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Benchmarking Study of the Global and Ukrainian Trends in Nanotechnologies' Scientific Research for the Future NBIC-Society

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Authors' contributions

This work was carried out in collaboration between all authors. All authors together designed the study and wrote the protocol. All authors read and approved the final manuscript.

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ABSTRACT

Aims: In the conditions of advanced countries industrial markets' competition escalation the issue of creating new economy on the basis of nanotechnologies as Nano-bio-info and cogno(NBIC)-technologies is becoming more and more important. As all developed countries, Ukraine conducts fundamental and applied research in the field of nanotechnologies, and the research priorities to be agreed with solving both global and specific national problems in view of building-up a modern NBIC-civilization.

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The main purpose of the research is to analyze the modern perspectives and to perform benchmarking study of the Global and Ukrainian trends in nanotechnologies development as part of NBIC-technologies' scientific domain to identify priority areas of scientific and technical policy of Ukraine.
Study Design: The reviews were carried out in the period 2010–14 on the basis of studying the world countries nanotechnologies development trends as well as on the basis of the research results obtained by Ukrainian academic institutions.
Place and Duration of Study: Scientific Research Center for Industrial Development Problems of the National Academy of Science of Ukraine, Department of Foreign Economic Relations and Touristic Business of V.N. Karazin Kharkiv National University conducted the research between January 2014 and December 2015.
Methodology: Content analysis and bibliographic retrieval have been used as the main methods of research, which allowed making a meaningful analysis of classic papers and researches of modern economists-practitioners devoted to the peculiarities of the Global and Ukrainian trends in NBIC-civilization emergence. Models of time series, including also trend analysis, were used for forecasting. Computations were performed in Application Software Package "Statistica 8".
Results: The article demonstrates main practical results of various economic sectors development achieved through implementing comprehensive scientific-technical programs to develop nanotechnologies during 2010–2014 in Ukraine. Benchmarking analysis of the researchers' publishing activity in the field of nanotechnology in the leading world countries and in Ukraine has shown that in general, the dynamics of research in Ukraine correspond to the global trends, but is much slower. Development of nanomaterials, nanobiotechnology and nanoelectronics are the main fields of nanoscience research. Nanomedicine & nanobiology are specific features of Ukrainian research field that allows us to consider those areas to have competitive advantages of nanotechnology development in Ukraine. At the same time a very small number of publications in the field of nano-electronics and nano-energy engineering testifies of a substantial lagging behind the main global trends. The low level of patenting in nanotechnology development in Ukraine satates the need, on the one hand, to stimulate applied research, and on the other hand, to improve procedures for obtaining intellectual property rights protection.
Conclusion: The priorities of Ukrainian nanotrechnology studies, as part of NBIC-technologies' scientific domain, need to be clarified in accordance with the global problems to be solved by any country and in accordance with the existing potential and possibilities of nanotechnology research as regards the emergence of NBIC-society. In order not to lose the existing potential in the field of nanoelectronics and nano-energy engineering the government should support the local development, especially at the stage of basic research. Institutional support to the interaction of science and business is required at the stage of applied research. Consequently, to revitalize high-tech engineering, the developments in the field of nanoelectronics should become a priority for the government support. Lack of international patents in Ukraine speaks of the need to ensure more active cooperation between Ukrainian, European and international patent organizations, particlualry under the Patent Cooperation Treaty.

Keywords: Benchmarking study; nanotechnologies; NBIC-society; comparative analysis; content and patent analysis; global and Ukrainian trends.

1. INTRODUCTION

NBIC-technologies convergence is the foundation to create 21st century "break-through" innovative technologies that provide for considerable development of social sphere to reach a qualitatively new level of life. Scientific research in that sphere concerns development of nanotechnologies, which in future are called to replace the existing technological platforms based on industrial technologies. Revolution in NBIC-technologies sphere as well as global challenges and crises also contribute to modifying traditional innovation policies and strategies of the industrially developed countries.

Ukraine, as all developed countries, also conducts basic and applied research in the field of nanotechnologies, agreeing its research priorities with the global and specific national problems to be solved by any country.

The named problem was tackled by many renown scientists, including also M. Roco, W.

Bainbridge, B. Tonn, G. Whitesides [1,2], R. Campano [3]; R. Silberglitt, P. S. Anton, D. R. Howell [4]; R. Voyer, N. Makhija [5]; L. Stenberg, H. Nagano [6], who studied the issues of knowledge, technologies and society convergence; many renown organizations, for example European Commission [7]; European Parliament [8]; Organization for Economic Co-operation and Development [9]; National Intelligence Council [10] and also Russian scientists A. Kazantsev, V. Kisilev, D. Rubvalter, O. Rudenskiy [11], together with Ukrainian scientists M. Kyzym, I. Matyushenko, I. Shostak, Yu. Moiseienko, V. Khaustova, O Khanova, et al. [12-23] dealt with the development and prospects of NBIC-civilization.

At the same time the growing implementation of NBIC-technologies into developed countries economies requires review of the prospects for their use in Ukrainian nanotechnologies development.

The main purpose of the research is to analyze the modern perspectives and to perform benchmarking study of the Global and Ukrainian trends in nanotechnologies development as part of NBIC-technologies' scientific domain to identify priority areas of scientific and technical policy of Ukraine for the future NBIC-society.

2. METHODOLOGY

Content analysis and bibliographic retrieval have been used as the main methods of research, which allowed making a meaningful analysis of classic papers and works of modern economists-practitioners devoted to the Global and Ukrainian trends in nanotechnologies' scientific research as NBIC-civilization emerges.

General scientific methods make up a methodological foundation of the research. They include: description, comparison, statistics review, system analysis and others, which help characterize this phenomenon development in a more comprehensive way. We also apply the methods of dialectic cognition, structural analysis and logic principles that provide for making authentic conclusions as regards the investigated topic.

Official statistical data of the state institutions and international organizations, publications of reference character, analytical monographs, annual statistical bulletins, Ukrainian National Academy of Science reports as well as annual Ukrainian State Statistical Bureau reports serve as the information grounds for our research.

Abstract database resources "Science Direct", "SCImago Journal & Country Rank" and "Ukrainika Naukova" (Ucrainica Scientific) made up the information database for publishing activities. The level of the nanotechnologies R&D patenting was monitored by the data from Intellectual Property Organization, State Intellectual Property Service of Ukraine, specialized database "Inventions (Utility Models) in Ukraine".

Models of time series, including also trend analysis, were used for forecasting. There were used linear, exponential, polynomial and logistic function of time variable. The regression was built by the OLS method. To justify the functions there were used the coefficient of determination (R^2), MAPE, F-statistic for liner models and t-statistic for model parameters significance. Computations were performed in Application Software Package "Statistica 8".

3. RESULTS AND DISCUSSION

3.1 Review of the Practical Achievements in Developing Nano-technologies when Implementing National Academy of Science of Ukraine's (NASU) State Target Programs (STP) during 2010-2014

As of today exactly nanotechnologies become a bridging element between different revolutionary technologies that have emerged in the recent 20-30 years: *computer* revolution of the 20th century latest three decades; *biotechnological* revolution of the 20th century latest decade; and tremendous progress of the *cognitive* science at the beginning of the 21st century.

Ukraine, as all world developed countries, has been also implementing fundamental and applied research in the sphere of nanotechnologies by the following directions: medicine (to include also venerology), biology, agriculture, ecology, energy, industry, space exploration, cybernetics, electronics, etc. [12-17,22,23]. At the same time it is important to specify *priorities* of the carried research against the global challenges to be met by any country with the account of the national specifics, as well as with regard to the available potential and capabilities to perform Nano-technological research.

To continue topical fundamental and applied research of nanotechnologies, NASU had developed *A concept of Target Comprehensive Program for Fundamental Research "Fundamental problems of Nano-structural systems, nanomaterials, nanotechnologies" for the period 2010-2014,* approved by the NASU Presidium Resolution #129 of 05.05.2010 [24; 25]. The programme consisted of 4 sections: "Physics and Nano-size systems' diagnostics", "Chemistry of nanomaterials and nanostructures", "Nanomaterials' technologies", "Bio-Nano-systems" [25].

Appendix A presents the most significant results of the named program accomplishment during 2010-2014 [26-30].

