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The Next Era of Molecular Biotechnology: Beyond DNA

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Abstract

Molecular biotechnology has advanced much beyond conventional DNA manipulation, into a phase characterized by precision, integration, and invention. This article examines the evolving domain of next-generation biotechnological instruments, encompassing gene editing technologies like CRISPR-Cas systems, synthetic biology, and RNA-based medicines. It shows how these new technologies are changing medicine by making treatments more personalized, making farming more productive by using genetically modified crops, and making industrial processes more environmentally friendly through bioengineering. The article also talks about how molecular biotechnology, artificial intelligence, and nanotechnology are coming together to speed up discoveries and push the limits of what is biologically feasible. There is also talk about ethical issues, regulatory problems, and the effects on society, which all point to the need for responsible innovation. In the end, this new era of molecular biotechnology holds the prospect of revolutionary solutions to global problems while changing how we may build and regulate living systems.

Keywords: Molecular biotechnology, editing genes, synthetic biology, RNA medicines, bioengineering

INTRODUCTION

In the last sixty years, molecular biotechnology has made amazing progress that has completely changed how we comprehend the molecular basis of life and started the era of precision medicine [1]. Oswald Avery, MacCarty, and Colin MacLeod discovered DNA as genetic material in 1944. In 1953, Watson and Crick figured out that DNA has a double-helical structure. This led to other important discoveries such as the isolation of DNA polymerases (1958), hybridization techniques (1960), restriction enzymes (1970), Sanger sequencing (1977), the polymerase chain reaction (1983), real-time PCR (1992), and DNA microarrays (1996). The Human Genome Project, which released the first draft of the human genome sequence in 2001, changed the way biological research is done and made genomics a real science [2].

These important findings built on the basic dogma and made it possible to translate the genetic code into the amino acid sequences of proteins. These molecular biographies and groundbreaking structural investigations led to the development of the areas of protein engineering and enzymatic catalysis. In recent years, growing interest in synthetic biology and metabolic engineering has spurred initiatives to design and build genetic circuits and establish bioplastic biosynthetic pathways in microbial systems. But biotechnology still relies a lot on the DNA-focused methods of the past.

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BASIC PRINCIPLES OF MOLECULAR BIOTECHNOLOGY

After the DNA sequencer and polymerase chain reaction (PCR) were invented in the 1980s, biologists sequenced the first genomes and used their own genomes to build family trees in the 1990s. By the beginning of the 2000s, they had broadened the information paradigm to include other biopolymers such as proteins, peptides, and

metabolites. Engineers, on the other hand, choose a different way of thinking about things: life as a chemical event or as a regulated reaction on a molecular and meso-scale [3]. There are three parts to molecular biotechnology. To begin, scientists take information out of a certain medium and put it back in. Second, they figure out what information they need or want. Third, they provide the retrieved information in a synthetic way. Biotechnologists store information in DNA and RNA, extract a selected part through transcription and reverse transcription, and then put the information back in. This is like how engineers store written information in magnetic, optical, and electronic media and send it over the phone, radio, and the internet. They do enzymatic and mass-action tasks, and they store comprehensive information at the molecular level using biological parts. They work on genomic, transcriptomic, proteomic, and metabolomic levels, and they also record how biological systems behave. Molecular biotechnology facilitates the manipulation of messenger RNA (mRNA), transfer RNA (tRNA), ribosomal RNA (rRNA), long non-coding RNA, short non-coding RNA, DNA methylation, and protein changes. Different types of machinery can stop unwanted acts on single genes, groups of genes, and entire genomes. Transcriptional operons, translational operons, and inducer signals facilitate the transmission of regulatory information within populations of living microorganisms. Large databases of biological devices and standardized assembly techniques speed up building, sharing, copying, and moving things around in biotechnology [4].

BIOMOLECULES AND SYSTEMS THAT ARE NEW AND DIFFERENT FROM DNA

Recombinant DNA technology and organic chemistry gave rise to molecular biotechnology, which led to the enzymatic amplification of DNA in the 1970s. The sequencing of whole genomes has created a new problem: we cannot systematically study, build, and engineer the molecular biology knowledge that exists in all living things. Mechanistic knowledge has been built up around information-based regulatory processes of life. Engineering constructs have been used to study, design, and build organisms and systems using a predictable and strict design-build-test-learn cycle that is supported by a growing set of tools for genome editing and other technologies. RNA, a natural polymer linked to mRNA-based vaccinations, has garnered significant investments to investigate its catalytic capabilities across several fields, its classification as a third groundbreaking biomolecule alongside DNA and protein, and the development of RNA therapies as an emerging business [5].

