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The impact of biotechnology on pharmaceutical manufacturing: Revolutionizing production processes

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***Abstract*---**Background _ Bioengineering tools have revolutionized the production of pharmaceutical bioproducts by streamlining processes and reducing the time required for development. These tools are applicable across various biological platforms, including plants, animals, and microorganisms, offering substantial advantages in the pharmaceutical industry. Aim of Work – This review aims to highlight the benefits and advancements in bioengineering tools for pharmaceutical production and to propose strategies for enhancing the economic feasibility of these processes at both biological and process bioengineering levels. Methods – A comprehensive analysis of current literature was conducted to evaluate the advancements in bioengineering tools, including system biology, synthetic biology, transcriptomics, proteomics, metabolomics, and nano bioengineering. The review also examined the challenges faced in pharmaceutical production and the tools available to address these challenges. Results – The findings indicate that the development of pharmaceutical bioproducts is significantly influenced by advancements in system biology and synthetic biology. Key bioengineering tools, such as

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transcriptome, proteome, metabolome analyses, and nano bioengineering, play a crucial role in addressing the challenges associated with pharmaceutical production. The review also identifies potential breakthroughs that can enhance the production process and improve economic feasibility. Conclusion – Bioengineering tools present new opportunities for the efficient development of pharmaceutical bioproducts. By leveraging advanced technologies and strategies, the pharmaceutical industry can overcome existing challenges and optimize production processes, ultimately leading to improved patient outcomes and reduced costs.

***Keywords*---**Bioengineering, Pharmaceutical Bioproducts, System Biology, Synthetic Biology, Nano Bioengineering.

Introduction

The majority of the organisms have been extensively employed as potential biofactories for pharmaceutical substances. The use of multiple hosts for bioproducts was expanded through the integration of development biology with bioengineering tools for genome manipulation **[1]**. Biopharmaceuticals are recombinant bioproteins that are of the highest benefit and are obtained through bioengineering techniques. They are the outcome of bioresources, including microorganisms, plants, animals, and genetically modified tissues and organisms **[2]**. It is equally crucial to utilize bioengineering tools to increase or expand metabolites, which are entangled in their enhanced endurance and enhance their bioactivities **[3]**. It fastens up novel opportunities in the field of biotechnology and pharmaceuticals. Bioengineering instruments included a variety of procedures for the isolation and identification of essential genes from a broad range of microorganisms into the genetic material of the host plant. This was done to advance inherently modified or altered hosts that possessed innovative features. However, it results in the enhancement of genetically modified or engineered (GM or GE) crops. It may include bioengineering pathways for a variety of characteristics, such as proteins, biocatalysts, and secondary complexes **[4]**.

The primary biofactories responsible for the production of approximately all beneficial proteins are plants, bacteria, fungi, and mammalian cells. In 2010, mammalian and microbial production met 68% and 32% of the global market requirements, respectively **[5]**. Conversely, biopharmaceuticals are employed in the treatment of antitoxin in human health **[2]**. Currently, numerous endeavors are underway to produce essential therapeutic complexes. For instance, taxol and artemisinin have demonstrated significant therapeutic benefits through metabolic bioengineering tools. The bioengineering tools have been employed to investigate the biosynthesis of a variety of recombinant proteins and therapeutic metabolites. This is supported by a variety of research data in the literature, including Mullein by *Penicillium janczewskii*, Taxol by *Fusarium maire*, *Aspergillus aculeatinus*, *Pestalotiopsis neglecta* and *Pestalotiopsis versicolor*, and *Alternaria alternata* **[3,6-10]**.

