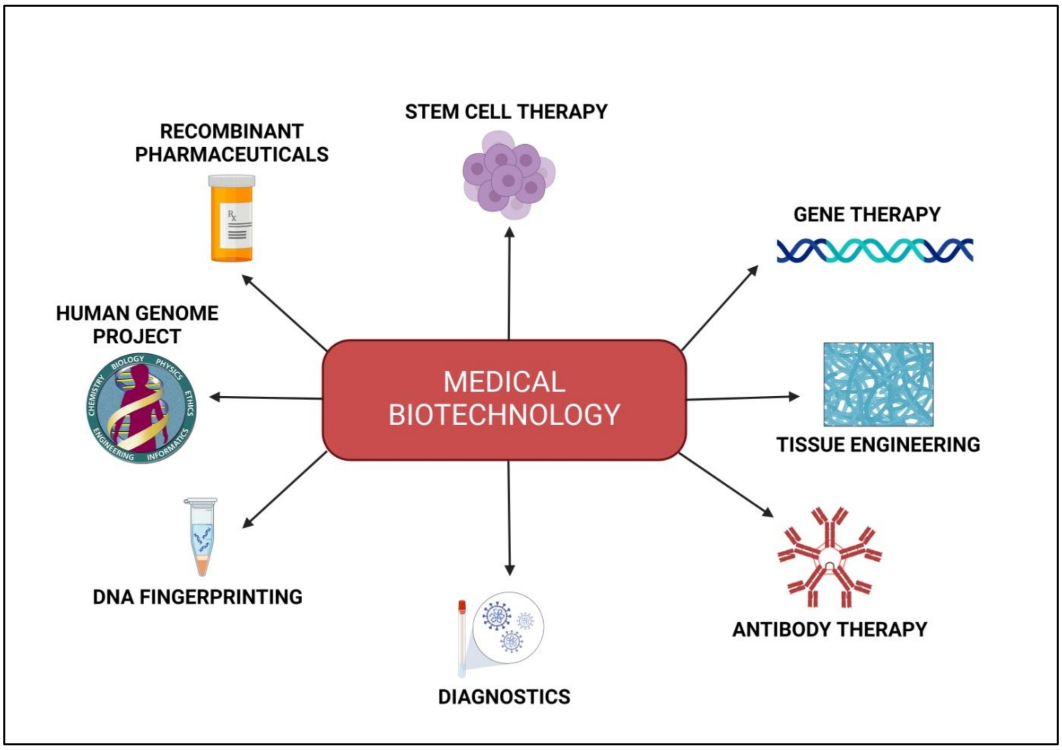

Figure 7.2: Different applications of biotechnology in medical field

7.3.2 Agriculture:

Genetically modified crops (GM crops) are one of the biggest inventions that have emerged in the agricultural food crop industry. GM crops aim to produce crops with more suitable traits that do not occur naturally by modifying DNA sequences.

This application of genetic engineering aims to contribute towards future food security by enhancing the yield and nutrients of crops in the urban agriculture sector. [16]

Food crops examples include resistance to pests, diseases, stressful conditions environmental uncertainty and increasing nutrient profiles in crops. [17]

Non-food crops include the production of biofuels that utilize corn, soybeans, sugarcanes and other feedstock for biomass yield. Biofuels are seen as a possible replacement for petroleum-derived fuels. By 2030, a 30% fall in petroleum-derived fuels has been estimated and ethanol consumption can be seen on the rise.

