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PROSPECTS FOR THE DEVELOPMENT OF INNOVATIVE NANO- AND BIOTECHNOLOGIES

Abstract
Nano- and biotechnologies are the key elements of the complex of NBIC-technologies, developed within the concept of continuous growth of innovations in the context of the transition to the sixth technological mode. The purpose of the article is to study the prospects for the development of nano- and biotechnologies in various sectors of the economy, as well as explore opportunities for accelerating the commercialization of research results in these areas. The article's relevance is confirmed by the strengthening of the role of nano- and biotechnologies in the sphere of innovation development of countries worldwide. The results of the study have shown that the nanotechnology market has a divergent structure, and the basic characteristic of nanoproducts is their interdisciplinary nature. The world leaders in the production and commercialization of nanotechnologies are the United States, China, Japan, Germany and South Korea. Biotechnologies are developing rapidly as well. Worldwide, the largest number of biotechnologies is created in areas such as health care (biomedicine and biopharmaceuticals), industry and agriculture. The leading countries in the field of development and commercialization of biotechnologies are the United States, France, Germany and South Korea.

Key words
biotechnologies, nanotechnologies, innovations, economy

Introduction

Most countries are now implementing the concept of continuous innovation development as part of the transition to the sixth technological mode. This statement is confirmed both by the large number of publications that consider issues concerning the development of complex NBIC-technologies and the continuous increase in the expenses to develop and assimilate new technologies. Erasing the boundaries between innovative technologies in different sectors of the economy forms a new unique phenomenon — complex nano- and biotechnologies as a tool for improving the population's quality of life. Thus, the relevance of the topic of this article is determined by the strengthening of the role of nano- and biotechnologies in the innovation development of countries worldwide. Issues concerning the development and introduction of nano- and biotechnologies are considered in works by authors such as M. De Wild, S. Berner, H. Suzuki et al. [1], K. E. Drexler [2], R. N. Kostoff, I. A. Stump, D. Jonson [3], U. Roos [4], P. Vettiger and G. Cross, M. Despont et al. [5].

The purpose of this article is to study the prospects for the development of nano- and biotechnologies in different sectors of the economy, as well as the opportunities to accelerate their commercialization. The development of nano- and biotechnologies can be characterized as being explosive, encompassing many branches of the economy. As L. Melnyk [6], Ponomarenko et. al.[7] and others have noted, almost all significant innovative inventions in the field of nano- and biotechnologies have been created over the past 15-20 years.

The term "nanotechnology" was first proposed in 1974 by Japanese professor Norio Taniguchi of Tokyo University in his report "On the Basic Concepts of Nanotechnology" given at the International Conference on Precision Engineering in Tokyo [8]. The term was used to denote the large set of knowledge, approaches, techniques, specific procedures and materialized results of nanoparticles. Let's consider in more detail the main types of nanoproducts and priority areas of their use now and in the future. Taniguchi [9] gave the following classification of nanoproducts:

- primary products: nanoobjects, nanosystems and ultrapure substances created using nanotechnologies, including basic raw materials and semi-finished products for the nanoindustry, in particular nanopowders and nanomaterials;
- products that contain nanoproducts (goods), nanotechnological components (nanoobjects, nanosystems, and ultrapure substances), including those produced using primary nanotechnological products;
- nanotechnological works and services, works and services provided by applying nanotechnologies or technologies for using primary nanotechnological and/or nano- containing products.

Expert analysis of the nanoproduct market [9] predicts a promising future for products manufactured using nanotechnology starting from 2015 and which belong to the fourth generation, the main feature of which is the use of heterogeneous molecular nanostructures (each complex molecule is a special nanostructure with a peculiar architecture and high functionality).

The basic trends in the development of nanotechnology and nanoproducts of the fourth generation include the following:
1. Developing atomic and molecular engineering based on still unknown laws of self-organization of matter.
2. Designing macromolecules with given properties.
3. Creating nanosized mechanical devices.
4. Ensuring a directed and multilevel self-organization of atomic structures with quantum mechanical control of assembly processes.
5. Creating nanodevices for medical supervision and treatment.
6. Ensuring direct human-computer interaction, implying contact between human nerve endings and electronic networks, etc.