In order to create medicinal and industrial complexes of significant human value, bioengineering instruments are employed to genetically modify organisms for recombinant bioproducts. Bioengineering of microorganisms, animals, and plants was extensively employed in the production of pharmaceutical products, including vaccines, monoclonal antibodies, cytokines, enzymes, and growth factors **[1]**. Genomics was designed for DNA, transcriptomics for mRNA, proteomics for proteins and peptides, and metabolomics for advanced metabolism products comprised the extant omics classification. Parallel investigation of thousands of proteins and genomes is now feasible through high-throughput analysis, thanks to technological advancements. Additionally, the complementary and comprehensive nature of hypothesis-driven investigation and breakthrough-driven examination by omics procedures is emphasized **[11]**. Molecular biotechnology and genetic engineering are significantly influenced by bioengineering instruments. Here are some examples of recombinant bioproducts that were produced through the fermentation process.

Bioengineering for pharmaceutical development encompasses a comprehensive array of instruments and methodologies (Figure 1). This innovative, exhaustive article has conducted a critical analysis of the most recent bioengineering tools and techniques, as evidenced by the publications on Scopus, Science Direct, and other reputable publishers. It has the potential to expedite the development and implementation of bioengineering tools and technologies that are capable, as well as life cycle assessment. This is a significant pharmaceutical and related issue, but its life cycle assessment has not been reported. These tools and techniques are intended to be compiled into well-organized, durable resolutions that fulfill an unmet need and can contribute to the deliberate understanding of life science through the application of bioengineering advancements. This critical review delineates the current state of bioengineering instruments for biopharmaceuticals and the process of obtaining industrially significant biopharmaceuticals, with a global perspective, challenges, and future possibilities.

A global perspective on bioengineered instruments and pharmaceuticals

Human insulin was the first recombinant protein to be produced through bioengineering instruments in 1982. The FDA granted approval for its use as a pharmaceutical product. The pharmaceutical industry is revolutionized by biopharmaceuticals. In 2015, the highest 25 most popular medications were deemed to be 10 biotechnologically linked bioproducts, four of which were produced by microorganisms, according to global profits. Biopharmaceuticals are high-molecular-mass medications that can be identified through nucleotides polymers (DNA or RNA) or peptides and proteins (amino acids) **[2]**. Nucleic acids are the source of pharmaceutical production. For instance, gene therapy, DNA vaccines, and siRNA (small interfering RNA) are highly effective pharmaceuticals that are produced using bioengineering tools. Bioengineering tools encompass a vast array of technologies, including genomics, proteomics, metabolomics, and genetic engineering, which are essential for the sustainability of pharmaceuticals. These technologies range from the outdated to the innovative. The treatment of a variety of maladies has been revolutionized by pharmaceuticals such as monoclonal antibodies. Currently, the industrial and academic sectors are beginning to demonstrate a greater appreciation for the natural science of cell

lines, such as Chinese hamster ovary cells. They are utilizing this information to develop processes and bioengineered tools, such as ribosome footprint outlining, and to stimulate the NGS (next-generation sequencing) system, which provides genome-wide evidence on translation **[12]**. New bioengineering tools have opened up a new era for enzyme bioengineering, surpassing site-specific mutagenesis through the recombinant DNA process to enhance the thermostability of the enzyme. In this regard, the computer-dependent gene designer tools have been established to facilitate the de novo formulation of genetic paradigms. Additionally, gene designers can effortlessly update, remove, revise, modify, and associate genetic fundamentals such as promoters, tags, and open analysis frames **[13].**

In the past, target proteins have been identified in plant tissues as screens. However, this is the first report to utilize mutant plant tissues that express an extraneous target protein to directly secondary metabolism to a specific pharmacological phenotype **[14]**. Breitling and Takano **[15]** have recently conducted a study on the new experimental and computational bioengineering tools for the detection, optimization, and manufacture of pharmaceutical biomolecules. They also outline the development in the applications. Li et al. **[16]** examine the bioengineered tools and associated databases for biological parts screening. The accessibility of bioengineering tools is also increasing as a result of the increasing availability of computerized model construction and curation tools. For instance, the comprehensive computational evaluation of potential production for heterologous paths. The bioelectronic sensitivity sensor was described by Wang et al. **[17]** through the use of bioengineered E. Electrochemical sensors are constructed by combining E. coli cells with indium tin oxide. The PanDaTox tool, which is web-based, was developed by Amitai and Sorek **[18]**. This tool provides investigational toxicity evidence for over 1.5 million genes across hundreds of dissimilar microbial genomes. Metabolic engineering developments can be expedited by PanDaTox, which enables researchers to eliminate toxic genes and verify the clonability of designated genes prior to the definitive metabolic bioengineering.