In 2009 the State scientific and technical program "Nanotechnology and nanomaterials" for 2010-2014 was approved by the CMU Resolution #1231 of 28.10.09 [31]. The following results were achieved: nanotechnologies, nanobiotechnologies and research-industrial technologies were developed; nanomaterials, instrumentation, parts types were manufactured; bioelements, nanophotocatalysts were created; certification centers and their subnits were set; nanotechnologies were practically implemented. The program also stipulated setting of basic scientific chairs by the profles: "Nanophysics", "Nanoelectronics", "NanobioMedicine", "Nanomaterials science" in all the state universities [32].

According to the program, 2010 witnessed a competition of scientific and technical projects, where 315 projects participated. Due to the fact that the allocated funds to implement the program were insufficient, only 120 projects were accepted for funding (in 2011 no funding was allocated at all). Research teams of 40 NASU institutions participated in the program implementation.

The most significant results of the Target Comprehensive Program *"State scientific and technical program "Nanotechnology and nanomaterials"* for the period 2012-2014 are presented in Appendix B [28-30].

For Ukraine it is important to create a system for long-term forecasting and strategic planning of scientific and technological innovation and development until 2030. However, above all, there is a need to evaluate nanotechnology research & development status, to identify nanotechnologies commercialization potential and its impact on economic development to solve urgent national problems.

State targeted programs should become a basis for strategic planning of scientific and technological development as well as for innovation activities to ensure effective use of allocated funds. The projects of varying significance: national, regional, local should become the ground for the state programs.

The combination of program-oriented and project-oriented approach will ensure emergence of practical implementation programs in each priority areas of science, technology and innovation.

3.2 Comparative Analysis of Global and Ukrainian Trends in Nanotechnologies' Scientific Research

The level of development in the field of nanotechnology research is today a "calling card" of the success of the implementation of science and technology policies of any developed country, which claims a place among the global technology leaders. Publishing activities review in the field of nanoscience and nanotechnologies [34] proves that the USA, China, Japan, Germany and Korea are the leading countries in that sphere. Those countries' total share in all the publications during 1996 – 2014 was 54.1%. EU countries' share was 28.1%, and Ukraine had only 0.3%. At the same time 11 EU countries had even lower indicators in comparison with Ukraine. China has started to lead the list in the recent two years, while the USA has started to lag behind in the recent 3 years.

Table 1 and Fig. 1 show dynamics of the number of publications in the leading world countries. It demonstrates that globally and in separate world countries the number of publications did not decrease except Japan, where the number of publications has been lower than in 2012. It proves the availability of constant interest to the R&D work and inventions in that sphere. At the same time there were some structural changes.

Table 1. The number of publications in the sphere of "Nanoscience and nanotechnologies" globally and in the leading world countries during 1996-2014

County	Year																		
	1996	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
WORLD	3299	3575	4259	3959	4527	5549	5465	6720	8173	9569	11331	15533	18487	19839	22589	26495	27685	29439	32042
China	132	184	164	213	288	340	358	654	717	1074	1740	2425	3355	3713	4575	5450	6333	7977	9317
USA	1018	866	1254	1147	1274	1396	1522	1893	2289	2834	3239	4202	4936	5245	6173	6647	6875	7024	7393
Germany	413	468	511	446	544	652	723	644	856	810	970	1317	1454	1466	1711	1861	1918	1940	2096
Japan	446	470	499	486	617	838	669	903	1021	1073	1216	1418	1476	1671	1633	1774	1826	1741	1781

Composed by: [33]

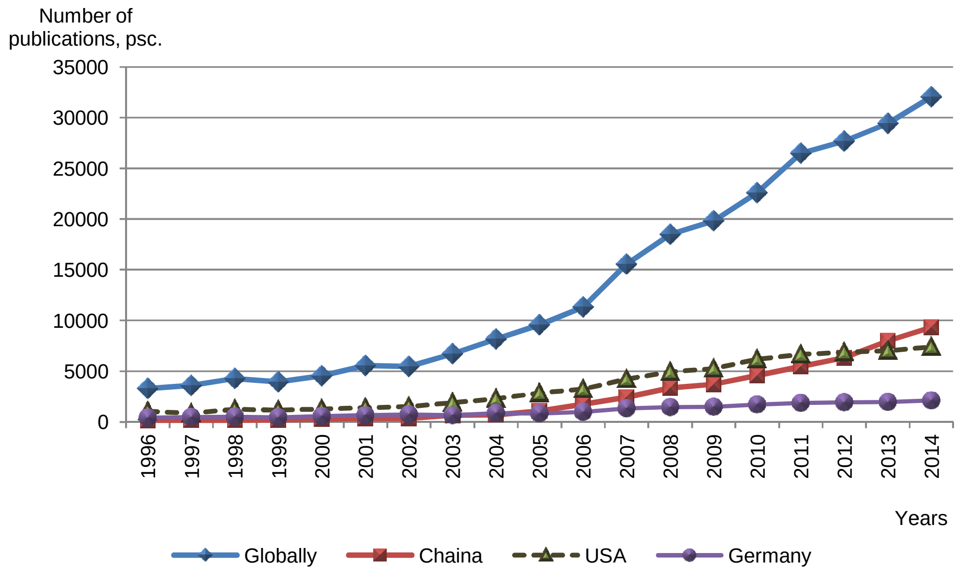

Fig. 1. Dynamics of the number of publications in the sphere of "Nanoscience and nanotechnologies" globally and in the leading world countries during 1996-2014
Composed by: [33]

The dynamics review shows the global exponential increase in the number of new publications that could be described by the model:

$$Y\ (t) = 2478.2 \cdot e^{0,1415t},\ R^2 = 0.98, \qquad (1)$$

where y – publications number, t – time variable, t=1 corresponds to 1996; R^2 – the coefficient of determination for the model. Statistic criteria for the best models are in Annex C.

But beginning from 2011 the forecast by the built model had been overstated, i.e., the publications growth rate had started to slow down. First of all, it could be attributed to the decrease in the US publications number. During the whole studied period the number of new publications in the USA could be adequately described by the exponential model:

$$Y_{USA}\ (t) = 727.87 \cdot e^{0.1328t},\ R^2 = 0.97, \qquad (2)$$

But when comparing with the earlier presented Fig.1 we can see a systemic error beginning from 2008. A more detailed analysis by time periods shows that during 1996–2002 the number of publications in the USA followed the linear law:

$$Y_{USA}\ (t) = 92.571t + 840.71,\ R^2 = 0.8. \qquad (3)$$

Similarly, the growth rate during the latest 6 years was also linear. It gives grounds for using logistic function:

$$Y_{USA}(t) = \frac{409.864}{0.043228 + e^{-0.23982t}},\ R^2 = 0.986. \qquad (4)$$

So, the USA have already accumulated sufficient theoretic and experimental backlog that helps concentrate on nanotechnologies commercial utilization. It's worth pointing out that the publishing activities growth rate decrease in the USA could partially be attributed to the confidentiality level increase due to the inventions probable use for military purposes.

Global number of publications could better be described by the logistic curve:

$$Y_{world}(t) = \frac{1572.09}{0.033213 + e^{-0.21857t}},\ R^2 = 0.99. \qquad (5)$$

China is a leader in the publications' growth rate increase in the sphere of nanoscience and nanotechnologies:

$$Y_{China}\ (t) = 183.993 \cdot e^{0.20871t},\ R^2 = 0.98, \qquad (6)$$

i.e., the increment rate is 0.208. Thanks to that China has overtaken the USA in the recent two years. And the China publications growth rate has not been noticed to slow down.

Republic of Korea had demonstrated the same growth rate during 1996-2011:

$$Y_{Korea}\ (t) = 71.76 \cdot e^{0,2141t},\ R^2 = 0.98, \qquad (7)$$

But beginning from 2012 the slowing down was noticed, and for Korea it is now more appropriate to use the logistic curve:

$$Y_{Korea}(t) = \frac{49.184}{0.010532 + e^{-0.27132t}},\ R^2 = 0.99. \qquad (8)$$

Germany demonstrates much lower publishing activities growth rate increase:

$$Y_{Germany}\ (t) = 373.171 \cdot e^{0.095t},\ R^2 = 0.97, \qquad (9)$$

Likewise Japan demonstrates lower publishing activities during 1996-2012:

$$Y_{Japan}\ (t) = 496.379 \cdot e^{0.075t},\ R^2 = 0.96, \qquad (10)$$

Or as the linear law for the whole period demonstrates:

$$Y_{Japan}\ (t) = 89.926t + 235.37,\ R^2 = 0.96. \qquad (11)$$

With regard to the decrease in the number of publications during the latest two years it is more expedient to use for Japan the following logistic model:

$$Y_{Japan}(t) = \frac{332.838}{0.15707 + e^{-0.20116t}},\ R^2 = 0.97. \qquad (12)$$

Therefore, the global interest to nanotechnologies remains to be rather high, but further developments are more focused on their commercial utilization.

