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Nanotechnology market research: Development and prospects

Investigación de mercado en nanotecnología: Desarrollo y perspectivas

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Contents

ABSTRACT:

The urgency of the research is justified by the fact that the industrial use of nanomaterials is the most promising innovation dimension for most key industrial sectors of the world economy today, in the opinion of leading experts. From this perspective, this article is aimed at developing a forecast for nanotechnology long-term development in Russia and its comparison with foreign advances in this area. The leading methods to research the problem are the Delphi method, scenario development, critical technologies, technological roadmaps, as well as forming expert panels that ensured a comprehensive approach to the development of a forecast for nanotechnology long-term development. The article reveals that the nanotechnology market is booming in many sectors of the economy and has great development prospects. More than 40% of Russian regions have all types of infrastructure for nanotechnology development, but most of the currently produced nanomaterials are used for scientific research. The most developed segment of the Russian nanoindustry is nanopowders, with the most significant potential for development. The financial crisis slowed down the flow of state investment in nanotechnology, but the policy of import substitution pursued by the state contributed to the growth of investment in nanotechnology. The article provides a comparison of findings of domestic

RESUMEN:

Actualmente según opinión de expertos el uso industrial de los nanomateriales es el área de innovación más prometedora para la mayoría de los sectores industriales clave de la economía mundial. Desde esta perspectiva, este artículo tiene como objetivo desarrollar un pronóstico para el desarrollo a largo plazo de la nanotecnología en Rusia y su comparación con los avances extranjeros en esta área. Los principales métodos para investigar el problema son el método Delphi, el desarrollo de escenarios, las tecnologías críticas, los mapas tecnológicos, así como la formación de paneles de expertos que aseguren un enfoque integral para el desarrollo de un pronóstico para el desarrollo a largo plazo de la nanotecnología. El artículo revela que el mercado de la nanotecnología está en auge en muchos sectores de la economía y tiene grandes perspectivas de desarrollo. Más del 40% de las regiones rusas tienen todo tipo de infraestructura para el desarrollo de la nanotecnología, pero la mayoría de los nanomateriales actualmente producidos se utilizan para la investigación científica. El segmento más desarrollado de la nanoindustria rusa es el nanopoder, con el mayor potencial de desarrollo. La crisis financiera ralentizó el flujo de inversión estatal en nanotecnología, pero la política de sustitución de importaciones seguida por el Estado contribuyó al crecimiento de la inversión en

and foreign research in nanotechnology on nanopowders, nanocomposites and carbon fibers. Russia lags behind the world leaders in all regards. However, the gap in the scientific and technical component can be narrowed with sufficient funding. This required to carry out reforms in science and offset lagging from the world leaders by stimulating the scientific sector (tax holidays, subsidizing innovation projects, attracting foreign capital, venture funds and banking sector). The materials of the article have practical value for creating the advanced samples based on nanomaterials, which have no analogues abroad, and disclose the necessary measures to support nanotechnology development.
Keywords: nanotechnology, nanomaterials, long-term forecast, science-intensive products, economic security.

nanotecnología. El artículo proporciona una comparación de los hallazgos de la investigación nacional y extranjera en nanotecnología sobre nanopolvos, nanocompuestos y fibras de carbono. Rusia va a la zaga de los líderes mundiales en todos los aspectos. Sin embargo, la brecha en el componente científico y técnico se puede reducir con fondos suficientes. Esto requirió llevar a cabo reformas en la ciencia y compensar el rezago de los líderes mundiales mediante la estimulación del sector científico (exenciones tributarias, subvenciones a proyectos de innovación, atracción de capital extranjero, fondos de riesgo y sector bancario). Los materiales del artículo tienen un valor práctico para crear muestras avanzadas basadas en nanomateriales, que no tienen análogos en el extranjero, y divulgan las medidas necesarias para apoyar el desarrollo de la nanotecnología.
Palabras clave: nanotecnología, nanomateriales, pronóstico a largo plazo, productos intensivos en ciencia, seguridad económica.

1. Introduction

Scientific and technological forecasting is the main means of sound management of science and technology development. Long-term forecasting of achievable results of scientific research and technological development is based on a comprehensive analysis of resource opportunities and limitations (financial, material, resource, production, technological, human resource, etc.). This allows to:

- identify the possible global technological breakthroughs;

- forecast the emergence of technological threats to Russia's lagging behind the leading foreign countries;

- define the priority areas for the development of science, technology and methods.

Analysis of foreign experience in this field reveals that the practice of selecting and implementing the priorities of science, technology and methods is described by a wide range of predictive studies, which is determined by the national specifics of each country, key problems of its development, objectives of the socioeconomic policy of the Government, tasks of ensuring national defense and security. The United States, Japan, as well as Great Britain, Germany and France are unconditional leaders in scientific and technological forecasting research (Development of Science and Technology, 2014).

Much attention is currently paid to nanomaterials and nanotechnology.