RNA as a Therapeutic and Regulatory Agent

Ribonucleic acid (RNA) is a key biomolecule in genetics and across the tree of life [6]. People have known for a long time that RNA can do many things such as messenger RNA (mRNA), transfer RNA (tRNA), ribosomal RNA (rRNA), and regulatory RNA (like microRNA). As a result, it is very important for cell growth and function. Since the emergence of messenger RNA (mRNA) as a therapeutic agent for clinical application during the COVID-19 pandemic, various RNA-based formulations, including mRNA, antisense oligonucleotides, small-interfering RNA (siRNA), and RNA aptamers have attracted attention for development alongside delivery modalities. These methods are of substantial theoretical interest owing to the diverse synthesis capabilities and putative mechanistic foundations associated with the utilization of RNA as a medicinal agent.

Current methods for delivering RNA confront a lot of problems such as stability, off-target effects, toxicity, and immunological activation. These problems make it even more important to worry about delivering RNA and delivery carriers at the same time. Stability and off-target effects are very important in mRNA applications. RNA is less stable than DNA or protein, even when chemically modified nucleotides are utilized. When mRNAs trigger the production of target proteins, unmodified mRNA breaks down quickly. Numerous changes, including 5’-capping and the incorporation of 2’-O-methyl-modified bases, have demonstrated substantial enhancements in mRNA stability, while concurrently increasing target protein expression. Differential control of mRNA stability across different cell types has been documented. For instance, poly(A)-tail hydrolysis is regarded as a prevalent mechanism in the onset of degradation for cytoplasmic mRNA. Therapeutic techniques are likewise becoming more varied, including genome editing and even studies linked to metabolism.

Proteins, Peptides, and Engineering of Enzymes

Proteins are important for all biological activities, and scientists have made them so that they can make certain chemical reactions. Protein engineering uses a variety of methods to create biocatalysts with new or improved functionalities. Most engineering plans are based on a few basic design rules. By changing the active site of a biocatalyst, you can make it more efficient in catalyzing a given reaction. Directed evolution is still the most widely used method for protein engineering. It involves random mutagenesis followed by a step to choose the best functioning protein [7, 8].

Site-directed mutagenesis at the atomic level can also be utilized to improve how a single biocatalyst works. Computer-aided design software helps you add a new function to a biocatalyst and find one that can do a new sort of reaction. The enzyme-cascade strategy makes it possible to link two or more sequential conversions between different biocatalysts. The method is focused on making individual biocatalysts that can do each reaction among thermodynamically suitable reaction [9] in a selective and efficient way.

Epigenetic Modulators and Non-Coding RNAs

Non-protein-coding RNAs (ncRNAs) are made from DNA but do not turn into proteins. ncRNAs create a network of activities that run through the cell and control gene expression during the cell cycle. A lot of ncRNAs help process and control other RNAs like mRNA, tRNA, and rRNA. Processing-type ncRNAs comprise small nuclear RNAs (snRNAs) that facilitate splicing, small nucleolar RNAs (snoRNAs) that alter nucleotides, and RNase P that cleaves pre-tRNAs. MicroRNAs (miRNAs) and short interfering RNAs (siRNAs) control target mRNAs and chromatin, which is important for gene silencing and methylation. Long non-coding RNAs also play a role in controlling genes. RNA interference (RNAi) uses small double-stranded RNAs that stick to mRNA sequences, stopping processing and stopping gene expression. There is a connection between RNAi-based ncRNAs and some longer ncRNAs and epigenetic regulation [10].