Dynamics of publications in Ukraine and in neighboring countries (Russia and Poland) is not as straightforward as the Table 2 and Fig.2 show. Russia is a leader among CIS countries and in Central-Eastern Europe. It ranks the 13th in the countries' rating [34]. Poland's lagging behind Russia is 2.8 times and it holds the 24th place being a leader among countries that recently have joined EU. Ukraine is lagging behind Poland 2 times and holds the 36th place being ahead of Czech Republic and other new EU members.

Russia demonstrates the fastest growth rate of the new publications among three countries during 2002-2014 and could be described by the following trend:

$$Y_{Russia}\,(t) = 116.63{\cdot}e^{0.1561t},\ R^2 = 0.87. \qquad (13)$$

The growth rate is somewhat higher than averagely in the world, but the dynamics is extremely non-uniform. Two waves of fast growth before and after 1999 default were replaced by more stable, but less dynamic growth. Therefore, it's more expedient to use the following logistic curve:

$$Y_{Russia}(t) = \frac{14.8761}{0.017837 + e^{-0.30757t}},\ R^2 = 0.87. \quad (14)$$

The number of publications in the sphere of nanotechnologies in Poland is also variable, but it has a stable trend for growing. At the same time new publications growth rate is much lower as the given lower trend shows:

$$Y_{Poland}\,(t) = 31.876{\cdot}e^{0.1159t},\ R^2 = 0.92, \qquad (15)$$

And it has also decreased in the latest three years.

Among the studied countries Ukraine has the least number of publications and generally slow growth rate:

$$Y_{Ukraine}\,(t) = 26.706{\cdot}e^{0.075t},\ R^2 = 0.71. \qquad (16)$$

Table 2. The number of new publications in the sphere of "nanoscience and nanotechnologies" in Ukraine and in neighboring countries during 1996-2014

Country	Year																		
	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Russia	75	158	264	135	259	391	106	199	217	151	190	341	467	508	577	571	712	627	698
Ukraine	13	40	52	49	42	49	38	47	51	61	56	55	88	57	76	72	110	106	133
Poland	37	58	34	40	64	65	57	68	131	82	112	158	184	155	168	191	247	255	262

Composed by: [33]

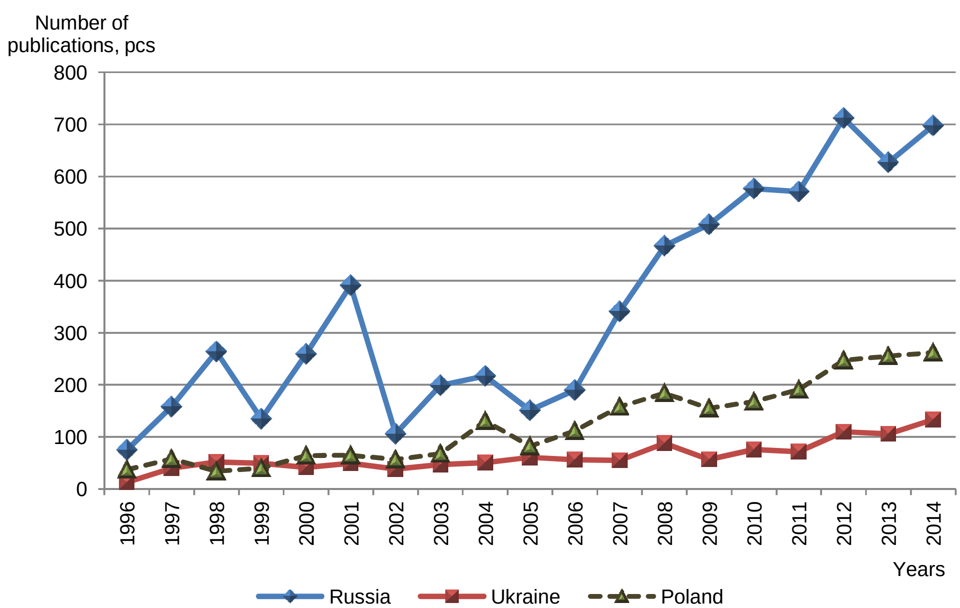

Fig. 2. Dynamics of the number of new publications in the sphere of "nanoscience and nanotechnologies" in Ukraine and in neighboring countries during 1996-2014
Composed by: [33]

As computation results demonstrate Ukraine is probably the only country, for which exponential growth appeared to be too fast and could be better described by the polynomial trend:

$$Y_{Ukraine}(t) = 0.2252t^2 + 33.614,\ R^2 = 0.82. \quad (17)$$

Table 3 shows forecasting results by the built models of new publications appearance in the next three years globally and in separate countries.

Table 3. Forecast for publishing activities in the world countries in the sphere of "nanoscience and nanotechnologies"

Years	2015	2016	2017
World countries, including	34 290	36 252	37 998
China	11 958	14 733	18 152
USA	7 960	8 242	8 479
Germany	2 489	2 737	3 009
Japan	1 917	1 954	1 985
Korea	3 294	3 542	3 758
Russia	745	767	783
Poland	324	363	408
Ukraine	127	138	149

Prepared by the authors

As Table 3 shows, scientific-technological inventions described in the publications would continue growing in number both globally and in Ukraine. But with the available growth rates Ukrainian role in the world process would remain low. China and the USA would be the leaders, and China would considerably leave behind the rest of the countries.

To perform a more detailed review of the publications in different spheres of nanoscience and nanotechnologies a focused data retrieval was carried out from the global and national abstract databases.

The specialized database retrieval was performed in the prospective areas: nanomaterials; nano-electronics; nano-biotechnologies; nanomedicine; new energy engineering; nanotribology.

The DB [34] retrieval results show that the global number of publications in all those areas grows. More than 2/3 of all the publications have been issued in the recent 5 years and only 29.1% occurred during the first 5 years. It testifies of the high topicality of the global inventions in different spheres of nanotechnologies, and of swift knowledge accumulation. It's worth mentioning, however, that the accumulated number of publications also grows rather quickly according to the polynomial law. Therefore, the phase of accumulating and exhausting interest to nanotechnologies has not yet come.

Nanotechnologies utilization in medicine against the rest nano-areas has not yet become of the leading importance. The same pertains to nanotribology. But the growth rates of publications dedicated to nano-biotechnologies (0.18) and nanomedicine (0.17) as well as to nanotechnologies utilization in new energy engineering are the fastest. Researchers' attention gradually shifts from designing and researching new nanomaterials' properties to their utilization in nano-biotechnologies, nanomedicine and new energy engineering. At the same time the shares of publications in Nano-electronics and Nano-tribology have remained unchanged.

Publications' DB [35] retrieval results in Ukraine provide for concluding that in general the trends in scientific-technical research in Ukraine go in line with the global research trends. But the number of scientific publications in Ukraine considerably lags behind the leading countries in all the spheres of nanotechnologies utilization. It's worth mentioning, however, that 2014 data as well as partially 2013 data could not be considered the final ones as there is a big lag between the publication issue and its entering into the abstract DB.

Publications dynamics in all nanotechnologies areas was not stable during the whole studied period of 2004-2014. E.g., 2006 demonstrated "nanomaterials" publications reduction (table 4). Later, the publishing activity in all the spheres kept growing.

As global trends show, the major share in the research belongs to creating nanomaterials and developing their properties. In contrast to the world trend Ukraine demonstrates a considerably smaller share in Nano-electronics research and inventing. First of all, it could be attributed to the decline of the national electronics industry. So, if such R&D is even performed, it does not have sufficient application and demand.

Comparatively high share of R&D in the spheres of nano-biotechnologies and nanomedicine is a specific feature of Ukrainian nano-research. It creates preconditions to develop new methods in solving health care problems, providing for food products safety and improving agricultural production. With regard to the global character of the population ageing problem, or food products national safe provision, or generally in fighting with global hunger those spheres are prospective for commercialization both globally and in Ukraine.