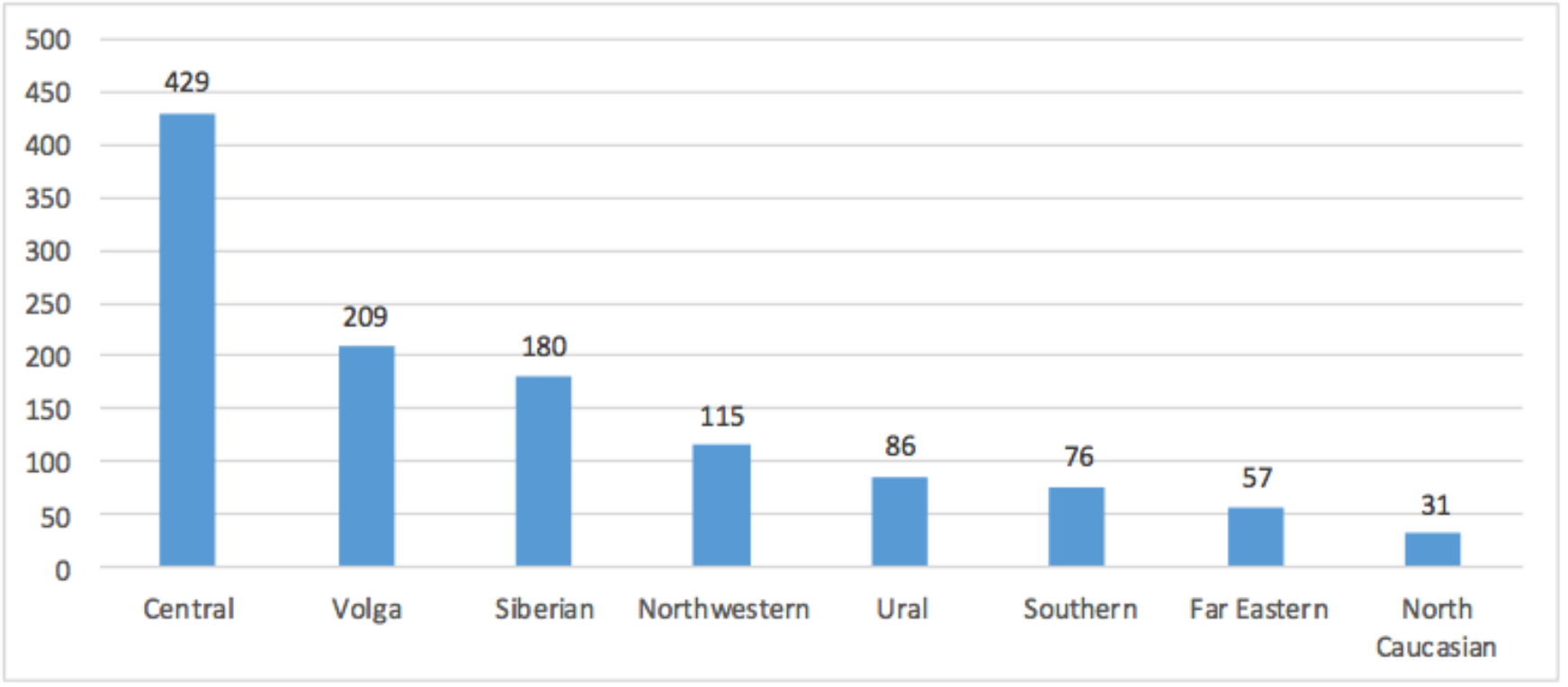
Problems related to the development of nanotechnology currently occupy a leading position in almost all fields of science and technology. Nanotechnology is defined as the method of producing materials at the atomic, molecular and nanometer levels.

The nanotechnology development was facilitated by the discoveries related to the quantum properties of nanoobjects, wide development of semiconductor transistors and lasers, development of diagnostic methods at the atomic resolution level, discovery of fullerenes and development of biotechnology. Transition from traditional technology of obtaining nanoobjects to technology accompanied by a decrease in the size to macroscopic allows to predict important breakthroughs in nanotechnology.

According to the forecast, nanotechnology development will define the shape of the 21st century.

There are more than 1,183 nanotechnology organizations in Russia. Their distribution by federal districts of the Russian Federation is presented in Figure 1 (Hullmann2009).

Figure 1
Distribution of organizations by federal districts of the Russian Federation



More than 40% of Russian regions have almost all types of infrastructure in nanotechnology.

2. Materials and methods

To determine the method of forecasting the scientific and technological development of Russia, the researchers should rely on the global practice of identifying new technological trends, as well as related basic methods (Sokolov 2007).

Technological trends today are defined by national research centers, universities, companies and consulting agencies. Technological monitoring is primarily required for regulation of the scientific and technological field at the interstate level, as well as for developing programs for efficient integration and standardization of scientific research activities in the field of science, technology and innovation.

Trend monitoring consists in regular collection and analysis of information on new areas of scientific and technological development. This information is not required for scientific purposes only, but also in the interests of business, as well as for preparation of recommendations on selecting national or regional priorities.

Corporations and even private companies monitor scientific and technological development, which helps them adapt in the conditions of a changing market and an unstable economic environment, as well as to ensure their high competitiveness in regional and international markets. Consulting firms use the results of their own monitoring to define the strategic priorities of their clients.

Trends are monitored both in the context of certain sectors and national economy branches in general. The horizon of forecasting can be 10 to 30 years.

Qualitative and quantitative forecast methods are actively used in monitoring. The main qualitative forecast methods include:

- review of sources,
- interviews,
- expert polls,
- scenario generation, etc.

The main quantitative forecast methods include:

- bibliometric analysis,
- patent analysis,
- collection and generalization of online data, etc.

Methods of automating the processing of information about technology, methods and science (semi-automatic approach) are actively used in forecasting, along with attempts to use web tools to publish and discuss the forecast results online.

A Technology Roadmap method, which was developed in the late 70s by Motorola, has been widely used recently. The roadmap method is used to develop long-term strategies for the development of industry technology or a large company. The idea behind this method is to arrange strategic planning. The process of planning involves experts on the main components of business: marketing, finance, manufacturing infrastructure, production and research technology.

The roadmap comprehensively indicates stages of the object transition from its current state to its phases of development for a long-term period due to the synchronous development of the business and the market, as well as technology, products and services. The main advantages of the method include developing a coordinated vision of the long-term objectives of the object development.

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3. Results

Nanotechnology development is primarily stimulated by the growing demand for new materials, due to the depletion of raw materials, on the one hand, and to the intensive introduction of nanotechnology in the production of goods with fundamentally new properties, on the other hand. Due to nanomaterials, efficient solutions for a variety of tasks in such sectors as power engineering, healthcare and food production can appear in the near future.

Nanomaterials will also take an important place in solving environmental problems. They will be the core of modern sensory systems, as well as water purification means, technological processes of separating aqueous mixtures into fractions and many other areas of "green" chemistry.