The PITCh tool, a newly advanced microhomology intermediated end assembly dependent gene strikes instrument, has been described by Nakamae et al. **[19]** and has been proposed for a variety of applications. Probiogenomics has been defined by Ventura et al. **[20]** as a novel approach to obtaining genetic insights into the variations of probiotic prokaryotes in the human intestine. The exhaustive genetic composition of characteristic associates of Lactobacilli and Bifidobacteria has been74uspidsed through the genomic sequencing of a large quantity of these bacteria. Numerous live attenuated and DNA-based vaccines against toxoplasmosis have been investigated over the past two decades; however, vaccination against chronic and acute infections has only achieved partial protection. Dziadek and Brzostek **[21]** demonstrated that recombinant antigen-cocktails were possibly employed as an immunoprophylaxis instrument for toxoplasmosis analysis. The arenas of life sciences have been revolutionized by the adaptive prokaryotic immune organization CRISPR-Cas, which has unlocked new boundaries for personalized drugs. The ongoing discussion of ethical issues that has arisen as a result of the CRISPR-Cas tool has been summarized by Kick

et al. **[22]**. This includes the extant design expansions, novel Cas organizations, and its antagonists, as well as current and potential impending applications.

The CRISPR/Cas9 tools for critical genome editing are presently being employed to report virus resistance in plants **[23].** An RNA-directed DNA endonuclease organization, CRISPR-Cas9 is composed of Cas9 nuclease, which exhibits restricted targeting bases through a protospacer end-to-end motif complexed by a single, easily customizable controller RNA that targets approximately 20 bp of genomic arrangement. The authors detailed the diverse enhancements and alternatives of CRISPR-Cas systems, such as engineered Cas9 variants, Cas9 homologs, and novel Cas proteins other than Cas9 **[24]**. The novel luciferase knock-in system was validated by the construction and application of a CRISPR/Cas9 transcription activation/repression system for the PGRN gene to the knock-in system. In addition, the system was treated with phorbol ester (phorbol 12-myristate, 13-acetate), which had been previously reported to activate the expression of PGRN **[25]**. Additionally, Rojo et al. **[26]** have characterized the non-genome editing applications of CRISPR-Cas and have provided a concise summary of the commercialization of CRISPR. Al-Omari at el **[27]**. The multi-elemental analysis of pharmaceuticals derived from plant seeds has been demonstrated using energy dispersive X-ray fluorescence spectrometry.

The importance of bioengineering interventions in the pharmaceutical industry

In the present day, bioengineering tools that utilize sophisticated technologies mandate the modification of the genetic makeup of plants, animals, and microorganisms to increase the significance of their pharmaceutical properties. Metabolic bioengineering could be employed as a focal point and valuable method for managing metabolic pathways within a biosystem by utilizing the regulatory and enzymatic functions of the cells through biotechnological means, such as rDNA (Recombinant DNA) technology **[3]**. The primary objective of bioengineering instruments is to advance the biotechnology of low-cost and high-yield procedures. Therefore, the bioengineering tools and techniques from biotechnology, as well as other recombinant with molecular biology procedures, can be employed to more effectively execute the amplified metabolic actions. Conversely, nano biotechnology is a cutting-edge, state-of-the-art field that encompasses the bioengineering tools necessary to create pharmaceutically useful nanomaterials (NMs) or a combination of nanocomponent myriad to generate devices/stages through exceptional biological, physical, and chemical interface properties **[4]**. As per the elemental configuration, these could be compiled from carbon-based polymers (synthetic/natural), radionuclides, and mixtures that exhibit a variety of morphologies (rods, elements, tubes, films, and lattices), as well as dimensions and proportions. It is possible to biosynthesize it using a variety of top-to-bottom methods. These may encompass instruments that are complex in bioengineering, such as rDNA technology, polymerase chain reaction, gene cloning, genomic transformation, and transgenics. A recombinant reporter phage (light-tagged) has been produced by combining the luxAB genes with the complete genome of the P. cannabina phage PBSPCA1. The potential of the diagnostic for disease identification is demonstrated by the recognition of the reporter phage in P. cannabina from diseased specimens. The reporter phage

demonstrates the ability to rapidly and accurately identify cultured isolates and infected specimens at a diagnostic level **[28, 29]**.

