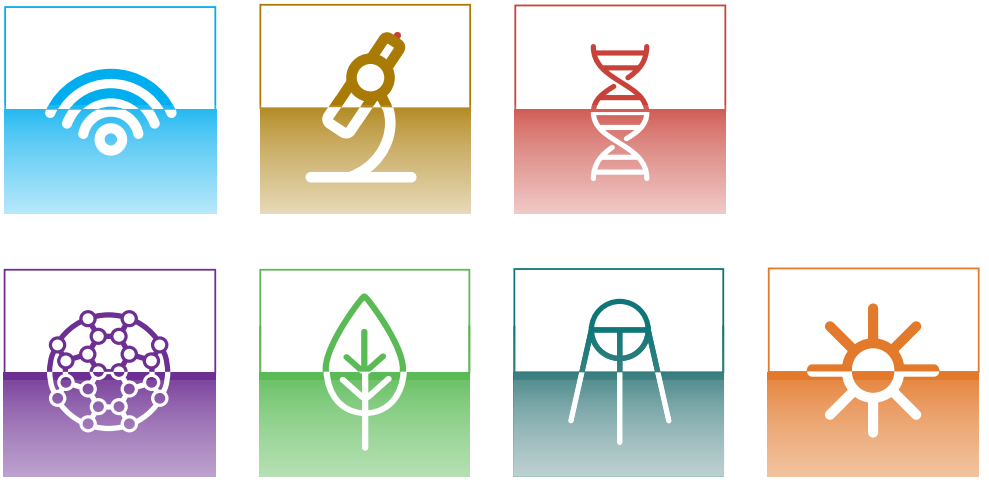
Ministry of Education and Science
of the Russian Federation

HIGHER SCHOOL OF ECONOMICS
NATIONAL RESEARCH UNIVERSITY

Russia 2030:
Science and Technology Foresight



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Russia 2030:
Science and Technology Foresight

Moscow 2016

УДК 001.18+62-047.72
ББК 72в6+3в6
R95

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Russia 2030: Science and Technology Foresight / Gokhberg L. (Ed.); Ministry of Education and Science
R95 of the Russian Federation; National Research University Higher School of Economics. – Moscow: HSE, 2016. – 232 p. – 300 copies. – ISBN 978-5-7598-1351-4.

Russia 2030: Science and Technology Foresight was approved by the Prime Minister of the Russian Federation on January 3, 2014 (№ DM-P8-5). This report presents materials for the Foresight that were prepared by the National Research University Higher School of Economics at the request of the Ministry of Education and Science of the Russian Federation. More than 2000 Russian and foreign experts, including representatives of leading research centres, universities, companies, technological platforms, and innovative regional clusters took part in this study.

The aim of the study was to identify Russia's most promising areas of science and technology that are capable of playing an important role in solving various social and economic issues and realising the country's competitive advantages. The Foresight examines current global challenges, the windows of opportunity and threats linked to these challenges, future innovation markets, radical new products and technologies, and research areas in seven priority fields: Information and Communication Technologies; Biotechnology; Medicine and Health Care; New Materials and Nanotechnologies; Environmental Management; Transport and Space Systems; Energy Efficiency and Energy Saving. The final recommendations have been widely discussed with a large number of Russian and foreign experts.

The report is of practical interest to international organisations, government agencies, companies, research organisations, universities, technology platforms, innovative regional clusters, and other organisations.

This publication was prepared with the support of Development Fund for Applied Research of the National Research University Higher School of Economics.

УДК 001.18+62-047.72
ББК 72в6+3в6

Please cite this publication as: Gokhberg L. (Ed.) (2016) Russia 2030: Science and Technology Foresight. Ministry of Education and Science of the Russian Federation, National Research University Higher School of Economics.

ISBN 978-5-7598-1351-4

GRATITUDE

The report has made use of expertise and research reports from the following organisations:

National Research University Higher School of Economics;

Centre for Macroeconomic Analysis and Short-term Forecasting;

science and technology Foresight centres based at leading higher education institutions (M.V. Lomonosov Moscow State University; the Moscow Institute of Physics and Technology; the National Research Nuclear University; St. Petersburg State University of Information Technologies, Mechanics and Optics; the Siberian State Medical University; and K.E. Tsiolkovsky Russian State Technological University);

research centres (Kurchatov Institute National Research Centre; the All-Russian Scientific Research Institute of Aviation Materials; the Central AeroHydrodynamic Institute named after Professor N.E. Zhukovsky; the Central Research Institute of Machine Building; Academician M.F. Reshetnev "Information Satellite Systems" (JSC); and others);

technology platforms ("Aviation Mobility", "BioTech2030", "High-speed Intelligent Transport", "Deep Processing of Hydrocarbon Resources", "Light and Reliable Constructions", "Medicine of the Future", "National Information Satellite System", "National Programming Platform", "National Supercomputer Technology Platform", "Reclaiming the Ocean", "Technologies of Ecological Development" and others).

The authors gratefully acknowledge significant contributions to the study provided by the following distinguished experts:

Sergey Abramov, Boris Aleshin, Nikolay Aleshin, Mikhail Alfimov, Grigory Andrushchak, Alexander Archakov, Mikhail Beburov, Mariya Belova, Nikolay Bortnikov, Valentin Chanturiya, Valery Charushin, Alexander Cherniavsky, Sergey Chernyshev, Mikhail Chetvertakov, Boris Chetverushkin, Andrey Dutov, Vladimir Fortov, Alexander Gabibov, Yury Izhvanov, Vladimir Ilyin, Evgeny Kablov, Igor Kalyaev, Pavel Kaminsky, Anatoly Karachinsky, Alexander Klimenko, Sergey Kolpakov, Leonid Komm, Anatoly Koroteyev, Boris Kryuchkov, Andrey Lisitsa, Dmitry Livanov, Vitaly Lopota, Alexander Makarov, Svetlana Maltseva, Tatiana Mitrova, Oleg Naraikin, Artemy Nikitov, Dmitry Paison, Valentin Pashin, Fedor Pekhterev, Anatoly Petrovsky, Andrey Polozov-Yablonsky, Alexey Ponomarev, Nikolay Ponomarev-Stepnoy, Vladimir Popov, Alexander Povalko, Alexander Putilov, Adam Rimashevsky, Yury Ryzhov, Alexey Sazonov, Rashid Shagaliev, Alexey Shalkovsky, Vladimir Skulachev, Igor Sokolov, Alexey Soldatov, Dmitry Stambolsky, Kirill Sypalo, Arkady Tishkov, Vsevolod Tkachuk, Mikhail Ugryumov, Yury Urlichich, Vladimir Vasilyev, Boris Velichkovsky, Vasily Velikhov, Roman Vilfand, Eduard Volkov, Viktor Zakharov, Andrey Zemlyanov, Sergey Zhukov.