Modern advances in the field of highly efficient nanotechnology and equipment in the field of environmental waste processing and water treatment in combination with smart technology will allow to create highly competitive cognitive systems that meet environmental requirements of modern Russian legislation. Environmental cleanliness is determined by the ability to completely eliminate or significantly reduce the use of chemical reagents in technological processes. Economic effect arises due to a significant increase in the efficiency of technological processes at the expense of reduction in labor, time, material costs, and also due to the improving quality and functional properties of the end products (Pavlov 2017).

A number of new drugs, as well as means of their delivery to the affected organ will be created on the basis of nanomaterials. Nanomaterials will allow to create new technology of prompt diagnostics of living organisms.

The development of the "New materials and nanotechnology" dimension will be determined by challenges and windows of opportunities conditioned by global trends in the medium and long term.

Specifics of nanomaterials’ production in Russia lies in the fact that no kind of nanomaterials is produced on an industrial scale, although enterprises can produce any kind of nanomaterials as prototypes. Nanomaterials are currently produced for scientific and other research in most cases. This fact is confirmed by statistics: 95% of consumed nanopowders are used in scientific research, the remaining 5% still find their application in end products for consumers. The global practice speaks about the primary financing of nanomaterials’ production by large corporations, which facilitates the introduction of nanomaterials into the real production process.

The authors' research reveals that nanopowders are mainly used in commerce. This is due to the low cost of their production because of the simplicity of nanopowders’ production technology.

Carbon nanomaterials – detonation nanodiamonds, fullerenes and nanotubes – are less used in the market of nanomaterials. Accoding to the estimates of Research.Techart, the volume of consumption of this kind of nanomaterials in Russia is about 380-390 kg per year, with a significant priority given to nanodiamonds (91%). Fullerenes account for 8% of the volume, and carbon nanofibres and nanotubes account only for 1%.

Current potential of nanopowders' production in Russia is about 100 tons per year.

Given a small volume of market consumption of nanopowders, the current potential for development and increase in their consumption is quite substantial and amounts to about 10-30 thous. tons. Experts believe that nanopowder producers will be engaged in the production of structural ceramics in the near future. The use of nanopowders in technological processes as catalysts, as well as in the production of functional nanocomposites, is another promising area (Vlasov 2012).

One more promising area of nanomaterials' development is polymer-matrix nanocomposites: metal-matrix, polymer-matrix and metal-polymer-matrix. They are produced by FSUE CRI SM Prometey.

Besides, RPF "Elan-Praktik" began commercialization of inventions. This company is engaged in applying modern nanocomposite coatings to machining tools. Hardening nanocomposites are used for this purpose – both with the inclusion of chromium and without it. As such, the process of commercialization of nanocomposite materials can be declared. This process is now taking place in the sectors of manufacturing products with high added value. They include the space industry, automotive industry and shipbuilding, as well as the military dimention of their application.

The nanotechnology market is booming. The number of companies using nanotechnology grows each year, and so does the volume of products manufactured using nanotechnology. Advances in nanotechnology are used almost in all branches of the economy today.

Analysis of the global nanotechnology market allows to define the following major trends of its development:

• an increase in the number of studies and publications, an increase in the number of patents related to nanodevelopments. About 800 thous. publications on nanodevelopments appear every year, and the number of patents grows, currently dominated by the US (Golubev, Chebotarev, Sekerin and Gorokhova 2017);

• an increase in investment in nanotechnology; competition for leadership in nanotechnology between countries is intensifying.

Flows of public investment in nanotechnology have slowed down under the influence of the financial and economic crisis. However, following the results of 2016 and the preliminary estimates of 2017, the state regained the role of the main investor in the nanotechnology sector of the economy, while the share of corporate funding under the influence of the crisis was reduced.

Nanoproducts worth $12.7 bln were produced in 2016, with an increase of 9.5% over the previous year. In the near future, an intensified entry into the market of nanotechnology and products manufactured with their use is possible (Nanotechnology in the power engineering market in 2015, 2009).

The share of nanotechnology products currently amounts to 0.01% of world GDP. SC "Rosnanotech" predicts that this percentage will increase to 0.5% by 2018, the share of nanoproducts in GDP by 2020 will amount to 2%, in 2035 it will amount to 40% (Golubev, 2017a).

At the same time, when determining the volume of nanoproducts, a number of companies include the cost of the entire product with the use of nanodevelopments in it, while other companies only include the cost of nanomodifiers in the volume of nanoproducts sales.

According to the estimates of the consulting company Lux Research, the volume of products including nanotechnology developments will amount to $4 trln by 2020 (Azoev 2011).

The area of nanomaterials' industrial use is a promising innovation dimension in all sectors of the world economy today. Therefore, new participants enter the nanotechnology market every year. For example, more than 16,000 nanotechnology companies have been created recently. Their number doubles every one and a half or two years. The growth rates of acknowledged companies engaged in nanotechnology exceed the entire market dynamics by 30-40% on average.

A survey of business executives in the US revealed that 52% of companies believed that the prospects for their business development would be linked to nanotechnology in the next 5 years (Golubev and Kuritsyn 2013).

The US has developed about 1,000 roadmaps related to nanotechnology and nanomaterials' production so far. Roadmaps reflect a set of measures that need to be taken for the production of nanomaterials. Similar indicators are also demonstrated in surveys in European countries.

According to most experts, the fundamental changes in the field of nanoscience and nanotechnology will occur after 2017. The most significant nanotechnology use is noted in the field of electronics. Nanotechnology electronics is already rapidly developing: electronic and ionic processes in gases and conductors are being studied, the use of new electronic devices in various sectors of the economy is being considered.

The laws of technical system development suggest a transition from conventional to molecular systems. In this regard, experts regularly speak about the fourth stage of nanotechnology development as a stage of "molecular nanosystems" or "drastic nanotechnologies". Experts predict that they will appear after 2020. They exist only in the form of concepts and forecast projects today. They include molecular devices, atomic design, etc.