Epigenetic processes are changes in the way genes are expressed that do not entail changing the DNA sequence. These changes can happen in DNA methylation, chromatin, histone configurations, and non-coding RNAs (ncRNAs). Non-coding RNAs (ncRNAs) are master regulators that affect the stability of messenger RNA (mRNA) and gene expression. More than 160 RNA-modifying mechanisms, including pseudouridine, N6-methyladenosine, and 5-methylcytosine, affect how RNA works and how it breaks down. To research RNA modifications, you need to know how they change the structure of RNA or how proteins that bind to RNA recognize these changes. This affects stability, translation, and splicing. “Readers” (RNA-binding proteins), “writers” (methyltransferases), and “erasers” (demethylases) are all involved in RNA methylation. m6A is a well-known alteration. Demethylases, such as FTO and ALKBH5, remove methyl groups from RNA [11]. Different types of ncRNAs, such as tRNAs, miRNAs, lncRNAs, circRNAs, and rRNAs, have important roles in regulating cancer, diagnosing it, and treating it. Contemporary study concentrates on the epigenetic ramifications of RNA alterations, the mechanisms involved in cancer pathogenesis, and the advancement of epigenetic pharmaceuticals aimed at ncRNA modifications.

TECHNOLOGIES THAT WILL SHAPE THE FUTURE

Molecular biotechnology includes a growing number of technologies and methods that make it possible to precisely change and describe biomolecules and cellular systems. The ability to put proteins together from their basic building parts is a common technological principle for several of these methods. Increasingly, engineering systems are being combined with biology to make living systems that can predictably fix themselves, allowing for management of their abilities and guiding their performance evolution.

DNA is an incredibly flexible molecule that can store information on a scale that has never been seen before. Molecules originating from DNA have been repurposed not only for information storage but also to send cellular instructions that exceed the cell division capacity of their original organism. To

speed up development in molecular biotechnology, we need to go beyond DNA and understand how existing cellular systems grow, divide, repair, and work. Then we need to create modular systems that can be added to both cellular and acellular contexts. Ongoing experimentation with biomolecular assembly processes, environmental conditions, and application settings produces extensive data sets that inform rigorous analysis, synthesis principles, and predictive models, aligning conceptual frameworks and explanatory strategies with engineering disciplines.

Molecular biotechnology is expanding its scope beyond RNA and proteins to include wholly novel and non-canonical materials that enhance functional capabilities. The complex nature of bacteria-compatible organo-silica hybrids has been utilized to create several synthetic devices that can do bioimaging with different textures and separate multi-color resolution. Developing complementary non-biomolecular building blocks into a third dimension, in addition to established two-dimensional parallel assembly processes, increases the diversity and combinatorial flexibility. This means that second-generation RNA sequences can be developed when combined with an orthogonal and a second parallel RNA-based device.

RNA-encoded therapeutics aimed at the nuclear genome in mammalian cells face delivery issues, as exemplified by the fact that over half of the human transcriptome consists of non-coding RNA. Non-coding RNA regulatory devices and epigenetic modification have emerged as novel therapeutic approaches, underpinned by comprehensive peer-reviewed biological characterization that endorses their advancement in synthetic biology. Non-coding RNA can also be included as entities with intricate mechanistic and kinetic characterization accumulated over decades of comprehensive research. These investigations endorse cell-free systems as conducive environments for the construction and synthesis of extensive and intricate synthetic operons, surpassing the capabilities of conventional microbial chassis.

Editing the Genome and Medicine That Works Perfectly

Genome editing technologies are now the focus of research and development. They are quickly advancing from proof-of-concept to clinical demonstration and early marketing. Projection studies often designate them as the most disruptive technology for the forthcoming decade inside the biological sciences. Recent advancements in precision medicine – targeted therapy strategies customized for individuals or subpopulations – emanate from the same basic foundation. Using either class would greatly enhance our understanding of these topics. But safety, biosecurity, and bioethics are still the most important things [12].

Editing is broadly described as the targeted altering of genome sequence, an intervention that is more successful than the correction of defective genes. Regulatory genomic features are hit less often than sequence-encoding open reading frames, which means that changes are found less often than expected during screening. Because direct corrections or additional modifications are still possible, restricted substrate transfer is another reason not to do it. There are four types of current genome editing that deal with differences in safety, efficiency, and precision among candidate systems [13].

RNA Therapeutics and Delivery Mechanisms

Even though there have been big advances in DNA vaccines and genome-editing technologies, it has been hard to turn messenger RNA (mRNA) into medicines that work in the clinic. mRNA is a type of RNA that carries information from protein-coding genes. It has regulatory roles at both the transcriptional and translational levels. Biopharma businesses and researchers are actively investigating the potential of mRNA molecules as next-generation therapeutics.