Genetically modified crops are produced through organisms that are introduced with a particular DNA manipulation that offers better productivity than techniques such as selective and mutation breeding.[18] Major genetic modifications that are majorly recommended by farmers are primarily seen in cash crops such as corn, soyabean, cotton seed, etc. [19]

Table 7.1: Agricultural Biotechnology Market Scope

Report Coverage	details
Market Size in 2023	USD 115.26 Billion
Market Size by 2023	USD 242.17 Billion
Growth rate from 2023 to 2023	CAGR OF 8.6%
Largest market	North America
Base Year	2022
Forecast Period	2023 To 2023
Segments Covered	By application by Organization type, By Typer, and By Technology

7.3.3 Industry:

Industrial biotechnology is also referred to as white biotechnology, it involves the introduction of biotechnology applications for industrial whereabouts. Biotechnology in industries involves the utilization of living cells such as bacteria, fungi and catalytic enzymes for the production of industrially beneficial products in the chemical, food and feed sectors. White biotechnology focuses on utilizing renewable sources for producing economically and environmentally viable products which is an advancing step towards minimizing greenhouse emissions.[20]

Synthetic biology is a vital component of industrial biotechnology, contributing financially and sustainably to manufacturing.[21] Together, biotechnology and synthetic biology help produce cost-effective, eco-friendly products using bio-based methods instead of fossil fuels.[22]

By using genome editing tools, synthetic biology can enhance model microorganisms like Escherichia coli to produce medicines and biofuels. For example, E. coli and Saccharomyces cerevisiae can be engineered in a co-culture to produce precursors of the chemotherapeutic agent paclitaxel.[23]

7.3.4 Environment:

Environmental biotechnology plays a critical role in minimizing environmental waste and ensuring environmental stability by proper optimization of renewable and non-renewable sources that are utilized. Environmental biotechnology can have both positive and negative impacts on the environment, where treating waste through environmentally acceptable such as biofiltration and biodegradation can positively impact the environment, whereas biodiversity loss can be seen as its negative role towards eco control and safety as it is operated by involving living organisms in its processes.[24]

To eliminate pollutants from the atmosphere, city trees are installed as a filtrate in many cities which is a good side of biotechnology in the environment.

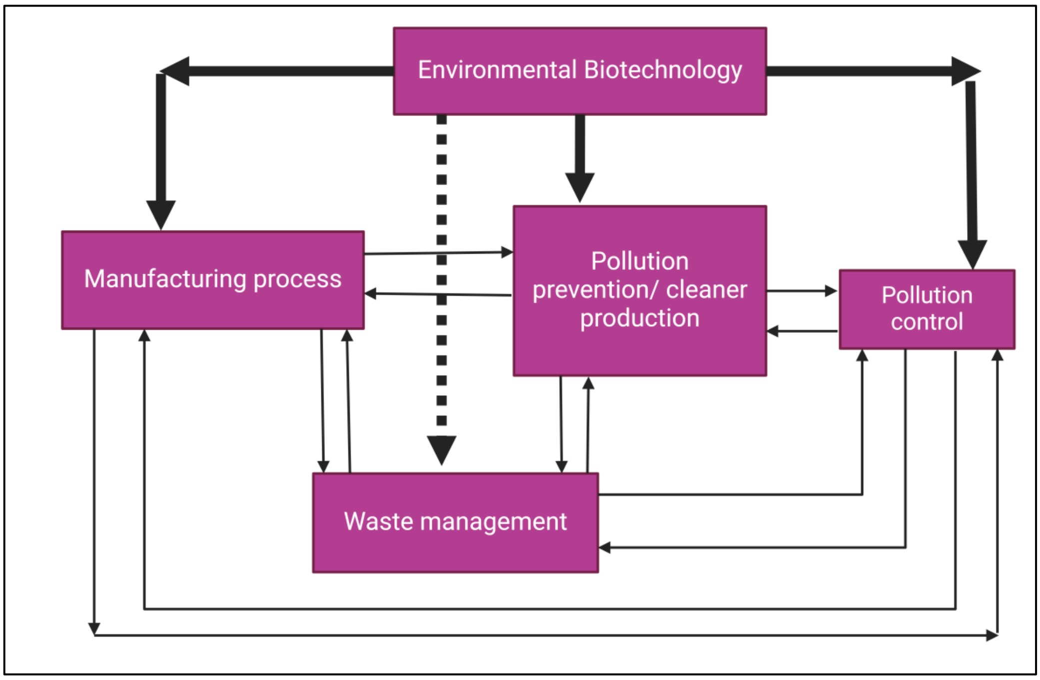

Figure 6.3: Key Intervention points of Biotechnology

7.4 Bioengineering:

Bioengineering, often referred to as biomedical engineering, is an interdisciplinary field that blends engineering principles with biological and medical sciences.