Modern nanotechnology offers new ways of efficient and early detection of viral and bacterial infections by using scanning probe microscopes and piezoceramic biochips in the leakproof fluid flow cells, which allow to perform measurements safely for operators with sensitivity from one to hundreds of pathogens per milliliter. This will allow to create a new generation of flu vaccines.

It will be possible to produce macroscopic objects at the molecular level. For example, a table nanofactory weighing 60 kg can produce objects with a volume within 1 liter and weighing about 4 kg with molecular precision in three hours. As such, it can create another such nanofactory, etc. (Golubev 2017b).

A significant leap is predicted in the biotechnology development for medical and cosmetic industry, as well as food production. Models of robots with mental abilities of a monkey may appear as soon as in 20 years. It is also predicted that nanodevices can be implanted into the human brain by 2030.

Experts divide the stage of "evolutionary nanotechnology" (2005-2020) into two independent periods:

1. "active nanostructures" (2005-2015),

2. "systems of nanosystems" (2010-2020).

The stage of evolutionary nanotechnology is described by a significant breakthrough in innovation activities. The first stage of evolutionary nanotechnology assumes creation of components of nanoelectronics, photonics, nanobiotechnology, medical goods and equipment.

Guided by the method described above, the authors carried out a comparative analysis of nanomaterials' production in Russia and abroad for the following types of nanomaterials: nanopowders, nanocomposites and carbon fibers.

Findings of research in nanopowders

About 3% of the world's nanopowders are produced in Russia. Although Russia has a sufficiently developed scientific base for nanotechnology, only 0.3% of all international patents obtained in 2012-2016 belong to Russia. The EU countries, the US, China, Japan and South Korea are the leaders in the number of studies and obtained patents (Table 1) (Nanotechnology and nanomaterials, n. d.).

Table 1
Activity of the leading countries in nanopowders in 2012-2015

	Total in the	US	EU	China	Japan	South	Russia

	world					Korea	
Scientific publications	44,786	10,908	10,797	9,927	4,218	2,659	1,261
Patents	3,389	1,649	794	46	340	164	9

According to the research, the actual share of Russian companies in the world market of nanopowders is only 1.5% of global production (this share is 54% of global production in the US, 19% in the EU and at the level of 19% in South-East Asia) (Research of the market for nanometals, 2015).

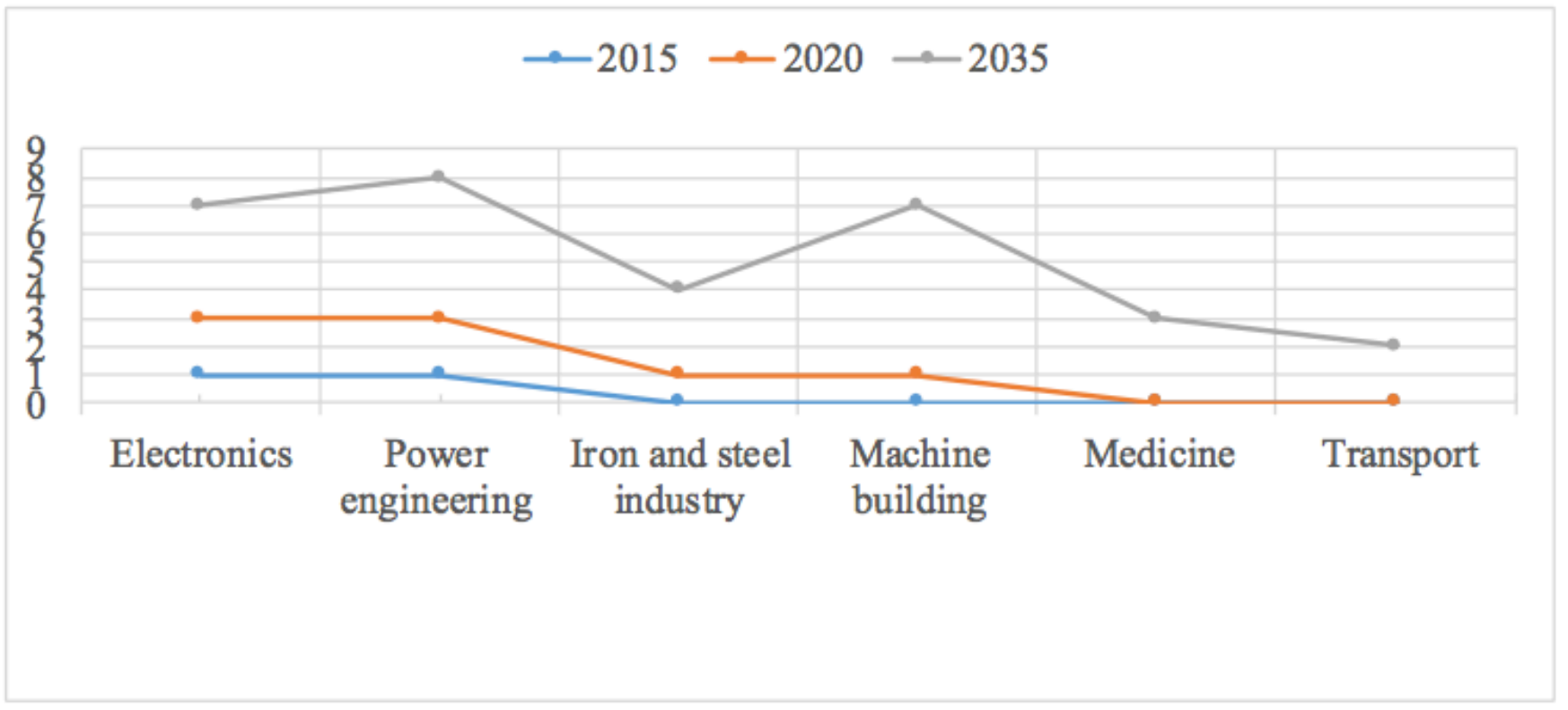
The research indicates that nanotechnology products are unique intellectual and material science-intensive products. They are required by various professional society groups and have high technical and economic performance indicators. It is in demand in solving various tasks of ensuring the state security and independence, as well as in implementing significant national projects and ensuring the quality and variety of goods and services.