There are now five main types of RNA therapeutics: (1) full-length mRNA; (2) modified mRNA; (3) non-coding RNA (ncRNA), which includes small interfering RNA (siRNA), microRNA (miRNA), and antisense oligonucleotide (ASO); (4) RNA-protein that forms ribonucleoprotein (RNP) complexes (aptamer); and (5) RNA modified and complexed (RNA conjugate). The medicinal applications of these

RNA classes are comprehensively delineated. RNA treatments have been approved by several regulatory bodies throughout the world, however RNA-mediated therapy still has problems with delivery, stability, and effects that are not intended.

Exogenous RNA still has trouble getting over biological barriers in situations that do not include cells. Because RNA is not stable, therapeutic RNA products are legally considered dangerous biological materials and need additional safety measures and tracking systems [14].

Metabolic Engineering and Synthetic Biology

The growth of synthetic biology has had a big impact on metabolic engineering, and the two fields are now very connected. Synthetic biology gives metabolic engineers more advanced parts and more information about how basic biological processes work. Metabolic engineering uses what we know about synthetic biology to improve the biological production of molecules we want. Both fields rely on a variety of DNA-modification techniques to add or remove genes, change pathways, and change metabolic flux. For example, Biobricks, recombinase technologies, Gibson Assembly, and CRISPR–Cas9 allow for targeted changes that direct the production of specific compounds and reduce interference from native regulatory systems. Still, there are a lot of problems to solve. For example, certain common methods do not work well for certain types of changes, their efficiency is typically confined to certain host organisms, and shuttle vectors are not always useful. The selection of the chassis organism is particularly crucial; the generation of hazardous intermediates and feedback regulation in overexpressed pathways can significantly reduce yield, and the availability of appropriate host species is frequently limited [15].

The design-build-test-learn cycle, which comes from engineering fields and is used by synthetic biology professionals, has become a key idea for metabolic engineers. The design process needs a good framework, the right chassis, and a techno-economic analysis, which looks at the costs of raw materials, energy needs, and how much value the product brings. These are all important things that are sometimes overlooked [16].

Omics and Systems Biology for Single Cells

The description and engineering of organisms are based on high-resolution mapping of molecular states and interactions. Bulk analyses that average signals from many cells miss important differences that are needed to understand biological systems and design them in a way that is predictable. Single-cell and spatial omics enhance capacities at the molecular, protein, metabolite, and cellular state levels, yielding insights that are increasingly essential for predictive biological modelling [17].

Single-cell RNA sequencing (scRNA-seq) offers a comprehensive perspective on cellular states at the transcriptome level and continues to be the most prevalent method. Its incorporation with proteomics, genetic disruption, and metabolic analysis enhances comprehension of cell type and disease transition pathways. Spatially resolved single-cell RNA sequencing, along with transcriptome and protein harmony integration, keeps spatial information while making it easier to compare different types of data. Spatially resolved multi-omics methodologies establish direct connections between transcriptome, epigenome, and proteome data and their native tissue localization. Additional innovations encompass high-throughput integrative spatial proteomics, which enables the simultaneous detection of target proteins in hundreds of individual cells derived from complete tissues. Complementary single-cell multimodal assays that can test up to five modalities at once considerably speed up research on finding new cell types, regulatory circuits, lineage tracing, and understanding how cells behave in complicated ways.

APPLICATIONS IN DIFFERENT FIELDS

Molecular biotechnology has a lot of potential to improve human health, food security, and the environment. By using the remarkable properties and functions of biomolecules, DNA-based techniques have already influenced precision diagnostics, targeted therapeutic treatments, crop

resilience, biofortification, sustainable nutrient source, and bioremediation. The first chapter of this academic work summarized significant historical milestones, fundamental concepts, and essential technologies of molecular biotechnology; positioned engineering principles as central to discipline; and delineated the primary methodologies, model systems, and data types that support the field. Burnett and Collins [1] recently put forward a conceptual framework made up of four interrelated parts: biology, engineering, mathematics, and computer science, all backed up by experimental data. This framework shows how engineering can work with biology and biosystems through mathematical modelling, machine learning, and computational principles, while also adding to established ideas like design-build-test-learn cycles. Bradshaw et al. (2023) give an example of the cycle with a project that uses DNA to make very nutritious foods that do not come from plants.