The interdisciplinary nature of the latest generation of nanoproducts is confirmed by the wide range of possibilities for their application in various branches of the economy. For example, new high-strength construction materials based on nanotubes (fullerene, nanofibers), as the main carrier component or filler in composite materials can use nanoparticles to strengthen automobile tires, polymers, paint coatings, glass and concrete. Nanoparticles can be used to help lubricate components and as additives to oils to carry out work under extreme conditions and increase the functional characteristics of rubbing parts of mechanisms. Hydrogen fuel tanks are adapted to create chemical cells, in particular lithium batteries. Contrast agents are widely used for magnetic resonance imaging based on paramagnetic atoms located in the fullerene-based scaffold, since they are less toxic than the commonly used chelate complexes and permit obtaining more clear images.

Although the US, China, Japan, Germany, and Korea remain the world leaders, Ukraine has relative experience in nanotechnology development and implementation. According to the data [10], Ukraine occupies 36th place in the world ranking by the number of publications indexed in the Scopus database in the field of "Nanoscience and Nanotechnology" during 1996-2014 (Table 1).

Table 1. Ranking of various countries by the number of publications indexed in the Scopus DB in the field of "Nanoscience and Nanotechnology", 1996-2014

Rank	Country	Publications	Citable publications	Citations	Self-Citations	Citations per publication	Hirsch index (H)
1	USA	67227	66236	2 077860	768154	39.03	405
2	China	49009	48560	853015	481098	26.98	239
3	Japan	21558	21378	426211	117370	22.6	192
4	Germany	20800	20560	497244	111477	28.68	221
5	Republic of Korea	19306	19158	321226	78223	24.23	178
6	France	13314	13169	243083	53670	21.87	155
7	UK	13101	12848	331524	59921	29.85	203
8	India	11458	11303	141484	40710	20.39	119
9	Taiwan	9533	9444	143996	31617	20.1	122
10	Italy	8555	8435	149249	33933	22.01	129
11	Spain	7392	7310	139582	29868	25.77	125
13	Russia	6646	6601	54186	14393	11.07	84

17	Netherlands	4829	4775	148042	19681	37.91	152
18	Sweden	3594	3554	84848	13756	30.22	117
19	Belgium	3460	3428	68064	10547	23.21	98
24	Poland	2368	2327	25334	5796	12.78	58
25	Austria	2124	2105	52402	7275	31.36	81
26	Denmark	1775	1750	39335	6090	31.06	83
29	Greece	1656	1622	25385	5001	18.21	67
36	Ukraine	1195	1187	12219	2301	12.24	47

Source: [10]

The presented data suggest that the number of publications in different areas of development of nanotechnologies will continue to grow among the leading countries and worldwide. If the trend continues, Ukraine's role in the world of nanotechnology will remain insignificant. China and the USA will occupy leading positions, with China being significantly ahead of the rest of the world.

Today, the world's largest industry that involves biotechnologies, according to the number of research projects, is healthcare, particularly, biomedicine and biopharmaceuticals. Production processes is the second largest industry that applies biotechnologies in terms of the number of research and development, and third — agriculture.

The United States is the leader in terms of absolute expenditure both on biotechnology research and development in the business sector with US companies spending nearly USD 39 billion on research in biotechnologies in 2014. The other top countries in terms of this indicator include France, Switzerland, South Korea and Germany. The USA is 5th place in terms of expenses on biotechnology for business enterprise expenses of research and development (BERD), behind Switzerland, Denmark, Ireland, and Estonia. Slovakia, which occupies the lowest position in terms of absolute expenditure, outperforms South Korea, Germany, Japan, Canada, Russia, Austria, Australia, Finland, South Africa and Mexico.