It is important to note that the dimension under study is interdisciplinary, i.e. is at the intersection of sciences. This is explained by the fact that obtaining and studying such small objects is possible only by combining the achievements and methods of various scientific disciplines. Besides, the results and advances of nanoscience and nanotechnology are extremely multidisciplinary in their concept. They are used in many sciences and fields of human activities: in chemistry, physics, mechanics, medicine, materials science, machine building, electronics, optics, etc. (Golubev, Burunova and Dosikov 2015).

A favorable factor for the rapid development of nanopowders is the fact that foreign countries do not fully satisfy their own needs for nanopowders.

The main consumers of nanopowders are currently the most promising industries at the stage of technological development: iron and steel industry, power engineering, electronics, machine building, medicine and transport (Figure 2).

Figure 2
Forecast rating of Russian industries consuming nanopowders for 2015-2035



The use of nanopowders in power engineering is quite profitable: the cost of production (in comparison with silicon semiconductors) is reduced, and the service life is extended.

Scientific research in nuclear energy is significantly ahead of the general development of the industry, while the potential for using nanopowders in this industry is limited. Potential consumption of nanopowders in the industry depends on the industry technological development. According to the optimistic scenario, the possible increase in nanopowders

consumption will amount to 6.46-7 bln rub. by 2035, while according to the pessimistic scenario, the forecast of nanopowders' consumption will amount to approximately 1.4-1.6 bln rub. (Global technological trends, n. d).

The iron and steel industry has an almost unlimited demand for nanopowders. Nanopowders are used in the iron and steel industry as ligating elements that enhance the mechanical characteristics of the metal. The nanopowders' market volume in this industry can amount to 150 bln rub.

There are great prospects for the use of nanopowders in the machine-building and automotive industries. The use of nanopowders in these industries leads to the synergetic effect and, correspondingly, to an increase in the economic efficiency of production. The cost/benefit ratio in this industry is 1:5, which is significantly higher than similar indicators in power engineering and electronics industries in aggregate (Golubev and Chebotarev 2017).

The total demand for nanopowders is not less than 1-10 thous. tons in a decade perspective. The capacity of the nanopowder market is enormous. Nanopowders allow to extend the service life of cutting tools and provide their adaptive control on the basis of optical measurements of the processed surface of the part and the tool directly during the technological process, which reduces the processing error from 40 microns to hundreds of nanometers.

The economic effect of using nanopowders can be enormous. They allow to reduce the rate of the machines' modernization from $300 thous. to $3 thous. At the same time, at least 1 million metal-cutting machines out of 2.5 mln machines on the books of Russian enterprises need modernization (Golubev and Zadornov 2015).

Nanopowders also find their application in the construction industry and creation of nanodiamond cutting tools. According to expert estimation, a large-scale development of industrial production of diamond cutting tools is planned in Russia by the end of 2030. This fact allows to forecast an increase in nanopowders' consumption by 240-410 bln rub. in physical terms by 2035 (New technology in aircraft construction are the basis for progress in aviation, n. d.).

It is planned to intensively use nanopowders in the aerospace and aircraft industries, as well as in rail transport. The demand of transport enterprises for nanopowders should exceed 1.8 bln rub. by 2035. This will be possible provided that the state and large companies implement investment projects in nanotechnology.

As such, the potential for nanopowders production in Russia is about 100 tons per year. At the same time, real volumes of production are much lower and are at the level of 3 tons per year, according to Rusnano estimates. Taking the intensive development of the global nanomaterials' sector into account, Russia's share in the world market is extremely small and amounts to about 0.003% (Forecast of scientific and technological development of the Russian Federation, 2013).

State support of nanotechnology has positive impact on the market, along with the significant amount of incoming investment in these programs under various government programs to support nanotech.

Research in nanocomposites

The scientific activity in nanocomposites is at a fairly high level in Russia. If one considers Russia's publication activity in this area, it is inferior only to such countries as Great Britain (15%) and France (35%). At the same time, the number of patents on nanocomposites is at an extremely low level.

The EU countries, China, Japan, the US and South Korea are leading in this field in terms of the amount of scientific and other research conducted, as well as of patents obtained (Table 2).

Table 2
Activity of countries in nanocomposites in 2012-2015

	Total in the world	US	EU	China	Japan	South Korea	Russia
Scientific publications	22,614	5,228	5,598	9,927	1,892	1,419	704
Patents	2,237	1,301	399	15	204	110	6

At the same time, the low level of implementation of research results must be noted. Only 2.5% of research results in nanocomposites is commercialized in Russia, while this figure is almost 20% in China, for example (Global technological trends, n. d.).

Russian finding of the research in nanocomposites outstrip foreign analogues, but no significant industrial results for their development have been achieved.

The global world market for nanocomposites is expected to grow 20 times by 2035. This is why Russia needs to intensify the development of works in nanocomposites and their implementation. Otherwise, Russia will not be able to implement its scientific and production potential in nanocomposites and be competitive in the market (Golubev and Chebotarev 2017).

Results of research in carbon fibers

The US, the EU, China and Japan are leading in carbon fibers. For example, 4% of all world researches in the field of carbon nanotubes are carried out in the US, 19.7% in China, 11.2% in Japan. The share of Russian R&D on carbon fibers is 2.9% (Table 3) (Global technological trends, n. d.).