The goal of bioengineering is to enhance healthcare by creating cutting-edge technologies and devices that improve diagnosis, treatment, and patient care, ultimately enhancing the quality of life for individuals.[26]

Bioengineering significantly transforms healthcare by enhancing how we diagnose, treat, and manage diseases. Breakthroughs in this field have led to the creation of life-saving devices and more effective treatments, while also deepening our understanding of intricate biological systems.

These advancements are not just technological; they directly contribute to better patient outcomes and improved quality of life.[27]

7.5 Applications of Bioengineering:

Bioengineering thrives to investigate and resolve implications that hinder human health and environmental safety. It encompasses a broad range of fields including biological sciences, natural sciences, engineering and mathematics. It holds a vital role in developing and manufacturing products that are economically viable and essential for specific purposes.

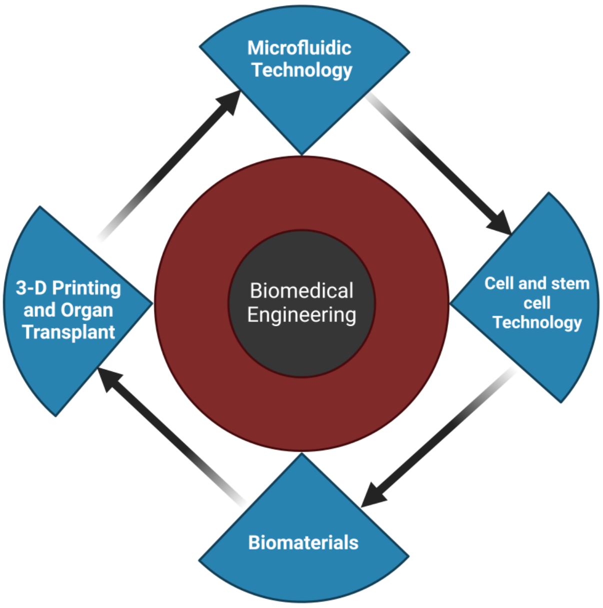

Figure 6.4: Schematic diagram of Biomedical engineering technologies (Zhu et al., 2022)

7.5.1 Medical Applications:

Bioengineering helps in the development of medical tools such as diagnostic kits, prosthetics and artificial organs. It also focuses on the development of tissue engineering and medicines that can be regenerated. It holds an important role as it opens a way to investigate critical rare diseases and it helps in rapid detection of some of the rare diseases that do not show any signs and symptoms at their early stages. It applies engineering design, concepts and principles in the medical field for healthcare advancements.[28]

7.5.2 Bioprocess Engineering:

Bioprocess engineering involves the development of technologies that are focused on monitoring and optimizing large-scale production processes such as biochemicals, biofuels, bioprocess design, bioplastics etc. It is an intervention of mathematics, biology and industrial design to design and develop manufacturing of products such as food, feed, pharmaceuticals and agriculture.[29]

7.5.3 Biochemical Engineering:

Biochemical engineering, also known as bioprocess engineering, is a discipline that combines chemical and biological engineering. It mainly concentrates on designing, constructing, and improving unit processes involving biological organisms (such as fermentation) or organic molecules (like enzymes). This field has wide-ranging applications, including biofuels, food production, pharmaceuticals, biotechnology, and water treatment.[30]