Particular attention should be paid to consideration of the expenses on biotechnology research and development of public companies in leading European countries. According to the ranking of the leading European countries in terms of R&D expense by public biotech companies, the largest investment in biotechnology research is done by public companies in the UK. Germany occupies 8th place, so it is clear that a large part of biotechnology research in this country is conducted on the basis of private companies, which places Germany, along with Britain at the top of the list of the most developed European countries in the field of biotechnology.

It should be noted that the size of government support for research in specific fields of biotechnologies depends on the chosen bioeconomic strategy adopted by the government of a particular country. The United States, Germany, and Japan have developed detailed strategies to accelerate the processes connected with the use of biomass and other innovative biotechnologies. Other countries, such as Canada and Italy, operate more pragmatically and, through their strategic documents, are trying to strengthen the existing private sector and public-funded research. A more detailed analysis of strategic documents of countries in terms of their place in the system of government support for the development of biotechnologies is presented in Section 4.1. Today, the issue of satisfying mankind's ever-increasing needs in the presence of limited resources is particularly acute. One of the tools to handle this difficult task is biotechnologies, which can fundamentally change the overall approach to production of goods and services, as well as the interaction between man and environment based on using the potential of living organisms.

Today, the United States is the undisputed flagship in the field of biotechnology. According to experts from Ernst & Young, the total market value of the US biotechnology sector is over USD 889 billion, with total annual revenues amounting to USD 107.7 billion [11]. The sector provides jobs for almost 132,000 people. The statistics refer to public companies only since information about private companies is generally kept confidential.

Moreover, in terms of revenue, the ranking of the 10 largest biotechnology and pharmaceutical companies in the world include five US companies: Johnson & Johnson, Pfizer, Merck, Abbott Laboratories, and Amgen, which combined receive 51% of the total revenues of the top ten such companies.

The prospects of the biotechnology sector are evidenced by the salaries of biotech researchers in the United States. In 2015, the average annual salary of a biotechnologist in the country was USD 82,150 and the average hourly earnings for work by such a specialist was USD 24 [12, 13]. To-date, the average annual wage in the USA is USD 46,120 [14] and therefore the annual remuneration for the work of specialists in biotechnologies is almost twice the country's average annual income. The average salary of a starting investigator in the field of biotechnology is currently about USD 75,000; specialists with work experience from 5 to 10 years can count on an annual salary of approximately USD 82,000; if a person has great experience in biotechnology (10-20 years), his/her salary per year is about USD 91,000; biotechnology experts with more than 20 years of experience in the industry receive an average salary of USD 96,000.

When examining the structure of revenues and employment in the EU's bioeconomy, it should be noted that currently the greatest productivity of labor is observed in the areas of application of biotechnologies that are only now being formed — those concerning biofuels and bioelectricity. However, agriculture, the industry that is the second largest in terms of the number of employees has the lowest productivity, which suggests that using biotechnologies does not necessarily imply a significant increase in revenue, since this industry is an initial element in the value-added chain.

An analytical review of the biotechnology sector in the United States and Europe shows that the key player in the international biotech market is the United States, in terms of all major monetary and quantitative indicators. Biotechnology R&D expense in the United States is more than five times higher than similar public expense in European countries. The net income of public companies in the biotechnology sector in the United States is 15 times higher than in Europe, and the number of such companies in the United States is almost twice the number of biotech companies as in Europe. Moreover, the bio-based economy of the United States engages almost twice as many specialists as the biotechnology sector in Europe (Table 2).

Table 2. Comparative characteristics of the biotechnology sector in the USA and Europe

Information about public companies in billions of US dollars	**USA**	**Europe**
Revenue	107.7	25
R&D expense	33.9	6.2
Net income	15.6	1
Market capitalization	889.3	182.2
Number of employees	131690	72160
Number of public companies	436	234

Source: [11]

Aside from the United States and European countries, four countries — Canada, Australia, India, China, and Japan — have taken a prominent place in the arena of global biotechnology.