Table 3
Activity of countries in nanocomposites in carbon fibers in 2012-2015

	Total in the world	US	EU	China	Japan	South Korea	Russia
Scientific publications	38496	9174	11107	7610	4330	1742	1108
Patents	2070	1005	426	26	258	136	11

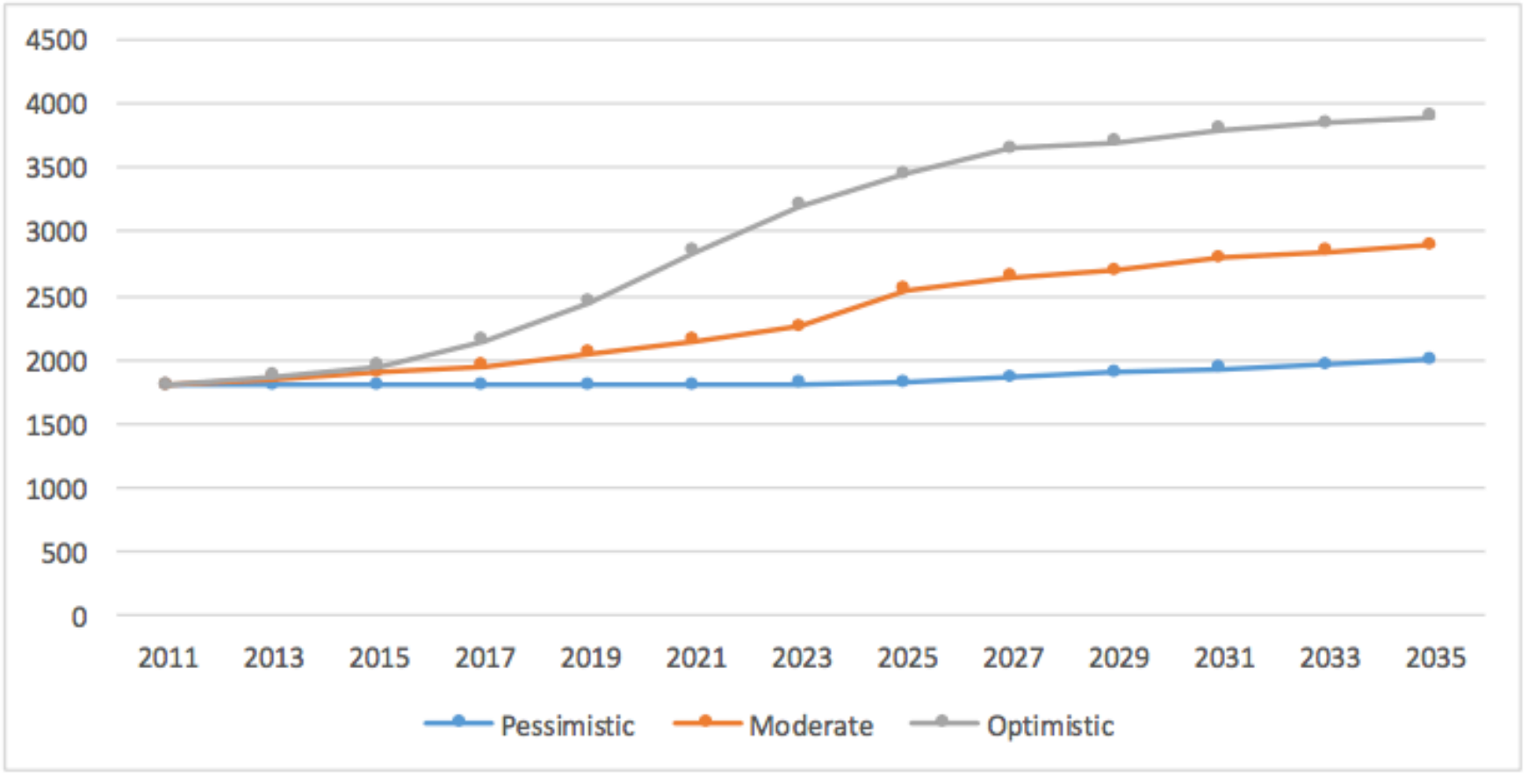
The world level of carbon fibers is estimated as not large. However, a significant number of ready-to-commercialize, innovation solutions in this area constantly emerge.

The world produced 27.5 thous. tons of carbon fibers in 2016. The demand for it is expected to grow up to 15% a year.

Annual consumption of carbon fibers is expected to reach 240-360 thous. tons by 2035. A race for reducing the weight of cars with a simultaneous increase in their strength is an incentive to this (Forecast of scientific and technological development of the Russian Federation, 2013).

The world market for carbon fibers (mln USD) is presented in Figure 3.

Figure 3
The world market for carbon fibers (mln USD)



The optimistic scenario is described by the fact that the global economic crisis will reveal in a reduction in the growth rate of the carbon fiber market down to 10%. With the resumption of global economic growth, the growth rate will amount to 20-25% per year. At the same time, the growth rate in monetary terms will be less – 10-15% – due to a price reduction. The main drivers of the market under this scenario are the following:

- growth in demand for carbon fibers;
- development and improvement of technology;
- reduction of the price for carbon fiber.

A moderate scenario is described by the fact that the growth in market volume will resume after a slowdown to 5%. The growth rate in 2020-2025 will amount 10-15% (5-10% in monetary terms – due to a price reduction) (Global technological trends, n. d.).