Rare publications deal with utilizing nanomaterials and nanotechnologies in energy engineering similarly to rare research in the issues of decreasing friction with the help of nanotechnologies. So, those two spheres have not yet attracted researchers' serious attention and Ukrainian local R&D efforts in those spheres have not yet been sufficient.

Similarly to the global trends, Ukraine faces researchers' interest shift from nanomaterials to nano-biotechnologies and nanomedicine. But the level of that interest shift in Ukraine is much more considerable. The R&D share in nanomaterials has decreased 1.5 times while nano-biotechnologies and nanomedicine technologies shares have increased 2 times. It demonstrates high potential of Nano-biotechnologies and nanomedicine technologies utilization in Ukrainian national economy (Table 5).

To determine global prioritized spheres of scientific-technical inventions for near term prospective, the forecasting models were built up to account the number of publications by nanotechnologies spheres on the basis of time trends that are presented in Table 6. The built-up models demonstrate high adequacy level according to the determination factor. The least adequate is the model for the sphere "nano-tribology". Comparatively low number of publications in that sphere prompts that the research is just on the initial stage.

All the trend models demonstrate the exponential growth. The highest growth rate could be observed in the sphere of nanotechnologies utilization in energy engineering. Slightly slower growth rate is observed in the spheres of nano-biotechnologies and nanomedicine. The slowest growth rate is demonstrated by nanomaterials research sphere, which testifies of the fact that the phase of new inventions slower emergence in that sphere is near-by. But the volumes of those R&D efforts would be prevalent over the other research spheres basing on the already accumulated experience. The least determination factor was obtained for the "nano-tribology" sphere, which testifies of the fact that such type of R&D has not yet been recognized in full scale as a separate sphere of global scientific research. So, that sphere is of secondary importance for research, because it is connected with R&D in other spheres, like, for example, in nanomaterials R&D. The last statement is indirectly supported by the almost similar growth trend of publications in those two spheres (Table 6).

During the next three years the general number of the publications in all the studied areas would exceed the volumes of the last three years publications 1.5 times. And R&D in nano-biotechnologies, nanomedicine and new energy engineering would have the biggest share in that process (Table 7).

Table 4. Publications dynamics in nanotechnologies areas

Nanotechnologies R&D spheres	**Years**										
	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Globally											
Nanomaterials	5531	6325	8080	8674	9786	10479	11180	12871	13946	16022	17522
Nano-electronics	3196	3614	4610	5145	5782	6456	7036	8332	9302	10994	12343
Nano-biotechnologies	1073	1256	1625	2010	2368	3156	3891	4742	5061	5912	6349
Nanomedicine	70	80	127	112	183	202	236	259	327	370	386
New energy engineering	646	763	863	864	869	1158	1430	1877	2214	2554	3227
Nano-tribology	52	50	82	71	88	86	107	93	111	173	163
Ukraine											
Nanomaterials	123	125	73	110	134	140	108	134	114	79	101
Nano-electronics	6	6	11	11	16	11	29	22	25	25	25
Nano-biotechnologies	17	16	19	21	23	35	64	69	100	100	78
Nanomedicine	7	3	10	16	31	27	42	40	47	53	36
New energy engineering	7	1	2	4	5	4	8	2	9	6	2
Nano-tribology	4	7	4	5	9	6	7	9	7	14	5

Prepared by the authors

Table 5. Global and Ukrainian distribution of the publications by nanotechnologies spheres during 2004-2014

Nanotechnologies R&D spheres	Share of the sphere in the publications total number	
	Globally	Ukraine
Nanomaterials	47.3	51.5
Nanoelectronics	30.2	7.8
Nanobiotechnologies	14.7	22.5
Nanomedicine	0.9	13.0
New energy engineering	6.5	2.1
Nanotribology	0.4	3.2

Prepared by the authors

Table 6. Trend models to forecast number of publications by nanotechnologies R&D spheres

Sphere of nanotechnologies R&D	Model of the scientific publications number forecasting			
	Globally		In Ukraine	
Nanomaterials	y= 2353.74*EXP(0.105871*t), R^2=0.98	(18)	RND (100; 160)	(24)
Nanoelectronics	y= 1034.78*EXP(0.130405*t) , R^2=0.99	(19)	*y* = 2.1947*exp (0.142571**t*), R^2=0.74	(25)
Nanobiotechnologies	y= 303.361*EXP(0.163925*t) , R^2=0.98	(20)	*y* = 1/(-0.91+exp(-0.0041**t*)) , R^2=0.86	(26)
Nanomedicine	y= 21.7361*EXP(0.155316*t) , R^2=0.96	(21)	*y* = -49.8+5.733**t*, R^2=0.95	(27)
New energy engineering	y= 99.1287*EXP(0.181985*t) , R^2=0.97	(22)	*y* = -6.459+0.8243**t*, R^2=0.71	(28)
Nanotribology	y= 17.5268*EXP(0.117786*t) , R^2=0.88	(23)	*y* = 1.567*exp (0.109**t*) , R^2=0.58	(29)

Prepared by the authors

The built trend models help us conclude that nanotechnologies research in Ukraine is a rather slow process. Only two spheres of nanotechnologies research (Nano-electronics and Nano-tribology) demonstrate exponential growth, but the growth rate is rather low and the initial values are within the limits of ten. Therefore, fast improvement in those spheres could hardly be forecasted.

Scientific-technical inventions in nanomedicine and Nano-energy follow linear laws, which testify of the lack of the research multiplication effect in those spheres. The only nanotechnology sphere where we failed to get any adequate trend model is nanomaterials sphere. Absence of the stable dynamics makes the forecasting impossible.

General number of publications during the forecasted period has grown 1.46 times in comparison with the period 2011-2013, which almost repeats the global dynamics. Publications in the spheres of new energy engineering and nano-electronics are expected to increase in number, but due to a small number of those publications they would hardly significantly alter the structure of the prioritized spheres. The major changes would occur due to the growing researchers' attention to nano-biotechnologies and nanomedicine. And thanks to that, nano-biotechnologies inventions would get the biggest weight factor. Nano-tribology and new energy engineering remain generally beyond researchers' attention. Such a low activity in using nanotechnologies in energy engineering and electronics does not match the global trends. Taking into account the need of Ukraine to develop new technologies in energy efficiency and energy saving, the research in those spheres would become one of the national priorities to support nanoscience and nanotechnologies.

At the same time Ukraine has accumulated relatively big inventions potential in the spheres of nano-biotechnologies and nanomedicine in comparison with global experience. Jointly those two spheres make up half of the Ukrainian scientific inventions. Therefore, they provide Ukrainian science and economy with competitive advantages. Due to their faster rate of development they are one of the major priorities for commercialization.

Concluding the review of the researchers' publishing activity in nanotechnologies spheres Globally and in Ukraine we have to point out that nano-biotechnologies and nanomedicine inventions are the most prospective. Exactly those spheres might become the major ones to promote nanotechnologies in the national economy. At the same time a considerable lag in the number of inventions in nano-electronics and new energy engineering prove the need to pay a special attention and provide more government and business support to those spheres.