The advancements of novel bioengineering tools are achieved by reevaluating the way in which we perceive and address the primary obstacles of the pharmaceutical generation. The next era of bioengineering tools is being shaped by a collective outline of numerous dynamic and progressively advancing ranges that are aimed at providing more precise cellular intuition, higher precision, faster observation, more specific delivery, and more accurate forecasts for pharmaceutical production. The continuous pursuit of accuracy, affectability, and selectivity is a common theme throughout these diverse ranges, as it brings us closer to the development of personalized bioengineering tools.

The76uspiporation 76uspidatec biology and system biology into the field of bioengineering

The requirement for comprehensive methods has been significantly increased in order to more fully understand the global framework of a metabolic scheme and to effectively implement the most recent bioengineering advancements. The fundamental principle of systems biology is to generate a unified multiform dataset of the functional biosynthetic pathways in microorganisms, animals, and plants **[3].** The rapid accumulation of biological statistics is now a common occurrence for a variety of elements, including genomic, proteomic, transcriptomics, metabolomics, and fluxomic. This is due to the current advancements in high-throughput sequencing.

Pharmaceutical bioengineering instruments

Numerous database packages and tools are technologically sophisticated in order to accomplish the numerous objectives of systems biology through modeling and simulation. The engineering strategies for biopharmaceuticals are being simplified through the continuous development of these instruments (Figure 2). Many tools and databases are included in the most recent update (2018). The database can be accessed and queried by the user by inputting relevant terms. These may be broadly described as follows.

Unified metabolic databases and networks

The metabolic data network records contain the essential evidence related to metabolic routes, bioreactions, and enzymes that are essential for the description of the physiological features and metabolic processes of an organism. BioSilico is a web-based record system that facilitates the analysis of metabolic pathways and exploration. The organized combination of heterogeneous metabolic data, such as ENZYME, EcoCyc, LIGAND, and MetaCyc, enables users to resourcefully retrieve the relevant evidence on biochemical compounds, enzymes, and reactions **[30]**. This procedure has been implemented in the metabolic system of the Arabidopsis thaliana plant by Radrich et al. [60]. Databases are extensively permitted to acquire a high-quality main consensus rebuilding by conducting a systematic assessment of compounds and their reactions between two genomes. The metabolic assemblage of cells is characterized by Genome-scale Metabolic Models

(GMMs) and BiGG Models, which are a valuable instrument for quantifying metabolic fluxes and simulating the organism's system through constriction-based mathematical approaches. The integration of omics information into structural data is precisely defined by GMMs, which enables the construction of supplementary precise evidence regarding metabolic positions **[31]**.

It is essential to have a user-friendly computer-based program in light of the significant application of metabolic change analysis in the context of metabolic bioengineering. It has the potential to offer investigators an abundance of assistance through the implementation of comprehensive computational methodologies. As a result, MetafluxNet has been developed as a framework, which provides a substantial biology systems stage for metabolic engineering and description **[32]**. Typically, three schemes are employed in bioengineering tools: whole plants, tissue culture cells, and plant genes in microorganisms **[3]**. Favorite proteins are synthesized in significant quantities through bioengineering to mitigate the numerous challenges of the bioindustry. Consequently, recombinant biopharmaceuticals are the most prevalent today **[33]**. The PITCh designer has the capability to autonomously generate the primers necessary to construct locus-specific donor vectors for PITCh knock-in, in addition to the appropriate micro homologies. A reporter cell line for monitoring endogenous gene expression and a transgenesis (TG) or knock-in/knockout (KIKO) cell line can be produced systematically using the newly established pipelines **[19]**.