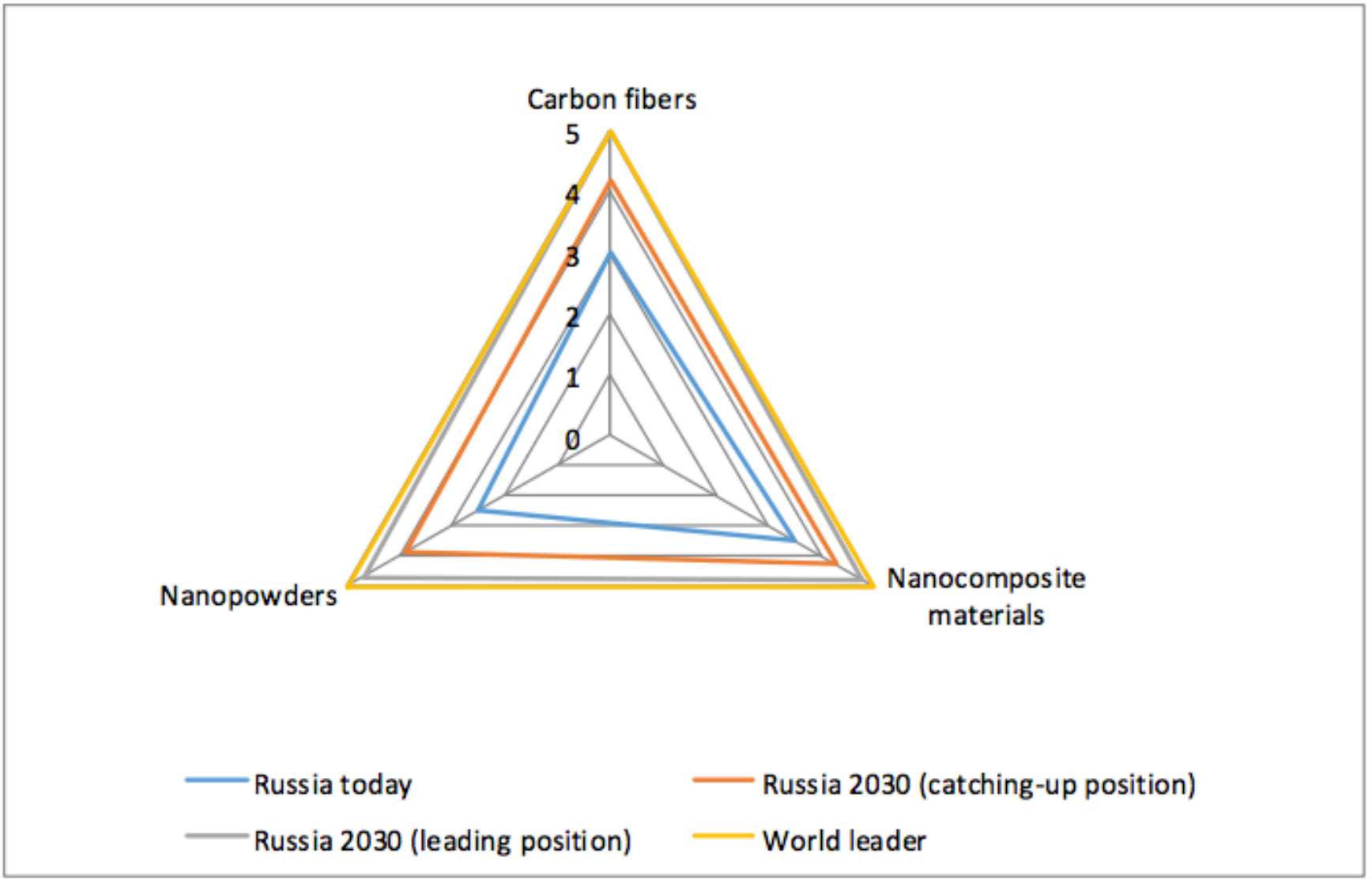
The main market drivers under this scenario are the following:

- support of strategically important industries for the state;
- development of new innovation dimensions;
- gradual and steady growth in demand.

The pessimistic scenario is described by the fact that problems in the world economy will primarily influence the knowledge-intensive industries. The market growth rate in the next two years will amount to 2-3% under this scenario. The annual growth of the nanomaterial market is projected at 5-6%. Experts estimate the probability of implementing a pessimistic scenario as very low (Gokhber 2014).

The expert level of nanomaterials' development in Russia and abroad is presented in Figure 4 (Mikova and Sokolova 2014).

Figure 4
Diagram of nanomaterials' development in Russia and abroad



As can be seen from the diagram, Russia lags behind the world leaders in all regards. However, the gap in the scientific and technical component can be narrowed with sufficient funding. Russia is currently at the crossroads: to be a catching-up country or to pursue the policy of a leading power. This requires to carry out reforms in science and offset lagging from the world leaders by stimulating the scientific sector (tax holidays, subsidizing innovation projects, attracting foreign capital, venture funds and banking sector).