The members of the International Advisory Council on Foresight and Science and Technology Policy, National Research University Higher School of Economics were involved in the discussion of the methodology and results of the study:

Luke Georghiou (Chair), Marc Boden, Cristiano Cagnin, Jonathan Calof, Jennifer Cassingena Harper, Mario Cervantes, Moonjung Choi, Jose Cordeiro, Kerstin Cuhls, Karel Haegeman, Attila Havas, Michael Keenan, Jonathan Linton, Ian Miles, Riel Miller, Mu Rong Pin, Rafael Popper, Anastassios Pouris, Pierre-Alain Schib, Ricardo Seidl da Fonseca, Philip Shapira, Kuniko Urashima, Angela Wilkinson.

Implementation of the foresight study would have been impossible without the active participation of the staff of the Institute for Statistical Studies and Economics of Knowledge, National Research University Higher School of Economics:

Mikhail Bokov, Anastasia Edelkina, Konstantin Fursov, Jean Gines, Elena Gutaruk, Galina Kitova, Maxim Kotsemir, Irina Kuznetsova, Tatiana Kuznetsova, Dirk Meissner, Nadezhda Mikova, Yadviga Radomirova, Vitaly Roud, Vladimir Salun, Ruslan Saygitov, Ozcan Saritas, Irina Skorodumova, Maria Sokolova, Thomas Thurner, Natalia Velikanova, Natalia Veselitskaya.

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INTRODUCTION

«Work is now being done to finalise Russia's long-term science and technology Foresight up to 2030. Specific directions have been identified both to improve traditional sectors and to break through onto the high-tech market…»

V.V. Putin

Message from the President of the Russian Federation
to the Federal Assembly of the Russian Federation,
12 December 2012

'Foresight should serve as a basis for the strategies and innovation programmes of the largest Russian companies. … The Foresight not only contains recommendations but is a background to prepare plans.

D. Medvedev
Meeting with deputy Prime Ministers,
20 January 2014

Russia 2030: Science and Technology Foresight (RSTF) was approved by the Prime Minister of the Russian Federation in January 2014[1]. The report containing the detailed results of the Foresight study was agreed with interested ministries and agencies (Russia's Ministry of Telecom and Mass Communications, Ministry of Health, Ministry of Transport, Ministry of Finance, Ministry of Economic Development, Ministry of Industry and Trade, Ministry of Natural Resources and Environment, Ministry of Energy, Russian Federal Space Agency) and the Russian Academy of Sciences. The Foresight report was approved at the meeting of the Intergovernmental commission on technological forecasting under the presidium of the Presidential Council of Russia on modernisation of the economy and innovative development[2] held on January 17, 2013. In the address to the Federal Assembly on December 12, 2012, the President of Russia emphasised the importance of the RSTF in identifying the strategic directions for the country's social, economic, scientific and technological development [President RF, 2012b]. Moreover, the Russian Prime Minister highlighted the same at a meeting with deputy Prime Ministers on January 20, 2014 [Government RF, 2014a].

The starting point for developing the RSTF was an analysis of global challenges in science and technology, and social, economic, and environmental development. These challenges include: the loss of strategic mineral reserves, the search for alternative sources of energy and energy security, ageing populations, changing ways of life at an individual and societal level, widespread socially significant diseases; greening of the economy and a shift to a carbon-free society; as well as a shift of the global economy to a new stage of technological development, accompanied by changing economic structures and factors of competitiveness.

One of the principal catalysts for the advancement of the new technological wave is the convergence of various fields of science and technology, a development capable of having a significant influence on finding technological answers to current global challenges. A vivid example of this trend is the exponential growth in the number of scientific publications that

[1] Resolution № DM-P8-5 of January 3, 2014.
[2] Set up based on a decision by the presidium of the Presidential Council of Russia on modernisation of the economy and innovative development taken on June 28, 2013 (protocol № 1), which implemented the Presidential Decree of the Russian Federation of May 7, 2012 № 596 "On long-term state economic policy" (paragraph 2, sub-point d, point 2).

are interdisciplinary in nature. For example, from the year 2000 the share of articles on the topic of medicine in the category of 'computer sciences' in Scopus-indexed international journals doubled.

The scale of the potential economic and social effects of this convergence in technologies is clearly shown by the example of widening human opportunities and greater creative potential. Research on the structure and functions of the human brain, as well as on the appearance of personalised sensory interfaces and 'humanised' technologies radically changes the boundaries of knowledge and communication. Improvements in health and the physical capabilities of humans will arise thanks to: progress in bioinformatics, genomics, proteomics, and other nanobioprocesses for developing medicine and treatments; the creation of implants and regenerated biosystems for organ replacement and monitoring the physiological state of the organism; nano-sized mechanisms and medical instruments of mild effect; multi-modal platforms for helping people with sight or hearing loss; 'brain-brain' and 'brain-computer' interfaces; the development of virtual environments for learning, and designing and running projects on any physical scale through remote working, etc.

Such fundamental processes will of course lead to a cardinal shift in existing global value chains (in particular, the displacement of profit centres in favour of industrial design) and to a change in the key actors. The configurations of global energy infrastructure, as well as transport and ICT systems will also experience fundamental changes.

Modernisation will affect the education sphere, which at the present time is undergoing a serious transformation in connection to the appearance of new educational technologies. The concept of lifelong learning is entering a new cycle thanks to the spread of distance learning, online courses, mass introduction of within-firm education, and the creation of a virtual environment to exchange knowledge and experiences among all participants of the educational process.