Instruments for protein bioengineering

The objective of protein bioengineering tools was to modify the biofunction of proteins by modifying their sequence at the molecule level. Connections and base pair incisions are the most valuable applications of the protein system. However, the protein structure changes are induced by oxidation or an unalterable decrease in disulfides, and they are similarly measured. The technique's advancement that enabled the molecular fortitude of protein's three-dimensional assembly was one aspect that decisively impacted protein bioengineering. The X-ray crystallography tool is certain to have a supplementary prominence among these tools due to its high tenacity, which is limited to less than 1 Å. Additionally, cryo-electron microscopy and nuclear magnetic resonance (NMR) have increasingly emerged as alternative methods for resolving structures **[2]**. The tools employed to investigate protein complexes assembled in signaling cascades have been delineated by Dwane et al. **[34]**.

Metabolic bioengineering instruments

Metabolic bioengineering tools are essential for the recovery or enhancement of metabolites that are intricate in plant and microbial enhanced existence, as well as for the enhancement of their cellular and biological actions **[3]**. Metabolic bioengineering is the targeted and advantageous modification of the metabolic system within living cells through the use of recombinant DNA (rDNA) for enzymatic, transporter, and regulatory purposes. Metabolic bioengineering can be further developed by regulating or overexpressing specific genes. For instance, the overexpression of the gene geranylgeranyl transferase can enhance the production of tocopherol. Currently, the extant methods and devices for modifying

microorganisms are expanding, including advancements in the design of ribosome binding positions, genetic promoters, riboswitches, modular vector arrangements, reporter proteins, and without marker selection organizations. As a result of novel toolkits, microorganisms have been effectively bioengineered to express diverse heterologous pathways for the synthesis of an extensive variation of treasured bio-compounds. The potential for bioproduction has been significantly increased by in silico methods **[35]**.

Due to their capacity to absorb solar energy, both medicinal and non-medicinal plants are frequently employed as chemical biofactories. The rDNA bioengineering instrument is the foundation of the metabolic bioengineering of these plants, which results in the formation of a transgenic variety of plants. In the pharmaceutical industry, crop plants are employed to produce a variety of plant chemicals in large quantities **[3]**. At present, tissue culture instruments are frequently employed to acquire a vast quantity of phytoconstituents within a certain timeframe. Plant tissue environments can be maintained under control mode (for example, example elicitors and stress enhancement action) that the suitable gene displays might be articulated. The advanced stages of metabolites are produced and collected. In tissue culture cell lines, the metabolic outlines could be reformed by altering genes, which encode production enzymes or controlling features of the metabolic path of curiosity. Tissue culture can also deliver an exposed area for gene screening that could be additional supportive for the formation of a transgenic variety of plants regarding to specific feature **[36]**.

Generation of a transgenic variety of plants proceeds more development periods than the progress of microorganisms. Carotenoid in addition to isoprenoid biosynthetic paths are hereditably changed via bioengineering instruments. These bioengineering techniques can also be utilized for the functional identification of a transgene encrypting putative enzyme. In such instruments, the plant genomes can readily be cloned in an appropriate vector and thereafter transformed into the host microorganisms. There is an additional period required for the construction of transgenic plants in comparison to the cultivation of microorganisms. The current trend is that biotechnology's instruments are being drawn to the discovery of novel enzymes and genes to enhance the understanding of metabolite flux. Several recent non-traditional methods have been employed to amplify metabolic flux, identify genes through genome or transcriptome mining, concurrently outline the expression of numerous genes in plants, and elude flux through silencing and overexpression. The published literature on instruments for metabolic engineering of Streptomyces over the past decade has been summarized and discussed by Bekker et al. **[36]**. Precursor engineering, structural and regulatory gene engineering, gene upregulation or downregulation, genome shuffling, and the utilization of genome-scale metabolic models comprise these strategies **[3]**.