Above all, Canada's success in biotechnology development is due to the system approach of public authorities to support all the industry's driving forces. This involves developing strategic documents (such as "2020 Biodiversity Goals and Targets for Canada"), raising public awareness to understand the need for introducing biotechnologies, and providing support to specialists in biotechnologies, including the promotion of immigration of experts in the industry within the BioTalent Canada project.

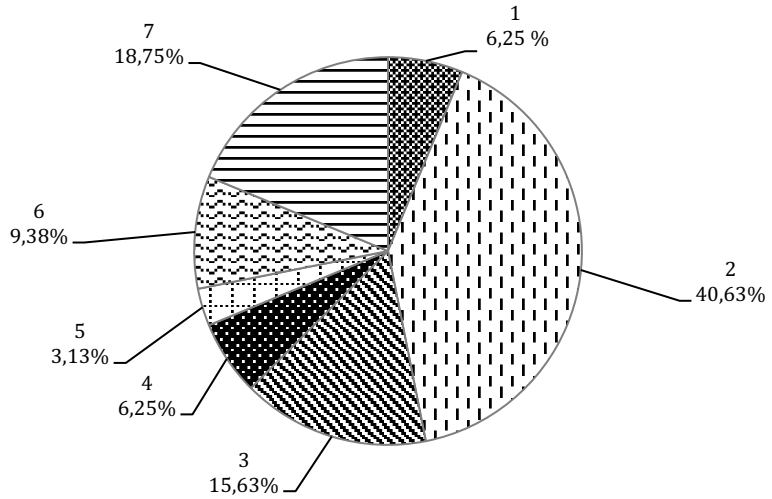
The above-mentioned project is a national information platform, designed to promote the development of highly professional labor resources in the country's bioeconomy. BioTalent Canada regularly conducts research on the labor market, identifies "bottlenecks" and develops recommendations that would positively affect the balance between the supply and demand of human resources in the field of biotechnology. For example, as of 2013, 33.2% of Canadian biotech companies pointed out that their employees lacked necessary practical skills and considered it to be one of the most serious challenges for their country's bio-based economy in the 3-5 years that followed. Therefore, one of the most important factors in the development of Canada's bio-based economy is labor resources, which is why the state and companies are actively investing in the training of professionals in the field of life sciences.

Australia also follows a similar policy concerning the development of a bio-based economy. In the sphere of legislation, the Biotechnology Ministerial Council adopted a document called the "National Biotechnology Strategy of Australia" and the Australian Department of State Development, Trade and Innovation created a strategy aimed at supporting and developing competencies of specialists in the field of lawmaking, project management and scientific and technical activities in the fields of bioinformatics and biostatistics. Similar to the BioTalent Canada information platform, in Australia the Bio-Link Education Center successfully operates a platform aimed to help with obtaining education in biotechnology (including from abroad), as well as assists in the recruitment of specialists. Moreover, this organization collaborates with biotech companies from Australia and abroad to commercialize achievements in biotechnology. Furthermore, Australia has borrowed the experience of the United Kingdom in the creation of innovative clusters in the field of biotechnology. For almost 30 years an organization called "AusBiotec" has been functioning in the country, uniting more than 3,000 scientists.

Particular attention should be paid to the special tax regime for innovative biotech companies in Australia: a reduced income tax rate (10%) has been introduced, which in turn stimulates the modernization of the industry and facilitates the commercialization of its achievements. Biopharmaceutical companies are provided a possibility of compensation of up to 43.5% of the total amount of R&D expenses. Due to this, clinical trials in Australia are 60% cheaper than in the United States. Moreover, in 2016 the Australian government allocated USD 250 million to promote the commercialization of biotechnology in the country [15].

The result of Australia's system approach to the implementation of a biotechnology strategy is the transformation of Australia into a global center that brings together leading researchers, companies, investors and partners into a holistic biotechnological ecosystem. Presently, Australia is among the top five countries in terms of biotechnology, with Australia's GDP share of biotechnology being the largest in the world [16].