7.5.4 Environmental Engineering:

Environmental engineering is a branch of professional engineering connected to environmental science that integrates various scientific fields, including chemistry, biology, ecology, geology, hydraulics, hydrology, microbiology, and mathematics. Its objective is to develop solutions that safeguard and improve the health of living organisms as well as enhance environmental quality. Environmental engineering is a sub-discipline of both civil and chemical engineering, with a particular focus on sanitary engineering within the civil engineering domain.[31]

7.5.5 Systems Biology:

Systems biology is an interdisciplinary field that involves computational and mathematical analysis and modelling of complex biological systems. Instead of breaking down biological systems into individual parts as traditional reductionism does, it takes a holistic approach by examining the intricate interactions within these systems to understand how they function as a whole.[32]

7.5.6 Biomimicry:

Biomimetics, also known as biomimicry, involves imitating nature's models, systems, and elements to address complex human challenges. This approach draws inspiration from the evolutionary processes that have shaped life over approximately 3.8 billion years, resulting in the development of highly efficient structures and materials from readily available resources. Biological materials demonstrate intricate organization across different scales, from molecular to nano-, micro-, and macroscales, often arranged hierarchically, contributing to their diverse functional properties. The biomimetic approach explores how surface interactions and material properties can be optimized by imitating nature's designs, offering solutions that integrate multifunctionality into materials and objects.[33]

7.6 Future Scopes of Biotechnology and Bioengineering:

The fields of biotechnology and bioengineering are expanding at a rapid pace and hold great promise for the future. These industries are probably going to keep growing as new uses and innovations are spurred by technological breakthroughs like CRISPR gene editing, synthetic biology, and customized medicine. Future applications of biotechnology and bioengineering could be found in many fields, including agriculture (GMO crops, sustainable farming methods), healthcare (personalized medicine, regenerative medicine), industrial biotechnology (biofuels, bioplastics), and environmental remediation (bioremediation, waste treatment). The fields of biotechnology and bioengineering remain extremely promising for future developments. These are some prospective areas of growth and future scopes:

A. Precision Medicine: New developments in biotechnology are opening the door to customized medicine, in which a patient's care is based on their genetic composition, way of life, and surroundings. The goal of this strategy is to reduce adverse effects and increase treatment efficacy. [34]

B. Regenerative Medicine: Tissue engineering and stem cell treatment are two bioengineering techniques that show promise for repairing damaged organs and tissues. Treatments for ailments including spinal cord injury and organ failure may be revolutionized by this discipline. [35]

C. Synthetic Biology: Developments in this field make it possible to create creatures and biological systems with unique functions. [36]

D. Wearable technology and biomedical equipment: Bioengineering is propelling the creation of wearable sensors that track vital signs in real time as well as sophisticated medical gadgets. Early disease identification and remote patient monitoring are examples of future applications. [37]

E. Environmental Biotechnology: It is anticipated that biotechnological approaches to environmental problems, including waste management, pollution control, and sustainable agriculture, would grow. This covers genetically modified crops and bioremediation methods. [38]

7.7 Conclusions:

In summary, the fields of biotechnology and bioengineering represent powerful intersections of scientific innovation and practical application. Biotechnology utilizes the genetic and molecular foundations of living systems to develop new therapies, agricultural advancements, and sustainable industrial processes. It has revolutionized medicine with personalized treatments and vaccines, transformed agriculture through genetically modified crops, and paved the way for eco-friendly biofuels and biodegradable materials.

Similarly, bioengineering integrates engineering principles with biological systems to address various challenges, from designing medical devices and tissue replacements to optimizing bioprocesses for pharmaceutical production and environmental remediation.

By leveraging advances in genetics, nanotechnology, and computational modelling, bioengineering continues to drive breakthroughs in healthcare, energy, and environmental sustainability. Together, these disciplines exemplify humanity's pursuit to understand and manipulate the building blocks of life for the betterment of society. As we navigate complex global challenges, biotechnology and bioengineering will undoubtedly play pivotal roles in shaping a more resilient, sustainable, and healthier future for generations to come.

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