Upstream instruments for bioengineering

The primary focus of the development course is the utilization of bioengineering tools to revolutionize growth into the anticipated metabolic bioproducts **[2]**. This entails the utilization of industrial-scale bioreactor instruments in well-regulated environments. The bioengineering instruments should be employed to measure a

variety of features, such as the process nature (batch, continuous, feed batch, and transient immersion), pH, temperature, and oxygen supply regulator, material sterilization, and environmental maintenance, to ensure that the material is free of microorganisms. In contrast, the virus-like particle stage bioengineering tool is expected to reduce the administrative stack of individual immunizations by streamlining upstream forms and utilizing a nonspecific virus-like particle's base. This is due to the fact that the controls for the base and its filtration will be well-defined. Indeed, the stages of virus-like particles may expedite the delivery of vaccinations in response to prevalent circumstances **[37]**.

Tools for downstream bioengineering

The downstream bioengineering tools are a comprehensive set of phases that are necessary for the separation of bioproducts from growth culture mediums to the final purified bioproduct. It comprises a multitude of stages that are designed to retain the target biomolecules and eliminate host tissue-associated impurities (e.g., DNA, cell proteins), course-associated impurities (e.g., leached ligands, buffers, antifoam), and product-associated contamination (e.g., fragments, aggregates, clipped species, etc.). Typically, downstream bioengineering tools consisted of three primary phases: (i) preliminary recovery (removal or separation), (ii) distillation (elimination of impurities), and (iii) improving (elimination of specific impurities and undesirable types of the molecule that may have been designed during separation and purification).

The separation of supernatant and cell is included in preliminary repossession. The elucidated broth is subjected to absorption (such as ultrafiltration) following purification if the key molecule is produced extracellularly. It is possible that the concealed and solvable proteins in the growth medium of P. pastoris could be directly stored through centrifugation. The samples could be combined, and the significant protein could be separated from the supernatant through precipitation, ultrafiltration, and chromatography. The cells collected must be transferred to lysis (sonication, pressure to homogenize, passing over mills) after elucidation to eradicate cell debris for intracellular molecules **[2]**.

The prospective prognosis, challenges, and perspective of bioengineered instruments

The current state of bioengineering instruments is contingent upon the rapid advancement of molecular biology techniques and the proliferation of innovative methods for metabolic and genomic mapping. The integration of bioengineering with the recently emerging biosciences has presented a unique opportunity to address significant challenges in the fields of pharmacology, natural biology, and human well-being **[38]**. In order to secure the potential of advanced bioengineering and establish a sustainable foundation for green innovation, researchers and engineers must be proficient in the regulatory issues of science and innovation. In comparison to previous biosensors, entire cell biosensors provide a fundamental approach to the identification of excessive metals **[39]**. In the past decade, bioengineered bioelectronic instruments have gained widespread recognition. The antidromic discharge of pro-inflammatory neuropeptides may exacerbate the pathology of infection in rheumatoid joint pain as a result of the

persistent enactment of C-fibres **[40]**. An effective bioengineered crossbreed translation promoter is achieved by combining RegCG with CMV. This promoter exhibits a more significant effect in stable cell lines than when both promoters are used independently, leading to the use of other promoters **[41].**

The utilization of hereditary circuits in bioengineering devices has enabled a greater emphasis on yields and biomimetic responses to neurotic conditions. The energetic control of translation is facilitated by hereditary bioengineering apparatuses that are constructed by industrial scientists, which enable the precise regulation of quality expression in stem cells. These hereditary devices have been employed to coordinate stem cell separation in order to generate desired cell ancestries, to construct organoids, and to construct therapeutic cells that can detect and respond to the disease **[42]**. The CRISPR/Cas9 framework has the potential to be a useful bioengineering instrument for eliminating undesirable qualities in cells. The RNA-guided CRISPR/Cas9 framework has the potential to be a highly effective tool for genome modification in a variety of life forms and cell types **[43]**.