Since the beginning of the DNA era, new biomolecules and systems have come into being. Molecular biotechnology now includes a much larger range of molecules and information processes than just the molecules of inheritance. However, the same basic ideas still guide the design, building, testing, and improvement of systems that work at the three levels of regulatory networks, metabolic pathways, and signal transduction. The focus has transitioned from DNA to RNA, proteins, peptides, and non-coding RNA – encompassing both endogenous active and exogenous informational types – alongside epigenetic modulators that affect gene expression without modifying the DNA sequence. The central role of RNA is evident in the increasing utilization of messenger RNA (mRNA) vaccines in both human and veterinary medicine, driven by the rapid global production of plasmid DNA templates through advanced synthesis and amplification technologies, which are estimated to be nearly ten thousand times the size of the global market for de novo DNA synthesis [18].

Health Care and Medicine

The need for adaptable and diverse molecular tools has grown because people want to find diseases early, treat them accurately, and stop them from happening in the first place. The aptamer platform can answer this need by solving the problem of delivering different types of treatments throughout the body. It is also seen as a promising biological tool for diagnosing and treating diseases. Aptamers are tiny oligonucleotides or polypeptides that can attach to a lot of different molecules with a lot of specificity and affinity. It usually proceeds through the systematic evolution of ligands by exponential enrichment (SELEX), which is the in vitro selection method that finds the best candidates from a huge library of compounds. Several aptamers that can bind to proteins, viruses, ions, organic dyes, drugs, and cellular targets have been successfully created. To broaden their target range and make them more stable in serum, different chemical changes have been made to them [19].

Farming and Food Safety

Production in agriculture is on a path to stagnation while demand for goods continues to climb. This need is being driven by population increase and the fact that at least 1.5 billion more individuals are predicted to be borne by 2050. Coupled with this growth are challenges presented by climate change, soil salinity, water scarcity, non-native pest introductions, and urbanization. Molecular biotechnology techniques are essential in addressing risks to sustainable food production by enhancing the resilience of high-demand crops and augmenting the nutritional value of staple foods. Rapid breakthroughs in genome and whole-genome sequencing and related technologies are helping us learn more about plant genomes, find new genes, understand genomic diversity, and change crops to get the qualities we want for the benefit of agriculture [20, 21]. Using biotechnological tools and methods has made it possible to keep crop yields high without having to open a lot of new farmlands.

To fulfil the needs of the world's expected population in 2050, the Food and Agriculture Organization says that the productivity of food goods will need to go up by around 50%. However, a lot of progress has already been made toward reaching this aim. Biotechnological methods that help crops grow better and increase their desirable qualities can help make sure that everyone has enough food. Rice, wheat, maize, sorghum, finger millet, and foxtail millet are some of the most regularly eaten food crops that are being actively researched by biotechnologists to improve their yields. In the Asian divisional sphere,

these crops are a top priority. In the African divisional sphere, potatoes, cassava, and sweet potatoes are the most important staple foods.

Farms that focus on optimizing processes in real time by constantly monitoring data points are being created by merging precision agriculture, modern record-keeping methods, and artificial intelligence. Cell cultures and genetically modified plants are moving disease-resistant characteristics from one type of plant to another. This range extension, which is already prevalent among microbes, is speeding up the process of improving crops. Other important areas of welfare improvement include finding new pathogens before they show up (like making crops that are resistant to them), ways to stop insects from eating crops, ways to slow down climate change (like traits that help plants survive on less soil moisture), and ways to make food more nutritious (like avoiding phenylalanine and other things that affect gluten maintenance and gluten-transcending cereal promotion).

Biotechnology for the Environment and Industry

Climate change poses an unprecedented danger to the stability of the natural world, with natural disasters becoming more often and undermining agricultural productivity and ecosystems. Overusing fertilizers and pesticides affects bacteria on land and in water and makes greenhouse gases worse. Making things also uses a lot of non-renewable feedstocks, energy, and water, which leads to a lot of waste. These pressing issues necessitate a profound reevaluation of production methods.