The global trends and challenges discussed above have entailed significant changes, in particular in the field of science and innovation, and the related reorganisation of science and technology policy to broaden the scope of its subjects and the spectrum of instruments used.

One of the most important problems facing Russia – searching for new sources of economic growth – is not possible to resolve without the large-scale modernisation of traditional economic sectors using modern technology as well as the creation of new industries providing an outlet onto emerging high-tech markets. Switching the Russian economy onto a path to innovation presupposes advances in high-tech industries and the services sector and a radical increase in the competitiveness of these sectors, which requires further improvement in science, technology and innovation policy, advances in the quality of its information and methodological support and strengthening of the case[3].

The set of tasks discussed above determined *the primary objective of developing the RSTF: to define Russia's most promising areas in terms of science and technology development which make it possible to realise the country's competitive advantages in the mid- and long-term*. To achieve this, systematic work has been carried out over the past few years in connection with Foresight studies.

The first major project on a national level was the Russian Science and Technology Development Foresight: 2025, initiated in 2007 by the Russian Ministry of Education and Sci-

[3] This issue has been the main focus of Expert Group № 5 "The Transition from Stimulating Innovation to Innovation-Based Growth" established in accordance with the Order of the Chairman of the Government of the Russian Federation V.V. Putin № VP – P13-209 dated 19 January 2011 to develop recommendations on current issues pertaining to the country's socio-economic development strategy for the period up to 2020.

ence. This project covered three main areas: a macroeconomic forecast of the Russian economy; a science and technology Foresight (in priority areas) and an industry Foresight, the aim of which was to elaborate options for the technical development of critical economic sectors. One of the central elements of the project was a large-scale survey of experts using the Delphi method. More than 800 technologies were categorised under 10 future areas in science and technology development; then 100 of the largest companies in key sectors of the Russian economy were surveyed to analyse current and future demand for these technologies.

During the next stage of the science and technology Foresight (2009–2010), the results of foreign and international Foresight studies in the socio-economic and science and technology spheres were combined and used to evaluate the future global economy and certain major global markets taking into account the expected consequences of the financial and economic crisis. The results obtained provided a basis for the macroeconomic forecast of the Russian economy, as well as scenario based technology Foresight for a number of sectors of the Russian economy. The project defined groups of prospective technologies and products which meet the priorities of the future modernisation of the country.

In 2013, work on the RSTF was completed, the results of which are set out in this report.

The work has given the following main results:

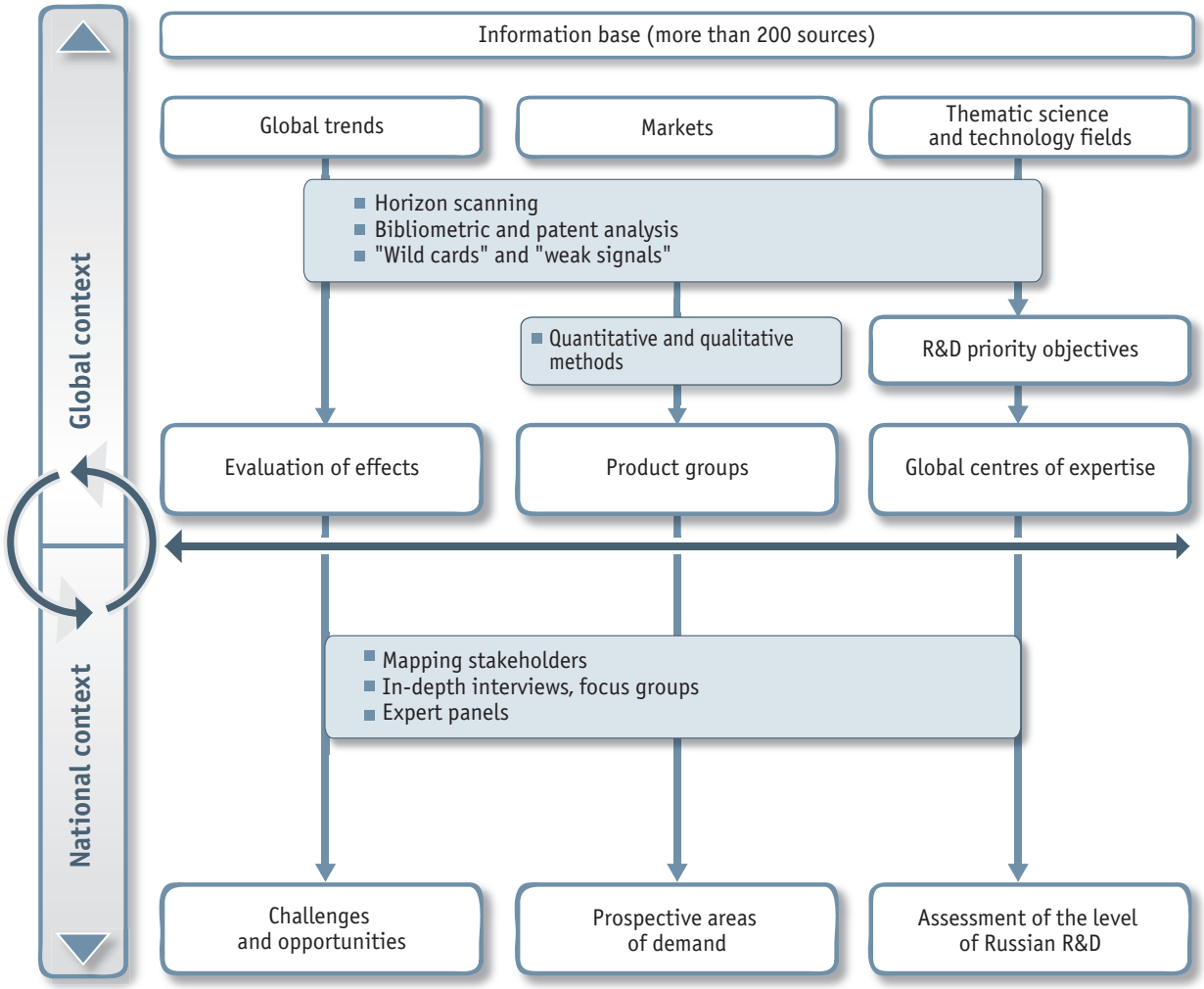
- the trends with the greatest impact on science and technology have been identified together with the challenges that they pose for the long-term development of the economy, science and society in the global and national contexts;
- for the seven priority areas of science and technology development ("Information and Communication Technologies"; "Biotechnology"; "Medicine and Healthcare"; "New Materials and Nanotechnology"; "Environmental Management"; "Transport and Space Systems"; and "Energy Efficiency and Energy Saving"):
  - based on the trends established, key threats and opportunities have been identified for Russia;
  - prospective markets, product groups and potential demand for Russian innovative technology and design have been identified;
  - a detailed description of priority thematic areas for development in science and technology has been drawn up and more than 1,000 research and development priorities needed for the emergence of the defined groups of innovative products and services have been identified;
  - an assessment has been given regarding the status of domestic research in these areas; "white spots" have been identified, together with parity and leadership zones, which could serve as a basis to form international alliances and to position Russia as a centre for global technological development;
- recommendations have been prepared aimed at promoting practical use of the results from the RSTF in science, technology and innovation policy, including when forming, adjusting and implementing public programmes in the Russian Federation, and notably special federal programmes relating to science and technology.