The recent expansion of quantum information, which has been facilitated by the abundance of evidence from the genome, transcriptome, and proteome of numerous crops, as well as numerous aromatic and medicinal plants, still necessitates significant effort to refine the tools for bioengineering that are more user-friendly. Nevertheless, the heterologous path's limited categorized portions, module's unsuitability, and cell acceptability toward product continue to present numerous obstacles to its integration into frame's cells for high-resolution production **[44]**. The bioengineered tools are 'ophisticated and advanced tools that are used in the pharmaceutical and other industries to obtain more authentic evidence for better diversities in horticulture, postharvest value, improved nutritional value, improved resistant variations, and high-value pharmaceutical compounds. In addition to cost-effective and efficient product, bioengineered instruments have generated numerous ethical, environmental, and socioeconomic issues. In the same way as in a small number of soybeans, the altered cases caused by Brazil's nut gene exhibit an anaphylactic response when fed to cattle. Consequently, a more rigorous examination is required.

The current agreement from the food development authority on the newest investigation and expansion of plant, animal, and microbe-based production systems using system and synthetic biology with molecular biotechnological approaches has well-established the perception of bioengineered tools for the formation of pharmaceuticals **[1]**. The cost of recombinant beneficial proteins remains high due to the manufacturing challenges associated with organism expression organizations and the regulatory burden associated with administering these pharmaceuticals to patients in a safe and effective manner. Additional effort is required to address the protection issues of genetically modified organisms and pharmaceutical production in order to mitigate the impact on the environment and health **[12]**. It is crucial to safeguard the intellectual property of all of these bioproducts by employing bioengineered instruments, as they are the result of distinctive genetic mutations. If we can demonstrate the effectiveness of the bioengineered instrument and procedure, living organisms could once again serve as a significant global source of pharmaceuticals, a status they have held for

centuries **[14]**. The primary challenges associated with nano bioengineered instruments have not yet been overcome, including the measurement of nano materials for the risk to health, their effects, observed exposure to nanomaterials, application methods, ecological hazards, manufacture cost, and user-friendliness in remote regions.

Conclusion

The bioengineered tools in the current review are heavily reliant on the rapid advancement of synthetic biology, system biology, and biotechnological molecular biology tools and techniques to the development of novel pharmaceutical outlining approaches. It concluded that the discovery, rational variation, production, and purification of significant biopharmaceuticals are constantly being expanded through the development of new instruments and technological advancements. The preliminary LCA models can also be a valuable tool for screening potential bioengineered alternatives. Bioengineering is a magical tool that can satisfy the global demand for bioproducts in the production of pharmaceutically and industrially valuable compounds.

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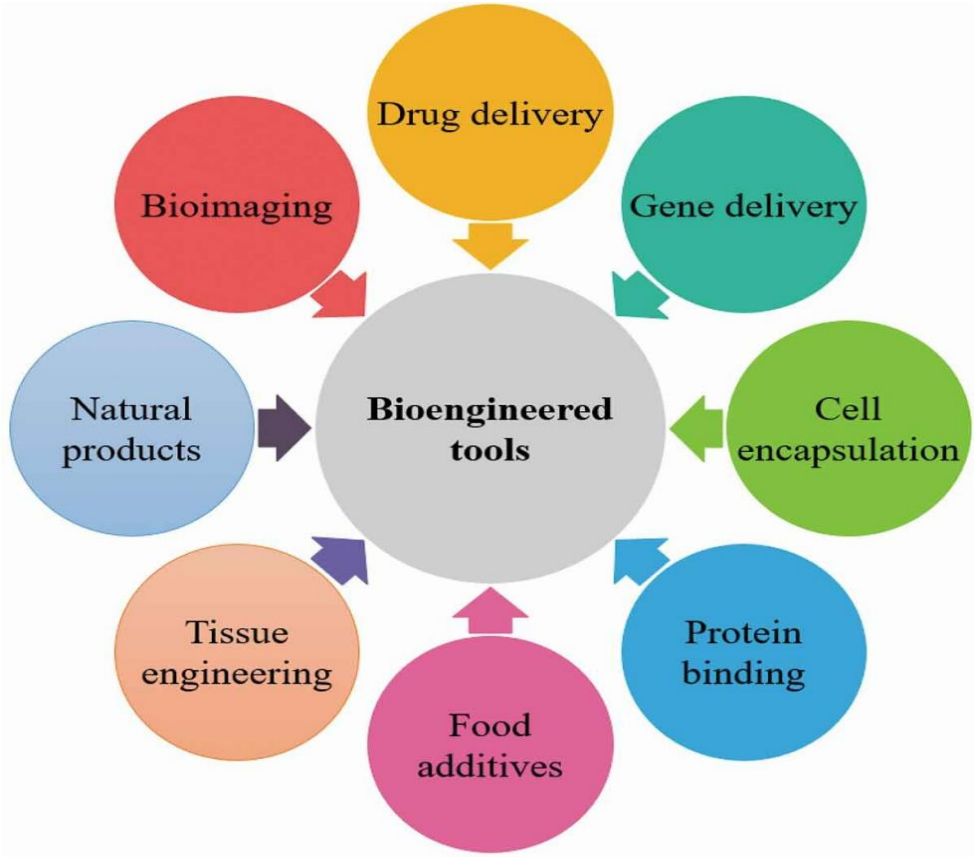