Table 7. Forecast for new publications emergence by nanotechnologies R&D spheres

Years	Nanotechnologies spheres						
	Nano-materials	**Nano-electronics**	**Nano-biotechnologies**	**Nano-medicine**	**New energy engineering**	**Nano-tribology**	**Total publications**
Globally							
2015	19 559	14 045	8 050	485,6	3 775	184,8	**46 099**
2016	21 743	16 002	9 484	567,1	4 528	207,9	**52 532**
2017	24 171	18 231	11 173	662,4	5 432	233,9	**59 904**
Forecasted weight factor for the nanotechnology sphere	41,3	30,5	18,1	1,1	8,7	0,4	
Ukraine							
2015	112	38	136	65	10	14	**374**
2016	113	44	147	71	11	15	**400**
2017	148	51	155	76	12	17	**459**
Forecasted weight factor for the nanotechnology sphere	30,2	10,7	35,5	17,2	2,6	3,8	
Declination from the global indicators	-11,1	-19,8	17,4	16,1	-6,1	3,4	

Prepared by the authors

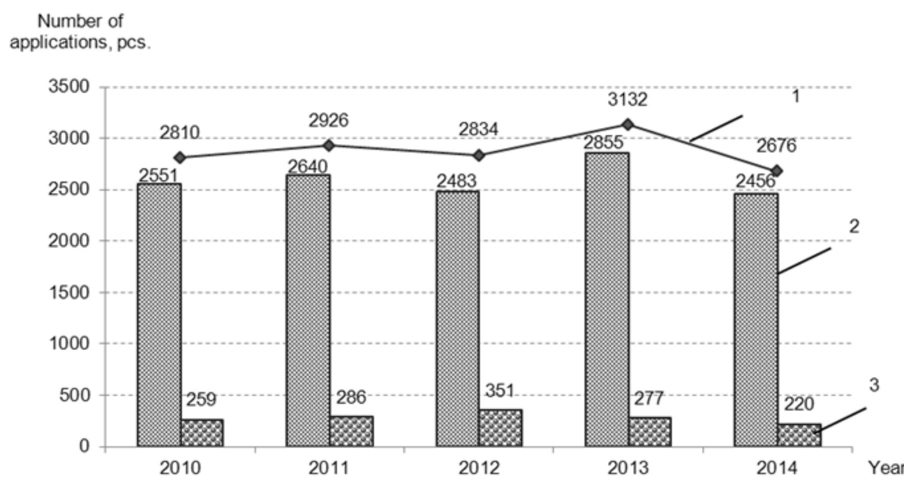

Fig. 3. Dynamics of the submitted patent applications for inventions in accordance with the national procedure: 1 – total number; 2 – from national applicants; 3 – from foreign applicants

Prepared by the authors

3.3 Analysis of Global and Ukrainian Trends in the Patent Statistics of Nanotechnologies' Scientific Research

The patent statistics was analyzed in addition to search publication activity to identify trends in research taking place in Ukraine and to compare them with global. The basis for this analysis was the database of World Intellectual Property Organization (WIPO) and State Intellectual Property Service of Ukraine (SIPSU).

According to WIPO nearly 210 thousand patent applications were published by Patent Cooperation Treaty (PCT) procedure in 2014 [36]. The majority of those applications came from US applicants (28.7%), Japan (19.8%) and China (11.9%). Ukrainian applicants submitted 160 applications or 0.1%, which testifies of the low level of local inventions patenting outside Ukraine.

Among all the applications the following technological spheres were the leaders: computers (17.7%); digital communication (16.2%); electrical machines, apparatuses, energy (15.2%); medicine (14.0%); measurement (9.0%). Ukrainian patent applications biggest shares were among the following technologies: engines, pumps and turbines (8.8%); computers (7.5%); transport (6.9%); medical drugs (6.3%); electrical machines, apparatuses, energy (5.63%), audio-visual equipment (5.63%); medical devices (5.63%); mechanical elements (5%).

In the sphere of micro-structural technologies and nanotechnologies only 4 Ukrainian patent applications were published during 2005-2014. The aggregate number of the published patent applications from all over the world during the same period of time amounted to 3172 with 14 % of monthly average growth rate [36]. However, it's worth mentioning that only a few countries, like China, USA, South Korea, Japan, Germany have unquestionable leadership by that indicator in the recent years (more than 80% of the total published patent applications).

The task of the SIPSU is to implement the state policy in the field of intellectual property and move proposals to the Ministry of Economic Development & Trade regarding the policy formulation [37]. In accordance with the set procedure the Service organizes expert evaluation of the patent applications as regards the intellectual property rights; issues patents/certificates for the intellectual property; performs state registration of intellectual property; registers contracts on transferring intellectual property rights protected on the Ukrainian territory, and registers license agreements; keeps state registers of the intellectual property and performs other functions in that sphere [37].

In 2014 a number of patent applications for inventions submitted to SIBSU by the national and foreign applicants was lower in comparison with 2013 (-14.6%) (Fig.3). Similar picture was observed with applications for utility models, the number of which was lower by 7.8% in 2014

Annual number of patent applications for utility models submitted by the national procedure averagely is 3.5 times bigger than the applications for inventions submitted by the same procedure.

Applications for inventions submitted annually by Patent Cooperation Treaty (PCT) procedure during 2010-2014 averagely were by 21% lower in comparison with the applications submitted by the national procedure [38]. During the whole period, however, there were only 8 patent applications for inventions and 2 applications for utility models submitted by the national applicants.

During 2010-2014 averagely 2271 patent applications for inventions were submitted annually to SIPSU by the PCT international procedure, and applications for utility models varied between 5 and 23.

According to SIPSU the majority of the applications for inventions in 2014 were submitted by the class IPC A61 "Medicine and veterinary; hygiene" – 13.1%; the second place belongs to C07 "Organic chemistry" – 9.9%; the third place belongs to A01 "Agriculture; forestry, animal breeding; hunting; animal trapping; fishing" – 6.9% [38]. However, if we consider the priorities in applications distribution by the applicants origin, we may notice considerable differences. For example, by A61 class, out of 630 applications 370 were submitted by foreign applicants; by C07 class, out of 477 submitted applications 457 were submitted by foreign applicants; by A01 class, out of 330 applications 213 were submitted by foreign applicants.

Specialized database (DB) "Inventions (Utility models) in Ukraine" is an open automated patent

DB to be used on the Ukrainian territory. It provides for data retrieval from the available patents by 20 fields including also key words, patent number, application number, applicant, inventor, owner, International Patent Classification (IPC) index, etc. [39]. To determine patent activity in nanotechnologies sphere the data retrieval was performed by IPC index B82 "Nanotechnologies" during all the available years except 2015. The year, when the acquisition of rights by a patent occurred, was selected as the patent reference year. The retrieval results showed that the number of patents sharply increased in 2008 (Fig. 4).

A specific number of patents stopped their actions due to different reasons.

Total number of the acting patents in the sphere "Nanotechnologies" at the moment of the research was 87, including 31 patents for inventions and utility models (Fig. 5).

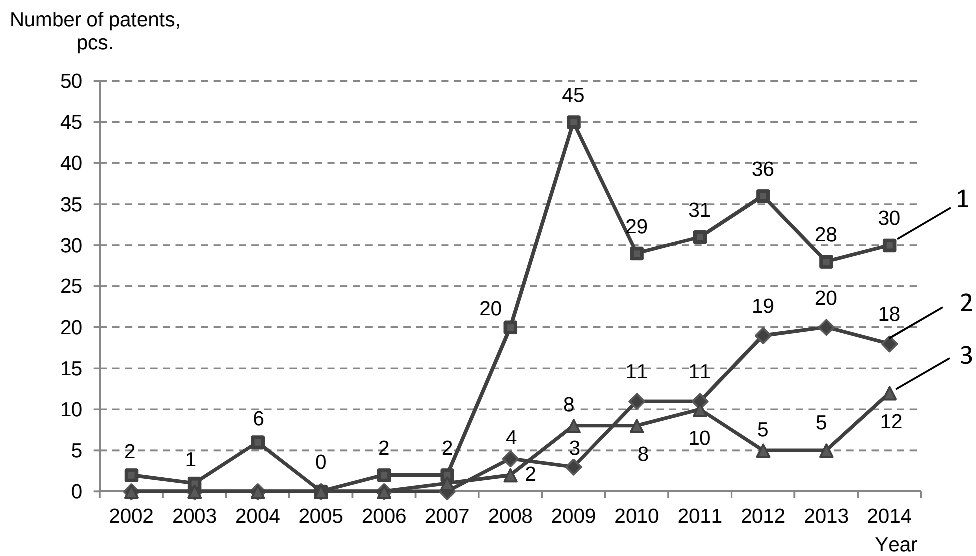

Fig. 4. Dynamics of the nanotechnologies patents in the specialized database "Inventions (Utility models) in Ukraine": 1 – patents in total; 2 – acting patents; 3 – patent action suspended with the opportunity to renew
Prepared by the authors