Organisation and Methodology of the Work

The research presented is different from previous Foresight studies on account of its more complex structure and the depth of the common concept. The organisational design of the RSTF is provided in figure 1.

The RSTF has relied on the use of Foresight's broad spectrum of modern tools which, on the one hand, are best adapted to the Russian situation and, on the other hand, have had their effectiveness confirmed in international practice. Whilst developing the Foresight, both norma-

Fig. 1. Organisational Design of Russia 2030: Science and Technology Foresight



Source: NRU HSE.

tive ("market pull") and research ("technology push") approaches were integrated. The normative approach was problem-oriented (market) in nature, in which key challenges and opportunities are identified first for the selected science and technology areas, followed by corresponding solutions in terms of "technology packages" or other responses. In the research approach, prospective break-through products and technologies were singled out which could radically change the existing economic, social and industrial paradigm. The recommendations of the RSTF have been developed simultaneously with three positions: markets, technologies and governance, which makes it possible, in the dialogue with the various groups of beneficiaries, not only to identify promising areas in science and technology, but also to understand who can take advantage of the fruits of their development and how.

In terms of Foresight tools both well-known traditional methods (priority setting, development of future visions, roadmapping, analysis of Grand Challenges) and relatively new approaches (horizon scanning, weak signals, wild cards[4], etc.) were used.

[4] Events that are unlikely to occur but have high potential effects (possibly negative) that can shape future developments in unexpected ways.

Sources of Information to Prepare the Foresight

The Foresight study was based on more than 200 sources including the following:

- analytical and Foresight studies by international organisations (OECD, European Commission, UN, UNIDO, World Bank, World Health Organisation, International Energy Agency, OPEC, etc.);
- national science and technology Foresight studies (UK, Germany, France, USA, Japan, South Korea, China, Brazil, South Africa, Finland, the Netherlands, Taiwan, etc.);
- Foresight studies by major corporations (Shell, BP, Siemens, Microsoft, Daimler, Deutsche Bank, etc.), as well as a number of international professional associations;
- materials by leading international Foresight centres (RAND Corp., the European Commission Institute for Prospective Technological Studies; the University of Manchester, the National Institute of Science and Technology Policy, Japan; the Telfer Business School at the University of Ottawa, Canada; the Korean Institute for the Assessment and Planning of Science and Technology; the Georgia Institute of Technology, USA; the Institute for Policy and Management at the Chinese Academy of Sciences; the Austrian Technology Institute, etc.);
- Russian S&T Foresight studies, including those commissioned by the Russian Ministry of Education and Science;
- strategic documents on long-term prospects for development in the Russian economy and its sectors (The Concept of Long-Term Socio-Economic Development of the Russian Federation: 2020; Forecast of Long-Term Socio-Economic Development of the Russian Federation: 2030; industry development strategies; programmes for innovation development for large companies, etc.);
- databases of patent offices (Russian Patent Agency, the US Patent and Trade Office, the European Patent office, the World Intellectual Property Organization, etc.);
- databases of international journals (ISI Web of Knowledge by Thomson Reuters, Scopus by Elsevier, the Russian Scientific Citation Index, etc.).

Foresight Infrastructure

In the framework of the Foresight study an expert network covering more than 200 organisations (research centres, universities, companies, etc.) and over 2,000 individual experts was established. The selection of the experts involved in the preparation of the Foresight was based on specially developed procedures and criteria. Experts in specific science and technology fields were selected primarily on the basis of objective gauges of their qualifications (academic citation indices, patents, involvement as keynotes at major international conferences, management of leading research centres, etc.). Members of innovative companies, engineering centres, marketing organisations, consumer organisations for innovative products and suppliers (distributors) were invited as expert practitioners to play a role in the development of the Foresight. From this, first rate expert working groups were formed for the key science and technology areas (more than 120 leading Russian and foreign academics, as well as more extensive working groups including representatives of the sciences, government, business and expert community, totalling more than 800 people).

Foreign specialists were also invited to participate in preparing the Foresight, including members of international organisations, leading universities and research centres, as well as directors of scientific laboratories set up under grants issued by the Government of the Russian Federation and allocated on a competitive basis to provide state funding for scientific research under the guidance of leading scientists in Russian higher education institutions and research institutes. In addition, a specialist methodological group of foreign experts was set up to dis-

cuss the methodology for the research being carried out and to validate the results obtained. The group was composed of more than 100 experts from the OECD, UNIDO and major global Foresight centres (from the UK, USA, Canada, Japan, South Korea, Germany, France, etc.).