Industrial biotechnology takes a broad view of bioprocess design, with the goal of creating bioproducts that do not pollute water, using energy that eventually restores the ecosystems that support supply and production, and getting all the necessary parts from within the circular economy [22]. Using renewable biofeedstocks to make equipment and materials is a new trend in biomanufacturing [23]. The shift to a circular economy keeps a wide variety of biocatalysts and microbiomes intact without harming the biome itself. Biotechnology [24] can change all feedstocks and co-products in a way that is good for the environment.

Biomanufacturing and Eco-Friendly Processes

To use molecular biotechnology on a large scale, we need biomanufacturing technologies that are both cost-effective and environmentally friendly. Optimizing the stages for manufacturing and recovery increases the yield and purity of the target biomolecules, which makes the economics of the downstream process better [25]. Process development usually balances several different parameters, such as throughput, efficiency, and total process time, by making models of possible setups that use existing unit designs [26]. Pilot plants check for scalability, validate models, test conditions, and create facilities from scratch for certain goods.

Life-cycle assessment measures the environmental impact of each stage of a process, taking into consideration things like feedstocks, additives, energy, and waste. This information helps people choose fewer invasive options.

LEGAL, MORAL, AND SOCIAL EFFECTS

Technologies that directly modify or control genomes keep getting better, and new ways to turn genetic information into medicines are also being developed. Genome editing with CRISPR-based techniques and the multiplexed control of transcription and translation are making it possible to build genomes and synthetic circuits on a massive scale. Engineered systems are being developed to diagnose diseases and provide treatments in ways that can be controlled and managed. Technologies that make novel biological agents available are coming together with these capacities to make therapeutic pools that work on multiple targets. These come from biomolecules like RNA, protein, peptide, and epigenetic or chemical modifiers. They go beyond nucleic acids and meet bigger needs. New activities make current assets even more useful for therapy. CRISPR-based genome editors change how genes are expressed by programming them; transcription factors set the target expression; and other agents work on chromatin and covalent changes. Convolutional architectures can now directly predict RNA

structures and protein folds from sequence, giving us new information on how to develop drugs at a level of detail never seen before. Synthetic biology methods make it possible to combine these assets into functional whole-cell therapies that can fight both infectious diseases and difficult environmental problems [27, 28].

Responsible Innovation, Safety, and Biosecurity

Biotechnology and synthetic biology are still at the cutting edge of technological progress, creating new ways to solve important problems in society. But the same technology could potentially have unforeseen effects that are dangerous to people in the area or even around the world. So, responsible governance of biotechnology must create a clear and fair framework for biotechnology risks by putting strong governance systems in place at both the national and international levels [29]. Sharing governance models across many industry sectors can function as benchmarks, offering compliance directives for donations, transfers, and requests for raw commodities and living creatures. For the full and methodical growth of synthetic biotechnologies [30], risk governance, oversight, and secure application must all work together with technical procedures.

Fairness, Access, and Global Health

The COVID-19 pandemic is an example of a global health crisis that shows how health dangers can cross boundaries. In today's interconnected world, it is clear that getting rid of global inequalities is necessary to achieve health equity at the national, community, and individual levels. Addressing gaps also affects how well we can deal with new threats and ongoing problems like poverty, hunger, the environment, and climate change in the future. There are several ways that biotechnology and equity are connected, including creating and managing knowledge and technology in ways that make them more accessible, useful, and affordable [31].

Life sciences research – especially understanding the genetic, molecular, and cellular foundation of health and longevity – is crucial for enhancing health, however it frequently concentrates on high-income nations. There are also health disparities in high-income areas, among marginalized, isolated, rural, and indigenous groups, and in many other low- and middle-income countries with large populations [32]. To turn these problems into opportunities, it is important to find ways for scientists, decision-makers, and communities to come up with and evaluate alternatives to current technologies that are more suited to their needs.

Recent breakthroughs in technology, including micro- and nanodevices, diagnostics, laboratory analysis, telemedicine, biological synthesis, simulation, and modelling, are happening very quickly. To avoid greater divides from growing, it is very important to collect and share knowledge with people who need it most and help them adapt and use it correctly in different situations [33].

Problems and Restrictions

Molecular biotechnology is drawing more attention and investment from a wide range of fields since it has a lot of potential for making money. The ongoing COVID-19 pandemic has made its potential in health care, farming, and protecting the environment even clearer. However, there are still a lot of technical problems that need to be solved such as reproducibility, scalability, regulatory and public policy landscapes, and data governance. Canada and the European Union have already begun to investigate some of these problems 1; [34].