Prospects for the development of nano- and biotechnology in Ukraine depend on their commercialization and support mechanism. The analysis of 32 projects from Ukraine, which was implemented by The 7th Framework Programme for the "Biotechnology" and "Biofuel" directions, shows such results (Figure 1).



1 - food biotechnology; 2 - biomedicine; 3 - industrial biotechnology; 4 - agricultural biotechnology; 5 - environmental biotechnology; 6 - biofuels; 7 - complex biotechnology.

Figure 1. Distribution of biotechnology and biofuels projects with Ukraine's participation in the 7th Framework Programme [17]

Most Ukrainian biotechnology projects are related to biomedicine technologies: research of cancer, bubonic plague, HIV cell membrane antigen splitting and others. Noteworthy integrated biotechnology development projects are: INCOMAT (study of surfaces and coatings of new biomaterials), PERCERAMICS (development of the innovative type of ceramics for the production of bone bioimplants), OPTIMISC (biotechnology for bioenergy). Due to Ukraine's participation in The 7th Framework Programme, important problems of the development of national biotechnologies are being solved, however, all projects are implemented under co-financing. From this perspective, the development of an effective national mechanism for state support for the development of

biotechnology is gaining importance and relevance. In the authors' view, the mechanism should include the concept of biotechnology development, legislative and regulatory support and specific tooling. The concept of nano- and biotechnology development should be based on the principles of biotechnology development with priorities established for state support and development methods. In the field of the legislative and regulatory support it is necessary to amend a number of laws governing the development of science and technology, that is, to create new methods and regulatory acts to regulate the development of biotechnology.

The specific tooling includes program-targeted financing instruments, the development of technology parks and technology clusters, and establishing tax and financial instruments. The broad analysis of the world's experience in the field of nano- and biotechnology makes it possible to draw the following conclusions:
1) the undisputed leader in the industry is the United States, which has managed not only to develop all types and sub-sectors of biotechnologies known today, but has successfully commercialized them;
2) the biotechnology sector is identified as one of the most promising innovative directions of development of EU countries. Within the EU there are 3 conditional clusters that differ in types of biotechnologies in accordance with their economic, geographical and historical features;
3) the pathway of all countries that have achieved remarkable success in the bioindustry is based on a systems approach and start precisely with the development of strategic documents identifying the top priority sub-sectors of biotechnologies most fitting for the particular country and optimal methods to ensure their development and improvement;
4) establishing a mechanism for effective interaction between academia and business as well as clustering and merging research centers in order to accelerate the development of innovation are the key factors that contribute to the commercialization of results of biotechnological research;
5) based on the experience of BioTalent Canada and the Australian Bio-Link information platforms, it is possible to conclude that one of the most important investments in the development of the bioindustry is the comprehensive support and training of specialists in the field of biotechnology.

Summary and conclusions

The rapid development of nano- and biotechnologies worldwide is supported by a steady increase of R&D funding which accounts for a significant share of the total amount of R&D expenses in developed countries. Both developed and developing countries have their own specific concepts and strategies for the development of nano- and biotechnologies, which specify the priority areas to receive government support for innovative research. Presently, the undisputed leaders in the practical implementation and commercialization of nano- and biotechnologies are the United States, Switzerland, and the United Kingdom, which is confirmed by their having the highest total revenues of companies in this sector. In light of the analysis of the current expanding state of the global market and current financial incentive possibilities available for Ukraine, the authors highly suggest full governmental support of the introduction of biotechnologies in the Ukrainian economy. The need is for immediate support and stimulation specifically of the development of biotechnologies in the fields of medicine and pharmacy, which will create jobs and ensure the existing social procurement and development of the country's pharmaceutical industry. Moreover, taking into account Ukraine's energy dependence and the availability of its own technologies, the development of biotechnologies in the field of biofuels is recognized as being highly promising for the country. The article complements citations [1–9] by clarifying the promising areas for the development of nano- and biotechnologies based on an analysis of the scientific activity of the inventors. A new contribution is the proposed components of the mechanism of co-commercialization of innovative biotechnologies for Ukraine, which can be marketed in other countries.

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