Discussion and Validation of the Foresight Results

The results of the Foresight study have been discussed at international and Russian forums involving leading academics and specialists, including the following conferences:

- Future-oriented Technology Analysis (May 2011, Seville);
- Euronanoforum-2011 (June 2011, Budapest);
- Foresight and Science, Technology and Innovation Policies. Best Practices (October 2011, Moscow);
- International Research Conference on Foresight and Futures (August 2011, Istanbul);
- Knowledge Intensive Service Businesses (October 2011, Karlsruhe);
- World Aqua Congress (November 2011, New Delhi);
- Foresight for Science and Technology Development in Aircraft Engineering. International Methodology Workshop (December 2011, Moscow);
- Symposium on Assessing the Economic Impact of Nanotechnology (March 2012, Washington);
- XIII April International Scientific Conference on Economic and Social Development Problems (April 2012, Moscow);
- Innovative Methods for Innovation Management (May 2012, Beijing);
- R&D Management Conference (May 2012, Grenoble);
- Bromley Memorial Lecture and Event on Science Technology Innovation Policy (May 2012, Ottawa);
- 2012 STEPI International Symposium (May 2012, Seoul);
- OECD Innovation Policy Platform (June 2012, Paris);
- 7th International Aerospace Congress IAC '20 (August 2012, Moscow);
- Foresight for Innovative Responses to Grand Challenges (October 2012, Moscow);
- XIV April International Scientific Conference on Economic and Social Development Problems (April 2013, Moscow);
- Creating Markets from Research Results (May 2013, Munich);
- R&D Management (June 2013, Manchester);
- Global Research and Social Innovation: Transforming Futures (21st conference of the World Future Studies Federation, June 2013, Bucharest);
- ISPIM 2013: Innovating in Global Markets: Challenges for Sustainable Growth (June 2013, Helsinki);
- 7th ESPI Autumn Conference "Space in a Changing World" (September 2013, Vienna);
- Russian Science and Technology Foresight: aimed at practical use of the results (September 2013, Moscow);
- Foresight and Science, Technology and Innovation Policy (October 2013, Moscow);
- Evaluating the effects of Foresight studies in Russia and the EU (January 2014, Moscow);
- XV April International Academic Conference on Economic and Social Development (April 2014, Moscow); and others.

Use of the Foresight Results

The RSTF is an important part of the system of technology Foresight that aims to provide for future needs in the processing sector of the economy, taking into account the development of key manufacturing technologies. This system was created in accordance with the Presidential

Decree of the Russian Federation of May 7, 2012 № 596 'On long-term state economic policy' (para. 2, sub-point d, point 2). A meeting of the intergovernmental commission held on October 4, 2013 to discuss the results of the RSTF approved an action plan to implement the results of Russia's long-term RSTF up to 2030 in accordance with federal level state programmes on science and technology as well as the priority areas of science and technology in Russia and the list of critical technologies. This plan includes a series of methodological, analytical and information-giving events.

Some of the results of the RSTF were used when:

- drafting the Long-Term Socio-Economic Development Forecast for the Russian Federation for the period up to 2030[5];
- preparing the draft government programme "Science and Technology Development" for the period up to 2020[6];
- adjusting the Foresight parameters of the "Energy Strategy of Russia for the period up to 2030" up to 2035; and developing a target vision for the development of the Russian energy sector for the period up to 2050;
- preparing a report for the President of Russia on drawing up a list of priority research tasks which require the use of the resources in federal centres of collective use of scientific equipment[7];
- carrying out industry Foresight studies and formulating corresponding road maps (development of space navigation, aviation science and technology, shipbuilding, oil refining and petrochemistry, biotechnology and genetic engineering, the production of composites, ICT and mass media, energy efficiency, photonics, water consumption and others);
- formulating development programmes for innovative regional clusters, strategic research programmes for technology platforms, and innovative development programmes for a number of Russian companies.

The results of RSTF can be used by the following stakeholders:

- interested federal agencies – as part of their work on creating, revising, and implementing state programmes, federal targeted programmes in science and technology, including plans and detailed timeframes for implementing the priority areas of science and technology in Russia, the list of critical technologies of the country, and sectoral documents of state strategic planning including sectoral critical technologies;
- state corporations active in the science and technology sphere that have a long-term planning remit (joint stock company United Aircraft Corporation, Rostec Corporation, Rosatom, etc.) – to help them draw up innovation programmes;
- institutes of the Russian Academy of Sciences – to develop research plans;
- academic community – to identify the areas of research that are in demand and promote existing technologies and technological solutions through communication platforms that have been created as part of the Foresight study;
- businesses – to develop company strategies and investment projects related to technological modernisation;
- technological platforms – to help them in creating, revising, and implementing strategic research programmes;
- development institutions that support innovation (Bank of development and external relations, joint stock company 'Russian Venture Company', joint stock company Rosnano) – to help them draw up long-term plans;
- innovative regional clusters – to help them design, revise and implement development strategies for the mid- and long-term.

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[5] Approved by the Government of the Russian Federation on March 25, 2013.
[6] Approved by the order of the Government of the Russian Federation dated 20 December 2012, № 2433.
[7] Letter of Ministry of Education and Science of Russia № MON-P-119 of January 17, 2014.

According to the Federal Law № 172 of June 28, 2014 'On strategic planning in the Russian Federation', science and technology Foresight should be carried out on a regular basis in tandem with other documents of state strategic planning in order to create scientifically justified visions on the directions and expected outcomes of the country's science and technology development.

The present report is composed of seven sections, according to the science and technology priority areas: information and communication technology; biotechnology; medicine and health care; new materials and nanotechnology; environmental management; transport and space systems; energy efficiency and energy saving.

For each area, we present detailed analysis on the challenges emerging from global trends, the windows of opportunity, new threats and the extent of their influence on Russia. We analyse the most important future market niches, products, and services that could have a radical influence on the dynamics of global markets and refer to their competitive advantages. We identify the prospective directions in applied research, and give a comparative assessment of the level of emerging research carried out in Russia and leading countries.

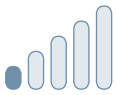
In the concluding chapter, we examine the possibilities for introducing the results of the RSTF – from choosing priorities and instruments for state science, technology and innovation policy to creating strategies for firms, technology platforms and innovative regional clusters.

METHODOLOGICAL NOTES

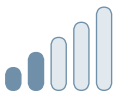
Several criteria are used to choose priorities for applied a research that focuses on creating science and technology capacity. Research is considered as priority if it:

- can lead in the long-term to new markets or market niches, products with new properties, or innovative services;
- is interdisciplinary and inter-industry in nature;
- brings answers to challenges that exist in a priority area;
- contributes to the creation of a technological platform of the future economy and society;
- is capable of solving key research problems in a given area and creating future research capacity.