Technical Challenges and Scalability

Molecular biotechnology uses the information stored in nucleic acids to create biomolecules, cells, and animals with specific functionalities. DNA is the main input medium, although other biomolecules, especially RNA, help with advanced post-transcriptional control and can be used as drugs. Plasmid DNA makes it possible to move parts that control the making of both upstream (RNAs, proteins) and downstream (small molecules, bioproducts) products. Biodiscovery seeks to utilize the great diversity of biology to inform selection and design processes. Biotechnology does not consistently function

through cycles of design, construction, and testing of structures and behaviors. Instead, it can use forward design methodologies that use what is typically called “homologous” or “meta” analysis, where several sequences are compared to a candidate input/output pair.

The modern field of biotechnology focuses on substantial gene clusters for the genomic reengineering of vital microbial chassis. To make RNA writing and protein-based synthesis possible, genome synthesis and genome-scale DNA assembly are needed at the assembly end. These kinds of endeavors cannot be modular and cannot use the same methods for gene or pathway synthesis. To start the next age, we need new approaches and solutions that let engineered lifeforms share information across plasma membranes. Presently, 13C- and heavy-water tracer methodologies yield 135 intracellular flux ratios, of which [32] are subject to active regulation. Genome-scale metabolic models assist take advantage of these limits to improve strains. They also aid with feedback-resolution simulations for untargeted strains using “dead-end” and “co-impact” methodologies [35, 36].

Price, Rules, and Public Support

Biotechnology is changing the way people make chemicals, cells, and organisms very quickly. The sector has entered a new phase because of the huge growth of technologies and applications. It is now focusing on molecular biotechnology. The sector has become more complicated since there are more goals, systems, organisms, and ways to distribute them. New macromolecules besides DNA are gradually becoming the new building blocks of molecular biotechnology. This opens new possibilities and problems that have never been seen before. Innovations and progress being made in the area beyond DNA are important for the future generation of biomanufacturing, medicines, and diagnostics. These extra systems need different technology and early investments than DNA systems need. So, the field is in its second infancy, where all sectors need to be able to scale up their capabilities at a cheaper cost, and where, with a few exceptions, it is still not possible to use the new biomolecules or molecular biotechnology in large amounts. Each of these new principles has its own development and instructional framework, and you do not need a lot of science or technical knowledge to use them.

The combination of DNA and RNA makes it easy for live cells to send and use genetic information. DNA and RNA-based systems can also change how proteins work, but they cannot be used to directly edit proteins or undertake high-throughput tests of how proteins work. Consequently, the formulation of a synergistic engineering methodology and molecules is essential to integrate the operations of the established domains of nucleic acid and protein biology. Proteins are more varied than nucleic acids and are important parts of living systems. This means that cells do not need to make new protein molecules all the time. Moreover, building protein systems with intricate regulatory mechanisms and specialized predictive capabilities regarding proteins can still be executed within numerous established model organisms and cell-free systems. So, protein modality is still very important for people who do cutting-edge molecular biotechnology, therapeutic biotechnology, metabolic or chemical biotechnology, and cellular biology [37].

Integrity and Reproducibility of Data

Synthetic biology, genome editing, and RNA therapies are examples of molecular biotechnologies that could have a big impact on health, food, energy, materials, and the environment all around the world. Reproducibility is a big problem that slows down development in the life sciences. Historical data indicate that roughly 11% of seminal cancer studies and 59% of various life science findings are replicable. Surveys show that 77% of biologists have trouble repeating published results. This is a big problem for science as a whole. This issue is made worse by the fact that modern research are more complicated, that people are relying more on big data sets and software, and that there are more collaborations, all of which make it harder to understand published work. Because molecular biotechnology is the focus of a lot of research and money, it is important to use the right organizational structures to make sure that results can be replicated and that benefits to society can be realized quickly [38].

Following standards, giving specifics for each part, and using the same words can all make it easier to reproduce. To make research data more open, it should be stored in places that are easy to find. This will allow for secondary analyses, which will help explain the importance of discoveries that are kept private. The origin of data is important for follow-up and meta-analyses, especially when utilized in models and simulations. This is why data sets should always come with an indicated provenance.