Figure 1. Bioengineered instruments employ a variety of methodologies to facilitate the development of pharmaceuticals.

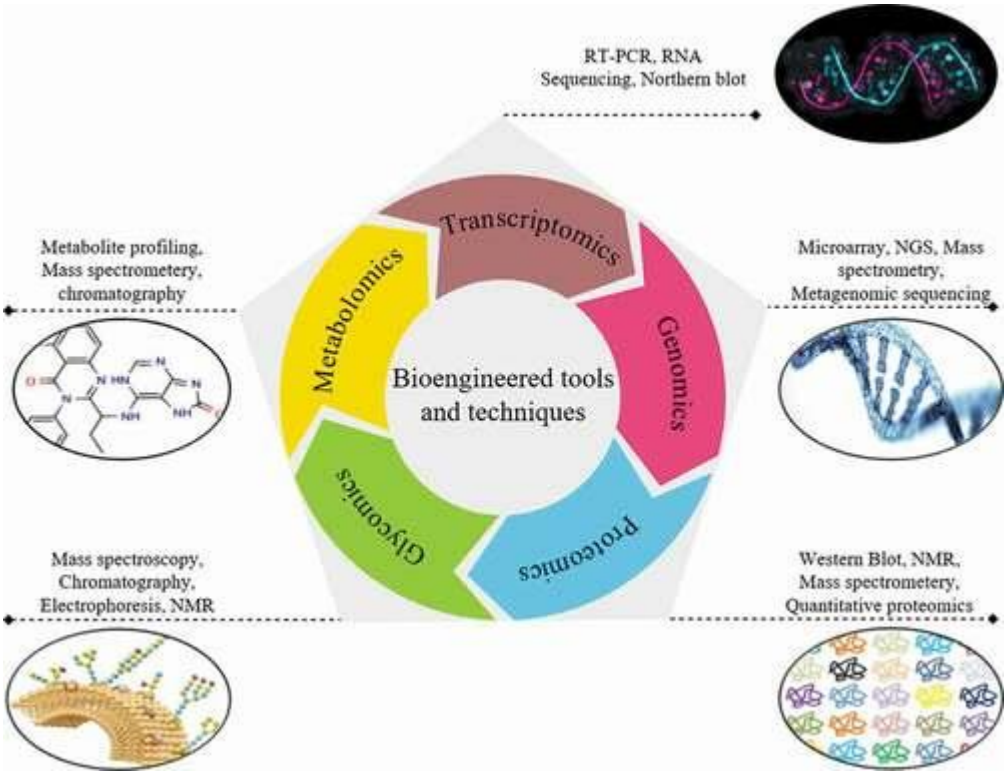

Figure 2. Bioengineered instruments and methodologies are currently available for the production of pharmaceuticals.