For each of these an assessment of the level of Russian research will be given based on the following scale:



"blank spots" – a significant lag behind global levels, lack (or loss) of scientific schools "blank spots" – a significant lag behind global levels, lack (or loss) of scientific schools



"groundwork" – the existence of basic knowledge, skills, infrastructure which could be used to boost development of the corresponding areas of research

"possibility for alliances" – the existence of a limited number of competitive teams carrying out research at a high level and able to cooperate with global leaders "on an equal footing"

"parity" – the level of Russian research is just as strong as global research

"leadership" – Russian researchers are global leaders

experts' estimations are dispersed

ABBREVIATIONS

4G	4th generation of mobile technology
5G	5th generation of mobile technology
ADC	Analogue-to-Digital Converter
AIDS	Acquired Immunodeficiency Syndrome
API	American Petroleum Institute – a measure of the density of oil developed by the American Petroleum Institute
BI	Business Intelligence
CMOS	Complementary Metal Oxide Semiconductor
DAC	Digital-to-Analogue Converter
DBMS	Database Management System
DNA	Deoxyribonucleic Acid
EPO	European Patent Office
EU	European Union
GIS	Geographic Information System
GLONASS	Global Navigation Satellite System
GPS	Global positioning system
HSE	National Research University Higher School of Economics
ICAO	International Civil Aviation Organization
ICT	Information and Communication Technology
IoT	Internet of Things
IP	Internet Protocol
LNG	Liquefied natural gas
M2M	Machine-to-machine interaction technologies and standards
MOX Fuel	Mixed-Oxide Fuel
MRI	Magnetic Resonance Imaging
NPP	Nuclear Power Plant
OECD	Organisation for Economic Co-operation and Development
OPEC	Organization of the Petroleum Exporting Countries
R&D	Research and Development
RNA	Ribonucleic Acid
RSTF	Russia 2030: Science and Technology Foresight
UN	United Nations
UNIDO	United Nations Industrial Development Organization
VLSI	Very-Large-Scale Integration

1 INFORMATION AND COMMUNICATION TECHNOLOGY

Information and Communication Technologies (ICT) are among the key drivers of the shift towards a knowledge-based economy. Their development contributes to increasing the quality of life, the efficiency of private businesses and public administration, the emergence of new forms of education systems, better communication and interaction between individuals, and access to a wide variety of information.

The innovative nature of products linked to ICT and related industries in many ways changes the technological processes. The exponential growth in technical features, miniaturisation and the reduction in the cost of components is leading to an increase in computing power and technological intelligence and the rapid overhaul of standards and technological platforms for information systems and networks and the corresponding goods and services. The emergence of pervasive, interactive, personalised and super high-speed networks, devices and global systems is contributing to the development of multimedia content and a wide range of services. It is forecast that with time ICT capabilities, in terms of individual needs, will only increase. There will be a simultaneous growth in the value of global innovation networks allowing users to manage the life cycles of their goods and services (CALS technology – continuous acquisition and life-cycle support). In connection with the unceasing growth of competition in ICT markets, which means lower prices of certain devices, it is foreseen that new models of sales will emerge where the value added will be determined by the 'device – software' package.

The accelerated evolution of ICT, on the one hand, and its rapid obsolescence, on the other, stimulates demand for new products. Thus, the development of cloud networks, new architectures and principles for organising computing entails a transformation in software and infrastructure solutions, leading to innovative changes in the business strategies of companies across all sectors of the economy.