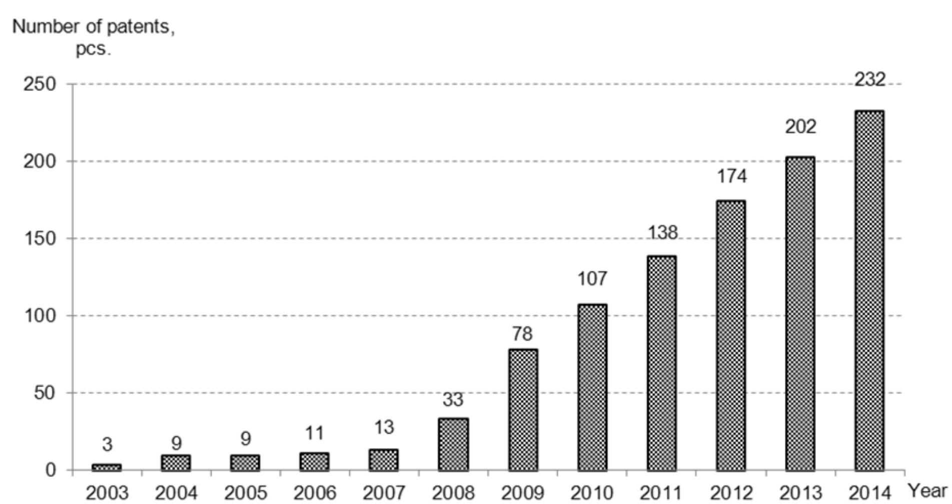

Fig. 5. Dynamics of the patents accumulation (displayed together: acting patents, not acting patents; suspended patents with the opportunity to renew) in nanotechnologies sphere
Prepared by the authors

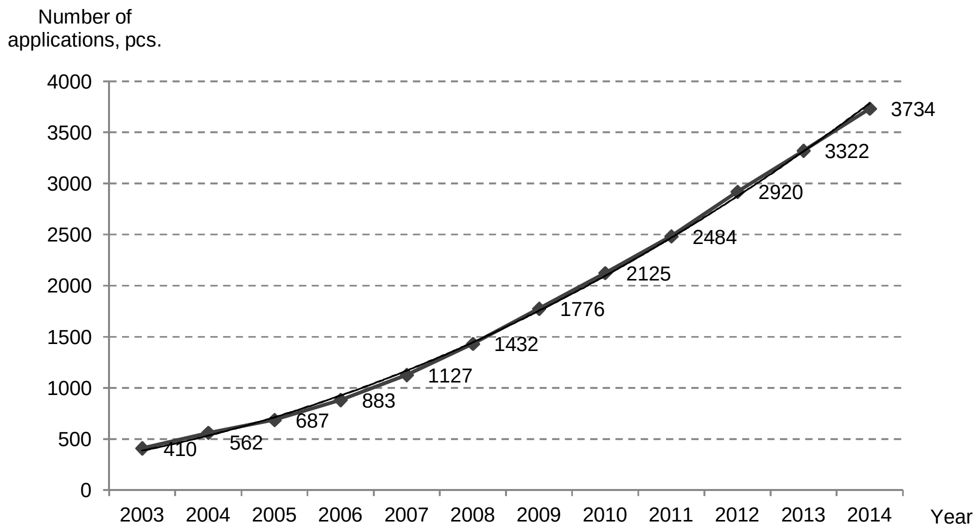

Fig. 6. Dynamics of accumulating applications in the sphere of “Microstructural technologies and nanotechnologies” during 2003-2014

Prepared by the authors

To simulate the number of patents growth the exponential model was tested:

$$y = 2.7364e^{0.407t},\ R^2 = 0.9499, \quad (30)$$

where y – number of patents;
t – time variable.

Though the determination factor is rather high, after 2012 Ukraine has demonstrated a considerable lag from such a trajectory. Therefore, it is more expedient to use growth rates of the number of patents, which are rather low for the period of a technology active development, supported also by the function linearity, which describes their accumulation:

$$y = 32.107t – 22.357,\ R^2 = 0.9971\ (2007\text{-}2014). \quad (31)$$

Although in a global scale exponential growth rates could not be achieved, research of the dynamics of all submitted by PCT procedure applications on the basis of WIPO data demonstrates a higher rate of knowledge accumulation in the sphere of “Microstructural technologies and nanotechnologies”. And its trajectory is most closely approximated to the parabolic function (Fig. 6):

$$y = 16.184t^2 + 98.624\,t + 270.82,\ R^2 = 0.9992. \quad (32)$$

The forecast for the number of patents in Ukraine, received by the national procedure, performed by the linear model for 2017 is 331 pcs, i.e., it should grow during 3 years 1.42 times. Globally, the growth would be up to 5392 patents, i.e., it would increase 1.44 times. The difference in the growth rates in the near perspective is not that substantial. But we have to point out that according to WIPO data there were only 4 Ukrainian origin applications during 2003-2014 [39]. To increase competitive power of the Ukrainian inventions the local researchers should concentrate more on getting international patents.

4. CONCLUSIONS

Ukraine has already exhausted itself as a country producing cheap labor force with predominantly low-technological and energy-inefficient industry. At the same time it has a chance to make a break-through on nanotechnologies market thanks to the accumulated intellectual potential.

Ukraine conducts fundamental and applied research in the field of nanotechnology in such areas as: medicine, biology, agriculture, environment, energy, industry, space exploration, cibernetics, electronics and others, the results of which received a number of practical results and technologies of the world level. At the same time, the priorities of those studies need to be clarified in accordance with the global problems to be solved by any country with regard to national specificities of the problems, and in accordance with the existing potential and possibilities of nanotechnology research for future NBIC-society.

Comparative analysis of the publishing activity of researchers in the field of nanotechnology in the leading countries of the world and Ukraine has shown that in general, the dynamics of research in Ukraine corresponds to the global trends, but it is much slower. In order not to lose the existing potential in that area Ukraine has to provide the state support to local development, especially at the stage of basic research, and institutional support to the interaction of science and business at the stage of applied research as the part of scientific and technical policy of Ukraine.

The main field of research in the field of nanoscience is the development of nanomaterials, nanobiotechnology and nanoelectronics. The peculiarity of Ukrainian research field is the high proportion of developments in the field of nanomedicine & nanobiology that allows us to consider those areas to have competitive advantages of nanotechnology development in Ukraine. At the same time a very small number of publications in the field of nanoelectronics and nanotechnology in the energy sector shows a substantial lagging behind the global trends. In this regard, developments in the field of nanoelectronics should be a priority of state support for the revival of high-tech engineering.

The low level of patenting in nanotechnology development in Ukraine expresses the need, on the one hand, to stimulate applied research, and on the other hand, to improve procedures to obtain intellectual property rights protection. The almost complete absence of international patents speaks of the need to ensure more active cooperation between Ukrainian, European and international patent organizations, particularly, in preparing, filing and maintaining patent applications under the Patent Cooperation Treaty.

It is important to create a Ukrainian system for long-term forecasting and strategic planning of scientific and technological innovations and developments until 2030. However, above all, Ukraine has the need to assess the availability of cutting-edge nanotechnologies in the country, and to identify the possibility of their commercialization to impact the economic development and solve urgent national problems.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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APPENDIX A

The most significant results of accomplishing the target comprehensive program "Fundamental problems of nano-structural systems, nanomaterials, nanotechnologies" for the period 2010-2014

Year	Program direction	The most significant results	Practical value	Industrial branch
1	**2**	**3**	**4**	**5**
2010	Physics and diagnostics of the nano-size systems	The possibility to perform non-destructive quality control of big number of carbon nanotubes together with their defects diagnostics within the layers structure and in graphene layers was ascertained.	Non-destructive control and diagnostics of nanotubes defects	Electronics, ICT
		Basing on the experimental research results and computer modelling, regularities of size impact on carbon Nano-crystal strength, samples from zirconium 3D glass and metal Nano-crystals were determined by the method of molecular dynamics	Nano-crystals properties study	Electronics, ICT
	Chemistry of nano-materials and nano-structures	Methods to obtain graphene-oxide colloids in water solutions and their stabilizing with anonymous surfactants were developed	New materials – graphene-oxides	Electronics, ICT
	Nano-materials technologies	The possibility to obtain Nano-structures in titanium industrial alloys by deformation was demonstrated	New properties of titanium alloys for the technologies to enhance resistance to cyclic loads	Nano-mechanics
	Bio-Nano-systems	Ferromagnetic impact on tumor cells' structural-functional and toxic characteristics was researched. It was demonstrated that metals Nano-particles genotoxic action manifestation depends on their nature and size. Experimentally it was proved that golden Nano-particles of 30 nm are mostly bio-compatible and bio-safe when performing target delivery of drugs.	Metals Nano-particles to be used as means for drugs target delivery.	Medicine
2011	Physics and diagnostics of nano-size systems	-	-	-
	Chemistry of nano-materials and nano-structures	-	-	-
	Nano-materials technologies	The way of obtaining tungsten diamond-carbide Nano-composite with Nano-particles additives by way of sintering under conditions of high pressure and temperature was developed	Nano-composite with high hardness and cracks resistance	New materials
	Bio-Nano-systems	When researching tumor cells with Ehrlich's ascite's carcinoma it was ascertained that the presence of Nano-particles – carbon Nano-tubes - had slowed down the process of tumor growing	Foundation for creating anti-tumor drugs to provide for apoptosis increase	Medicine, , Pharmacy
		Functional fluorescent composites were obtained; in their Nano-particles	More efficient delivery of drugs to	-«-