FUTURE PATHS AND GOALS

New biomolecules make it possible to deal with important global problems by using new life principles to control, grow, and program living systems. RNA and other protein systems manage biological processes that go beyond changing the DNA to control cell fate, get rid of poisons and viruses, or kill cancer cells. Epigenetic, non-coding RNA, and chromatin-modifying strategies seek to direct biological systems toward specific states, including enhanced development, resilience to biotic and abiotic stress, or reduced metabolic requirement [39]. We may now focus on infections, ageing, and other random problems instead of only genetic data. The development of biological alternatives to chemical processes, biomanufacturing, and metabolic modulation have made it possible to directly create fungus, algae, and plants. Biological capacities must begin to emphasize the integration of biology with engineering, physical sciences, and socio-economic concepts. Emerging technologies must not only provide more precise data regarding individual systems but also enable high-throughput analysis of numerous samples and components to enhance current detailed understandings of biology by acquiring comprehensive knowledge and thoroughly characterizing emergent behaviors such as oscillations, silico ecology involving large microbial consortia, reconstruction and visualization, polyphasic analyses, combinatorial drug library observation and modelling, gene-drive liberation, and multi-parametric antibody engineering.

Platforms That Work Together and Technologies That Come Together

Key discoveries in molecular biology, such as finding DNA as genetic material, developing hybridization procedures, and creating recombinant DNA technology, have helped integrative platforms and convergent technologies grow. The discovery of the DNA double helix, the isolation of DNA polymerases, and the first DNA sequencing methods are all important occurrences. PCR and other methods changed the way DNA is amplified and diagnosed, making it possible to quickly find diseases and analyze genes. The Human Genome Project produced the first draft of the human genome, which led to the establishment of molecular and genomic laboratory medicine. Professional groups, like the Association for Molecular Pathology, have organized this subject, which has led to new ideas and ways of combining diagnostics and biological research.

Long-Term Prospects for Research and Policy

Changes in Governance, Funding Models, and Strategic Priorities

Research strategy must be adaptable to accommodate the dynamic advancements in biotechnology capabilities, applications, and societal challenges. The Federal Government has committed to promoting biotechnology by establishing a dynamic Bioeconomy Initiative that will last until 2040. This initiative will help shape a national vision and long-term mission-oriented funding for research and biotechnology issues that affect everyone, such as safety, biosecurity, equity, and how the public views biotechnology.

Investments are in line with the changing National Artificial Intelligence Strategy, which aims to meet long-term goals in biotechnology including chemical synthetic biology and bio-sustainability. This shows that the company is thinking ahead about biotechnology [1]. Future unification should make it easier to join a cooperative Bioeconomy Initiative.

CONCLUSION

Since the beginning of life, people have used protein-based tools for food, health, and energy. Even though DNA-centric biotechnology has been successful in creating smart proteins from first-generation cells and organisms and RNA-guided genome editing from second-generation cells and organisms, DNA is still limiting and undervalued. New and revived biological molecules and systems that are the base of life can greatly increase the range of biotechnology.

Gene activators, repressors, editors, and programmable regulators all use new RNA forms and changes. Non-coding RNAs (ncRNAs), CRISPR, RNAi, and epigenetic technologies exhibit enhanced potential for the next generation of cells, organism, and living-factory biotechnology. Proteins, peptides, and enzymes, including functional therapeutic antibodies utilizing sophisticated peptide or minimum protein systems, remain essential targets. Next-generation guide RNA (gRNA) engineering, multiple gRNA design, target identification, and RNA combinatorial search make it easier to work with genomes and other biopolymers. Software that works with generic sequencers finds first-generation tools. More work leads to second-generation "ready-to-use" repairs. Improvements in sequencing that do not require cycles or amplifications have opened many new areas that have not been studied much yet. De novo linkage-building chemistry, which is very similar to protein sequence-based nucleic-acid-approach synthesis, provides a steadily easier way to acquire clones of sense-and-respond ("programmable-type") materials.

It is time to start using the wide range of molecular parts that are available to make important, condition-dependent IDR agents and emerging desirable system blueprints. These parts include complete genomes, plasmids, DNA or RNA devices, genes and their circuits, and lysis techniques. Many service providers, editing companies, databases, institute founders, and well-known plastic bio- and nano-wrappers speed up the first voyage by giving people free access or a small fee.

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