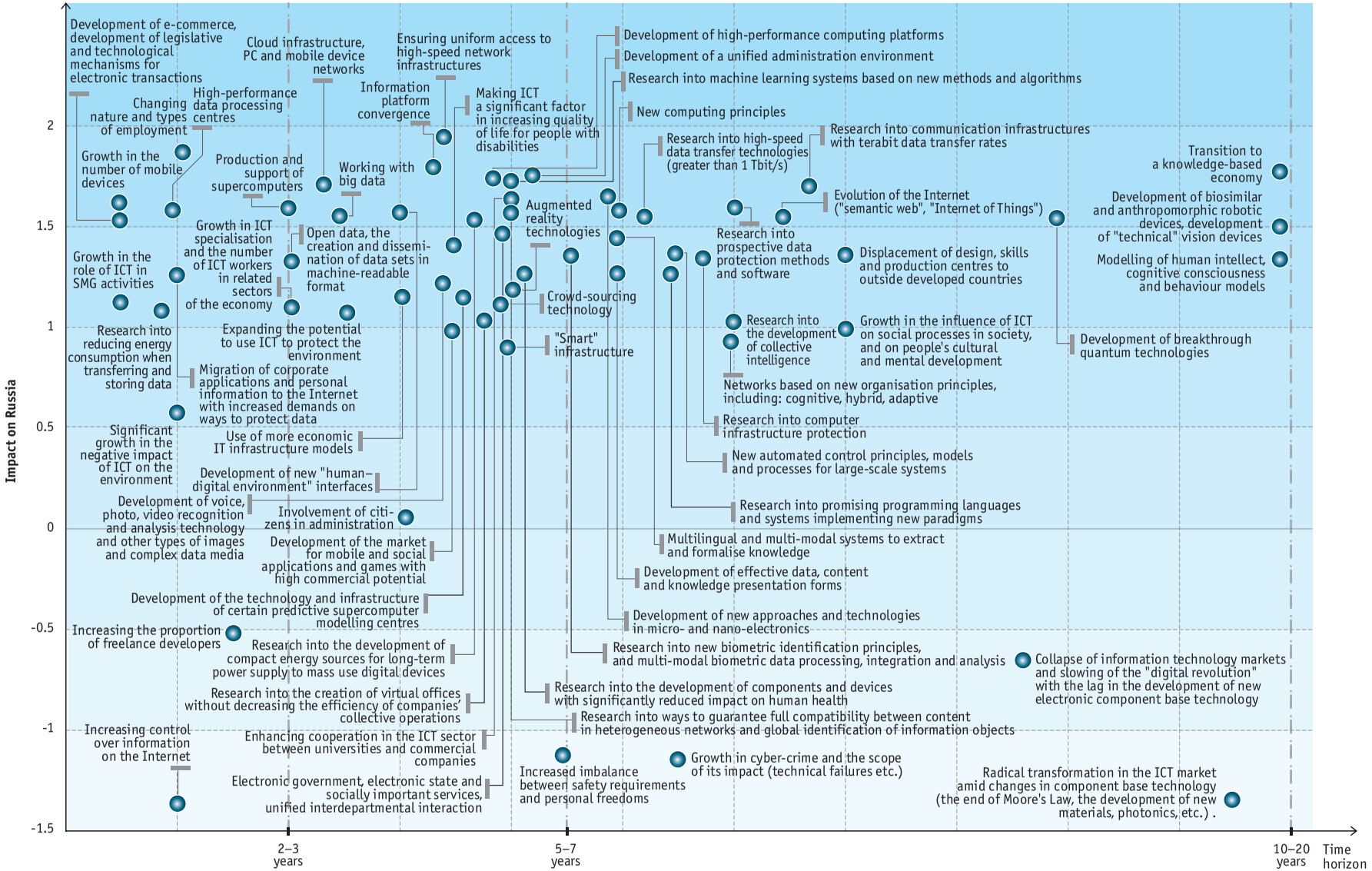
1.1. Challenges and Opportunities

The further development of the "Information and Communication Technology" priority area is shaped by the challenges and opportunities outlined in figure 2.

The widespread penetration of ICT into most aspects of life has a positive impact on the development of economic activity and social processes. However, in the long-term, one of several extremely serious challenges in this field is *the growth in cybercrime and the scale of its effects (technical failures, etc.)*. This, in turn, is leading to greater control over information on the Internet and, as a result, to an increasing imbalance between security requirements and personal human freedoms. It is expected that this trend moving towards illegal activities on global networks will remain stable throughout the forecast period. At the same time, inefficient forms of verification will die away and new methods for socio-political manipulation will start to emerge.

The likelihood of scientific breakthroughs is high in the field of systems aimed at formalising and extracting knowledge and in *machine learning* based on new methods and algorithms.

Fig. 2. Information and Communication Technology: Challenges and Opportunities



Source: HSE ISSEK.

Research and development in next-generation analytics systems and *predictive supercomputer modelling systems* will create fundamentally new possibilities for analysis of integrated processes, decision-making and identifying situations using very large data packages and flows which will have a positive impact on productivity growth in information systems. In this regard, it is worth paying attention to *improvements in technology to produce and support the functioning of supercomputers*.

To provide solutions to problems related to the rapid increase in the volume of unstructured information and processing needs for huge data packages, semantic text analysis methods and *big data processing* technologies will be developed. The problem of "big data" is exacerbated by the need to manage colossal amounts of unstructured data in various formats. This should generate demand for specialised tools to establish connections between data and draw meaningful conclusions based on these connections.

Among the promising areas in the further introduction of ICT into "horizontal" markets, one of the most notable is the *emergence of a single management environment*. In particular, the creation of an information space for transport infrastructure (an environment to exchange unified information between vehicles) will contribute to solving the problem of organising circulation in cities brought about by a continual increase in the density of traffic flows. The creation of a single unified information exchange environment will lead to increased effectiveness in formed logistics chains.

The changing technological base of network infrastructures will bring about the emergence of *methods and devices for high-speed data transfer (greater than 1 Tbit/s)*, which will increase the potential sizes and efficiency of computing clusters and give rise to the development of universal trunk broadband lines.

New computation principles are associated with the emergence of chip-based next-generation classic architectures; hybrid devices combining classic and innovative solutions; and the search for new market niches where destructive technologies can be expected to be developed. Breakthroughs are possible in cryptography, modelling, and new-generation intelligent telecommunications systems.

The development of the distributed networks concept with independent nodes and adaptive routing between them and the incorporation of new classes of *"Internet of Things"* objects into the infrastructure will take place as part of the *evolution of the Internet*. The potential for machine processing of content will increase the effectiveness of such networks, will make it possible to create a unified network infrastructure which will connect all of the devices used by people, and will simultaneously lead to a reduction in the life-cycles of standards and technological platforms of ICT systems and networks. The emergence of mechanisms for focused interaction between people in communities through virtual communication; the development of new generations of "man-machine" interfaces, speech recognition technologies, hybrid cognitive mechanism models and human speech-thought models; and mobile applications offering various interfaces between the "Internet of People" and the "Internet of Things" will all greatly intensify the interaction between users and the digital environment.

As noted above, the forward-looking nature of ICT will in many respects determine the *transition to a knowledge-based economy* which began with the penetration of these technologies into material production and is now gaining speed as they start to saturate the services sector (finance, insurance, trading, transport infrastructure, etc.). However, its effects will only be seen in full in the future. This process provides a vector for further changes in the struc-

ture of economic activity and added value aimed at the intellectualisation of production and consumption.

The development of biosimilar and anthropomorphic robotic devices will lead to a dramatic change in the structure and forms of employment and the use of robots in systems geared towards "human-human" interaction.

A key direction for the development of robotics and data analysis systems will be *the modelling of human intellect and the development of cognitive knowledge and behaviour models*, the relevance of which will continue throughout the forecast period. This, in turn, will contribute to the development of systems which gradually replace the human element in decision-making.

Experts have outlined the following ***threats to Russia*** in ICT:

- the growing "digital divide" related to the accelerated creation of a single global information space without participation of Russia;
- reluctance to adopt widespread medical and other social services being provided through ICT;
- the potential to use ICT to undermine national security and violate state and public order;
- poor skills and lack of resources to ensure an effective (protected) workflow;
- reluctance towards mass use of virtual reality technology;
- the growing vulnerability of private life and personal living space.

1.2. Prospective Markets, Products and Services

The "horizontal" nature of this field facilitates the introduction of both infrastructure and specific sectoral solutions in virtually all sectors of the economy. In the long-term they should provide for the greatest possible growth in core businesses in the ICT industry (telecommunications and IT equipment, software, IT services) as well as in industry, the energy sector, health care, transport, etc.