Year	Program direction	The most significant results	Practical value	Industrial branch
1	**2**	**3**	**4**	**5**
		nucleus they have fluorescein, and on their surface – reaction functional coating. It was demonstrated that fluorescein marked carriers to deliver drugs could solve several principally important problems for pharmacy and therapy.	target cells at the expense of decreasing their acting dose. Visualization of Nano-composites entering cells with the help of fluorescent marking	
2012	Physics and diagnostics of nano-size systems	Scientific recommendations to improve technologies of obtaining the following materials were developed: - Nano-granular magnetic films - High-efficient quick acting non-linear materials on the basis of metallic Nano-structures; - Carbon Nano-tubes; - Oxide Nano-films	To be used in: - spintronics; - devices to control light flows; - gas sensors; - industrial catalysis and in protecting metals against corrosion	Electronics, ICT, Enginee-ring industry
		Original silicon field transistor was created to identify terahertz/submillimeter radiation. Amplifier and receiver were designed on its basis	To be used in night vision devices, defects inspection, in acoustic-optical terahertz converters	Electronics, ICT, Enginee-ring industry
	Chemistry of nano-materials and nano-structures	The structure and mechanical properties of Nano-size and ultra-disperse friction layers on carbon steel surface were researched to understand impact of cooling lubricants on such layers formation. Efficient mechanic-chemical method to obtain graphene oxide with different oxidizing levels was found with no applying aggressive environment	Nano-coating for friction surfaces	Nano-mechanics, new materials
		Thermic-chemical technology for fiber materials hydrophobization was developed to decrease their moisture uptake, increase microbiologic resistance and fire resistance, ensure stable increase of heat insulating properties by 50% in the conditions of high moisture content and temperature gradient	To be used in house construction, municipal economy, heat pipelines, pipelines, in refrigeration equipment	New materials
	Nano-materials technologies	Technology to weld heat resistant alloys and intermetallide materials on nickel and titanium bases; utilization of Nano-layered coating and and foil	Provide for considerable increase of new generation gas-turbine devices parts' quality and reliability	Aerospace complex
		Method to obtain sintered 3D composites Cu-W was developed with low content of W, which have increased electric conductivity, hardness, strength and plasticity	Possibility to widely use materials for multifunctional purposes	New materials
	Bio-Nano-systems	The technology to synthesize spherical iron nanoparticles of 40 nm size modified by ascorbic acid, which are promising in creating new generation highly efficient anti-anemia drug	Prevention and treatment of iron deficiency anemia and anemia of chronic disease	Medicine, , Pharmacy
		Calixarenes, which serve as prospective molecular platforms to create new drugs, were synthesized	Antithrombotic drugs and means to treat smooth muscle's contractile	Medicine, , Pharmacy

Year	Program direction	The most significant results	Practical value	Industrial branch
1	2	3	4	5
			function	
		A series of nano-biomaterials used in medicine, agriculture and food industry were synthesized	A new class of antithrombotic and antimicrobial agents; bioceramic implants; pharmaceu-ticals of targeted application; new diagnostic and sensor test systems	Medicine, , Pharmacy, Biotechno-logies
2013	Physics and diagnostics of nano-size systems	Efficient organic phototransistor based on semiconductor fullerenes (C_{60}), characterized by high sensitivity was manufactured for the first time	Basis for the realization of highly efficient organic photodetectors and optical storage elements	Electronics, ICT
		The effect of intensity optical limitation during interaction between nanosecond laser pulses and thin nanostructured silicon carbide films of different polytypes was identified	Creating optical switches and limiters that operate at high and low temperatures, in chemically aggressive atmosphere and under high radiation	Electronics, ICT
		Laser-induced processes of ferro-magnetic tunnel nanostructures' magnetization reversal and conductivity change were studied under the impact of super-short polarized laser radiation pulses	The structures could be the elements of the laser-guided spin-polarized current	Electronics, ICT
	Chemistry of nano-materials and nano-structures	Technologies to obtain nanoscale semiconductor structures based on PbTe-SnTe solid solutions with the set thermoelectric properties (optimum thermoelectric Q-factor) were developed	Nanostruc-tures with the set thickness, size and density	Electronics, ICT
	Nano-materials technologies	New nanostructural states of coarse-grade titanium having high strength and plasticity were obtained by the method of the titanium twisting under the temperatures of 300 and 77 K	Using the titanium to create new structural materials	New materials
		Impact of nanoscale oxide particles on copper mechanical properties in hydrogen enviroment was researched under high pressure	Disperse- strengthened copper, insensitive to hydrogen embrittlement having high resistence to radiation swelling	Energy
		Nanocomposite tungsten diamond - carbide was synthesized and its performance during materials blade cutting was assessed	Working element made of such nanocomposite provides for cutting with high efficiency and surface high quality	New materials
	Bio-Nano-systems	New Gd-B-containing nanocomposites on the basis of nanoscale magnetite were synthesized; the method of their modification with immunoglobulin was developed. Methods to form up Ami-nobisphosphonates functional layer on the modified magnetite surface was proposed for further functionalization with chelating Gd^{3+} complexes	Using those nanocompo-sites in neutron-gripping cancer therapy and in integrated MRT diagnostics in medicine	Medicine
		In vivo research on the iron-fdeficient diet model the efficiency of synthesized	The pharmaceutic substance with a	Medicine

Year	Program direction	The most significant results	Practical value	Industrial branch
1	2	3	4	5
		bio-safe iron nano-particles of 40nm size were studied as potential pharmaceutical substance with a pronounced anti-anemic properties. The method to synthesize target platinum nanoparticles functionalized by folates and modified by polysaccharides was developed; their impact on the tumor cells of different oncogenesis was researched	more pronounced anti-anemic properties. Nanoparticles with selective toxic effects on cancer cells	
		The influence of the different nature nanomaterials (fullerenes, nanotubes, gold nanoparticles, magnetic liquid) on phenotypic and cytogenetic features of normal and tumor cells was researched	Nanomaterials in low concentrations stimulate proliferative effects in the cells of mesenchymal origin	Medicine
		The new design of magnetic systems to create magnetic forces acting on the nanoparticles in a given volume of biological object was proposed. The possibility of nanoparticles prevalent concentration in different object parts with the help of changeable pole tips	Magnetic system prototype sample with changeable magnetic tips for possible targeted drug delivery	Medicine
2014	Physics and diagnostics of nano-size systems	Physical principles were developed and technology to obtain regular grids and nanostructures on refractory metals surfaces in dielectrics array under the impact of femtosecond laser pulses radiation was created	Those grids can be used in telecommunication devices mikrooptycs, plasma sensors	Electronics, ICT
		New nanostructural states of coarse-grade titanium having high strength and plasticity were obtained by the method of the titanium twisting under the temperatures of 300 and 77 K	New applications of such materials in reactors engineering, aerospace and cryogenic machinery and in medicine	Energy, Aerospace complex, Medicine
	Chemistry of nano-materials and nano-structures	Liquid technology to obtain well- ordered monolayer organic films with lateral conductivity was developed. The effect of molecules electronic structure switching in diarileten monolayers under the impact of electric field was identified	Technology with the effect that can be used in a controlled molecular electronic devices	Electronics, ICT
	Nano-materials technologies	The technology to weld high-temperature alloys and intermetallic materials on nickel and titaniumium substrates was developed using composite nano-layered coatings and foil was developed	A significant increase in the quality and reliability of new generation gas turbine units parts	Energy, Aerospace complex
		The technology to obtain and apply coating based on titaniumium nitride, molybdenum, zirconium in nanostructured state with extremely high hardness and wear resistance was developed	Improving the performance of titanium blades of powerful steam turbines operated at Ukraine NPP	Energy
	Bio-Nano-systems	The methods of synthesis, where natural lactobacilli cells matrix are used, were developed to form up nanostructured hybrid materials having high bactericidal and fungicidal properties, which are filled with silver nanoparticles	Materials with high bactericidal and fungicidal properties	Medicine
		Calixarenes were synthesized to be promising molecular platforms to create a new generation of drugs	Creating drugs to treat smooth muscle contractile function disorder as well as antithrombotic drugsagents	Medicine