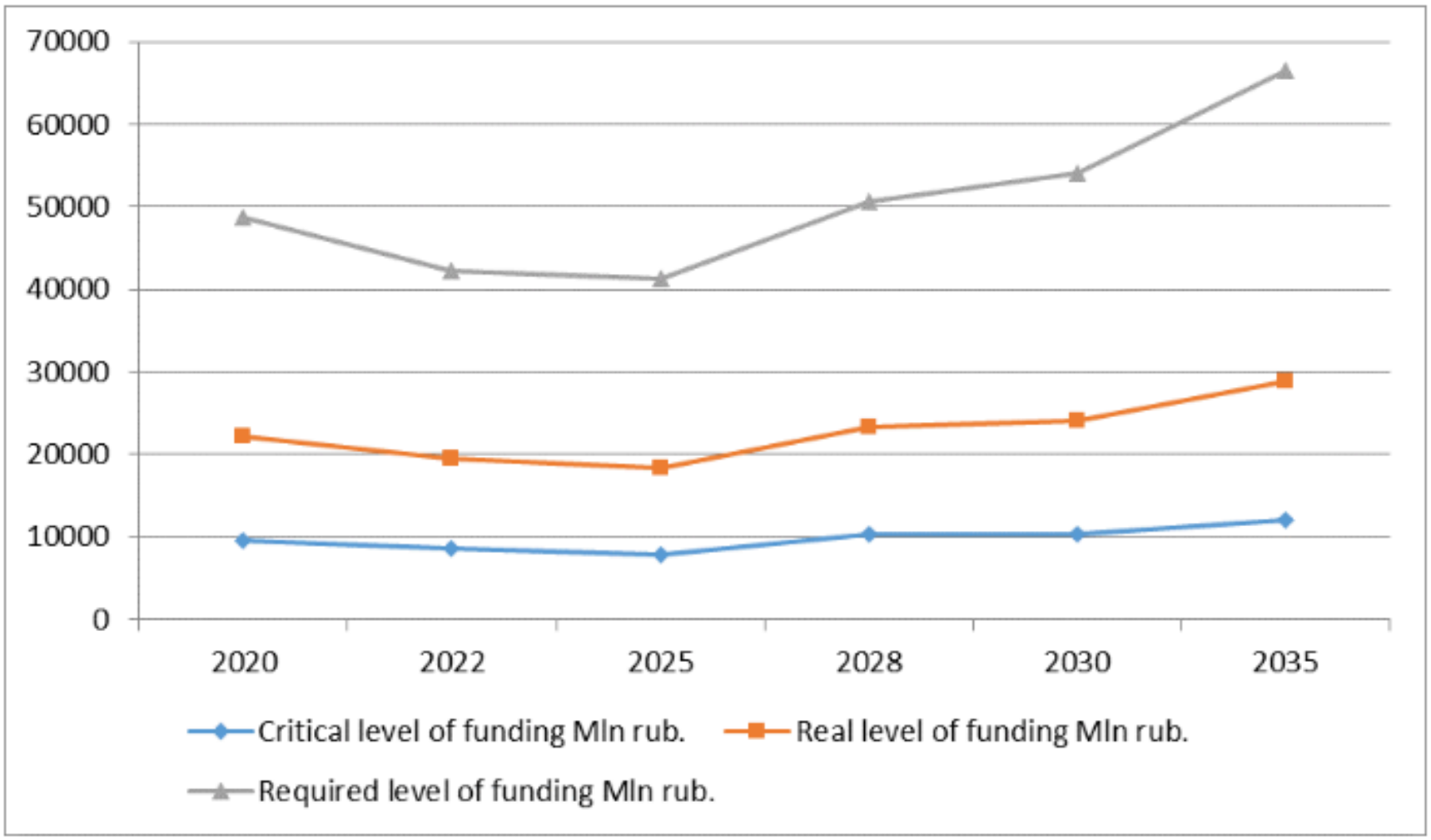
4. Discussion

The process of forming an infrastructure for nanomaterials' funding, which is already quite extensive (102 centers for the collective use of scientific equipment, more than 390 technology transfer centers, about 180 innovation and technology centers and technology parks, over 90 business incubators were established), is currently ongoing in the national economy. In this case, the national institutions of the financial infrastructure of innovation are of particular importance, as they carry out the largest amount of funding, such as the Russian Venture Company, the Russian Fund for Technological Development (the Industrial Development Fund since 2014), JSC RUSNANO (Sokolov 2012; Sokolova, Mikova and Gutaruk 2016).

Due to the recent geopolitical events, the introduction of Western sanctions against Russia in particular, the task of improving the competitiveness of the domestic real sector of the economy becomes urgent. This predetermines the need to innovatively update the obsolete production potential, introduce cutting-edge technology and products of creating the competitive and efficient high-tech industrial capacities (Decree of the President of the Russian Federation dated May 7, 2012 No. 596).

According to expert estimates, the volume of the real, required and critical funding of the nanomaterials' sector in the Russian Federation is shown in Figure 5 (Gokhber 2014).

Figure 5
Expert estimates of the nanomaterials' sector funding in the Russian Federation



The factors accelerating the nanotechnology development are the following:

• attention of public and media;

• obtaining state subsidies and tax holidays for enterprises engaged in science-intensive production;

• import substitution factor. Isolation from the European countries engaged in high-tech production encourages Russian companies to actively implement their developments on the market in order to quickly occupy their niche in the created vacuum (Chebotarev and Selensky 2016; Chebotarev and Yakhont 2016).

Factors of negative impact include the following:

• duration of the period of bringing the products to the market due to the unsatisfactory interaction of science and production;

• duration of the period of creating new enterprises for nanomaterials’ production;

• high technological risks;

• high cost of development and introduction of nanotechnology;

• need to use unique equipment;

• interdisciplinarity of research;

• lack of legislation on investors' rights protection and defining principles of nanotechnology functioning and development;

• multidimensionality of the created nanotechnology application;

• significant gap between the level of development in the field of nanotechnology and the level of infrastructure development;

• high cost of patent protection and complexity of patenting process,

• territorial non-uniformity of nanoindustrialization.

According to the authors, the main factor that negatively affects the nanotechnology market development in Russia is a large gap between scientific developments and practical implementation of these developments in production. This is because Russian scientists lack experience of commercializing inventions created by them.

5. Conclusion

It must be noted in conclusion that the following new results have been obtained and the following proposals have been developed as a result of the research.

1. A general conclusion based on the results of clarifying the comparative assessment of the levels of science, nanomaterials and nanotechnology in the Russian Federation and abroad is the long-term preservation of Russia's lagging behind the world leading powers in nanotechnology under all forecast scenarios for the long-term socioeconomic development, except for the forced (required option).

2. The most significant lagging in nanomaterials and nanotechnology is forecasted by 2030-2035 in case of a failure to adopt a system of measures to modernize the domestic sector and fundamental science, a significant increase in their efficiency, concentration of efforts on breakthrough scientific and technological areas, accelerated overcoming of import dependence, increase in the efficiency of interaction between the knowledge generation centers, business and state customers (Ryzhkin 2014).

3. An additional negative impact of the sanctions regime on the development of nanomaterials and nanotechnology was noted during the forecast development.

As such, the domestic industry possesses the required potential for creating advanced samples based on nanomaterials that have no analogues abroad, and doing this requires to carry out the measures specified in the paper to support the development of nanotechnology.

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