Composed by: [26-30]

APPENDIX B

The most significant results of the state target scientific and technical program "Nanotechnology and nanomaterials" for the period 2012-2014

Year	Program direction	The most significant results	Practical value	Industrial branch
1	**2**	**3**	**4**	**5**
2012	Nano-materials	Technologies to manufacture nanopowders based on ZrO_2 were developed; business-plan to build up manufacturing facilities to produce such nanopowders and ceramic products made of it was prepared. Materials based on zirconium oxide nanopowders have lifetime 30-50 times greater than metal analogues	Materials to be used in sandblasting devices, artificial joints, fuel cells	House construc-tion, medicine, energy
		New nanoscale materials based on silicon and lithium-iron-phosphate were produced	Lithium-ion batteries with maximum high electrochemical parameters	Energy
		Nano-ceramic materials based on silicon nitride with low friction factor, which increase mechanisms service life 2-3 times, were produced. Such materials can operate at high temperatures and in aggresive environment	To be used in aircraft engines and turbines	Aerospace complex
	Nano-technology	Pilot technology to obtain nano-structured titanium alloys was developed	Production of aircraft engine's turbine blades	Aerospace complex
		Technology to obtain industrial nanostructured zinc-silicate coatings	Corrosion resistant coating for metal rolling	Enginee-ring
	Nano-bio-technology	Immuno nano-conjugates for highly sensitive detection of biomarkers in blood plasma were manufactured	Detecting neurodegenerative diseases and cancer at the early stages	Medicine
		Technology to obtain different kinds of nanostructured bioactive ceramics was improved	Pilot manufacturing of implants to restore bone tissue and targeted drug delivery	Medicine
2013	Nano-materials	On the basis of quantum mechanical calculations the theory of magnetic ordering in the diluted magnetic semiconductors was researched	To be used when developing spintronics basic materials	Electronics, ICT
		Test structures with using controlled local electrochemical oxidation reactions and mass transfer on semiconducting materials surface were obtained	To be used as new generation nonvolatile memory elements	Electronics, ICT
		Nanocomposites with core-shell structure based on graphene, $LiFePO_4$ and electro-conductive polymer were developed. Those nanocomposites perfoprm better in batteries than the existing ones	To be used as a cathode in lithium batteries	Energy
		Nanocomposites and nano heterostructures based on graphene oxide Ti, Mn, W and cadmium selenide were obtained	Electrodes of photo-electrochemic systems to convert solar energy	Energy
		The possibility to use nano composite polymer materials as optical adhesives to connect structural components when manufacturing optoelectronic devices was ascertained	To be used when manufacturing optoelectronic devices	Electronics, ICT
	Nano-technology	Water and waterless technology to grow noble metal nanocrystals was	Technology to generate new	New materials

Year	Program direction	The most significant results	Practical value	Industrial branch
1	**2**	**3**	**4**	**5**
		developped, which is important for developing physical principles of the controlled 2D nanostructures forming up basing on organic molecules and metal nanoparticles	nanomaterials	
		Process flow sheet to manufacture small-size chip for temperature sensor was developed basing on nanostructured layers of high-resistance SiC-on-sapphire	Creating highly reliable process temperature control devices	Sensors
		Sketchy design documentation to build up subharmonic mixers on diode Schottky barriers was prepared; prototypes of such mixers were manufactured for the frequency range 325-400 GHz	New systems for radar location, radio navigation, radio vision, for experimental and scientific instrumenta-tion	Electronics, ICT
		The methodology to measure the thickness distribution of elements as well as thickness of the multilayered nanometer size solid surfaces by mass spectrometry of secondary neutral particles method was developed by the State Enterprise "Ukrmetrteststandard"	Diagnostics of nanomaterialsnanostruc-tures and amorphous alloys	New materials
		Pilot technologies to obtain nano-powders of barium titanium, nitrides of boron and titanium, titanium carbonitride were developed; the site for experimental powders production was designed	Creating components for passive electronics devices	Electronics, ICT
	Nano-bio-technology	A draft model regulations to manufacture bioactive hydroxyapatite and tricalcium phosphate powder with adsorbed drugs were prepared	Adsorbed drugs for clinical use	Medicine
2014	Nano-materials	Manifold increase of mechanical properties, improved corrosion resistance, enhanced wear resistance and biocompatibility of pure nanocrystalline titanium were achieved	Improved performance of nanomaterials	All indusries
		Synthesized nanostructured carbon materials that can be used: - in devices for energy storage; - for the protection of the environment	- Double layer capacitors, anodes of lithium-ion batteries; - methane adsorbents, concentrators of substances' small volumes, etc	Energy, Environ-ment protection
	Nano-technology	A new method to reduce pulse duration from 160 fs to 65 fs was proposed and implemented in research precise time-resolving methods	Improving research methods for nanotechno-logy	All indusries
		The technology to form up resonant tunnel structures on silicon nano-conductors and nano-whiskers was developed	Allowing to manufature acceleration sensors for supersensitive accelerome-ters	Electronics, ICT
		Technology to manufacture structured nanophase catalysts based on metal oxides for the integrated treatment of gas emissions to remove toxic admixtures, for oxidating hydrocarbon fuel in catalytic heat generators, for obtaining hydrogen fuel (syngas) was developed	Purifying gas emissions from toxic agents; the technology to generate hydrogen fuel (syngas)	Environ-ment protection; Energy

Composed by: [28-30]

APPENDIX C

Statistical tests for the best models

Formula	t-statistic and p-level	mape, %	F-statistic and p-level
(4)	t_a = 5.12; t_b = 6.92; t_t = -10.67; p<0.01	7.3	-
(5)	t_a = 5.97; t_b = 9.33; t_t = -11.88; p<0.01	6.9	-
(6)	t_a = 7.03; t_t = 25.28; p<0.01	6.3 (2005-2014)	-
(8)	t_a = 2.76, p<0.05; t_b = 4.54; t_t = -8.75; p<0.01	12.4	-
(9)	t_a = 12.7; t_t = 18.6; p<0.01	8.2	-
(12)	t_a = 7.18; t_b = 9.13; t_t = -8.72; p<0.01	7.5	-
(14)	t_a =1.5, p<0.1; t_b = 2.12, p<0,1; t_t = -3.72, p<0.01	12.9 (exclude outliers 1998, 2000, 2001)	-
(15)	t_a = 7.95; t_t = 13.48; p<0.01	16.7*	-
(17)	t_a = 7.56; t_t = 8.72; p<0.01	14.7*	-
(18)	t_a = 16.77; t_t = 28.73; p<0.01	3.7	-
(19)	t_a = 2.28, p<0.05; t_t = 3.86; p<0.01	2.8	-
(20)	t_a = 5.46; t_t = 15.12; p<0.01	6.1	-
(21)	t_a = 5.55; t_t = 14.48; p<0.01	9.6	-
(22)	t_a = 6.3; t_t = 19.59; p<0.01	9.5	-
(23)	t_a = 3.78; t_t = 7.29; p<0.01	10.4*	-
(25)	t_a = 2.12, p<0.1; t_t = 4.19; p<0.01	21,1*	-
(26)	t_a = -62.26; t_t = -4.52; p<0.01	29,0*	-
(27)	t_a = -7.4; t_t = 11.77; p<0.01	33,1*	F=138.59, p<0.01
(28)	t_a = 2.28, p<0.05; t_t = 3.86; p<0.01	57,0*	F=14.92, p<0.01
(29)	t_a = 1.93; t_t = 3.24; p<0.05	21,0*	-
(31)	t_a = -33.84; t_t = 45.34; p<0.01	3.0	F=2055.3, p<0.01
(32)	$t_{t^\wedge 2}$ = 16.28; t_t = -4.74; p<0.01; t_c=2.14, p<0.05	3.8	-

** These high value are coused by the very low number of publications*

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