Prospective markets for the "Information and Communication Technology" priority area:

- telecommunications and IT equipment;
- software and IT services;
- mechanical engineering;
- chemical industry;
- space sector;
- energy sector;
- mineral extraction;
- transport;
- science;
- management;
- education;
- health care;
- individual demand for ICT products.

With the growth in the volume of system and application software there will be an increase in the relevance of the problem of guaranteeing the quality of programmes. An important trend in approaches to developing software is the development of models to verify and test large software systems.

Many spheres of economic activity are gravitating towards the introduction of sensory networks based on the drastic change in the role of humans. The interaction between their elements

(in most cases wireless) is coming to have a proactive, anticipatory controlling influence on human operators. In the long-term the use of sensory networks in various economic sectors could have a significantly greater effect than the spread of the Internet.

In a similar way to the "silicon revolution" in the computer element base in the mid-20th century, there is expected to be radical innovation in the field of electronics (in particular in optoelectronics) conditioned by the emergence of new generation polymers. Electronic devices based on polymer materials will lead to a change in the operating conditions of electronic equipment, an expansion in the capabilities of information technologies and the development of the prerequisites for a transition to new training, welfare and recreation organisational principles.

The evolution of industrial computerisation processes are closely linked to the intensification of computer modelling and improvements in design, engineering, planning and production systems taking into account safety requirements for human health and the environment as well as customisation of manufacturing to meet particular individual requirements.

A current problem is the use of supercomputers with operating speeds of up to several trillion operations per second which are designed to solve problems requiring lengthy calculations. In particular, in the chemical industry such technology is necessary to model the design and development of computer-based experiment modelling technologies.

The creation of clusters (mass-parallel systems) of servers with a large number of processing cores making it possible to scale peak productivity is coming to be a common trend in the development of supercomputer systems for computing tasks. For the most in demand classes of computing tasks (numerical methods, modelling, molecular dynamic problems, etc.) the performance of processor cores is not so much reliant on increasing the clock speed, but rather carrying out a greatest number of floating-point operations in one clock cycle. The active application of prospective tools in high performance computing (HPC) systems, for example, graphics processors (graphical processing units – GPUs) with high technical specifications, will allow manufacturers to reduce costs with increased demand.

In the mechanical engineering sector, key drivers include production engineering technologies (instruments, controllers, sensors, industrial robots, etc.); automated technological process control systems solving the problem of increasing the capital productivity of core technological equipment at a new level of reliability; and automated discrete production operative management systems (predominantly custom-made, small-scale and one-off) and in-shop planning and discrete automated systems (manufacturing execution systems – MES). In the long-term the automation market and mechanical engineering control systems market will become fully "network-centric" and integrated into the ICT sector.

In the medium term there will be developments in design and construction technology for energy-efficient buildings allowing for reductions in energy costs during use by 2.5–3 times, as well as methods to increase the efficiency of process management in the energy sector by using sensory networks and "smart" sensors; and intelligent monitoring, diagnostics and automated control systems for energy systems.

In the transport sector there is considerable potential in the IT services field for groups of services geared towards increasing the quality and broadening the functionality of vehicle and pedestrian navigation. Solving the issue of seamless navigation has given rise to the development of new geographic information systems services and augmented reality applications.

In health care, thanks to the development of ICT, there are significant enhancements in the capabilities of medical care provided to the population, as evidenced by the recent decade's successes in combatting dangerous diseases.

In summary, there are signs of a number of innovative products and services based on ICT development breaking onto the aforementioned markets in the period up to 2030 (table 1).

Table 1. Prospective Markets and Product Groups for the "Information and Communication Technology" Priority Area

Markets	Groups of innovative products and services	Characteristics
Telecommunications and IT equipment	Compact energy sources to provide mass-use digital devices with a long-term (weeks, months) power supply Metamaterials and software to process and transfer high-resolution images Photon devices and components Equipment for new-generation mobile communications	Reduced dimensions Extended active use period Increased reliability High resolution power of light paths in technological complexes of the electronics industry Increased level of element base performance and digital devices based on this High sensitivity sensors Possible development of micro devices (nanophotonics)
Software and IT services	Grid-algorithms and software for distributed solutions to certain classes of complex computing tasks Formalisation and extraction software for knowledge on complex data objects Algorithms and software to verify large programmes Algorithms and software for machine learning, including drawing on grid computing supercomputer models Next-generation analytics software Software development tools, testing and debugging programmes for various classes of parallel computing systems Augmented reality applications	IT system stability High efficiency in the distribution of tasks across grid-system resources Completeness of verification High efficiency of algorithms on work time and memory consumed High level data recognition and clustering adequacy Short reaction time to human command and actions Effective algorithms to formalise data, including qualitative Increased productivity and resource-intensiveness of programmes High level of virtual object presentation adequacy and quality Convenience of receiving data in real time Content customisation
Mechanical engineering	Algorithms and software to build complex 3D scenes using still and moving images in real time (computer vision) Robot assistants freely travelling and interacting with people Digital devices with replication and/or self-healing properties	Short reaction times to changes in the situation and adequacy of event recovery Fault tolerance Modularity Increasing the flexibility and adaptability of line production systems

(continued)

Markets	Groups of innovative products and services	Characteristics
	Development of methods to automatically create material objects based on digital models of such objects (additive technologies, etc.)	Reducing the cost of customised production Significant increase in protection capabilities, high level of self-healing algorithm effectiveness Possibility of "new industrialisation" in traditional industries Growth in standards for replacing human resources in production Expanding the employment opportunities of people with disabilities
Chemical industry	Algorithms and software for computer modelling of physical, chemical and biological processes to provide reliable forecast results for interdisciplinary pilot studies Algorithms and software for computer modelling of materials with given properties	Model adequacy and short query response time Accuracy, high speed and timeliness of results
Energy	Algorithms and software for smart grids, i.e. software and technological complex conducive to converting the energy network from a "passive" device in the transportation of electrical energy into an "active" element to control operating modes Algorithms and software to assess risk and plan measures to mitigate emergencies in energy infrastructures Energy information system software to implement "energy-efficient home" and "energy-efficient city" programmes	High efficiency of work time and memory algorithms Short query response time Low algorithm resource-intensity Significant increase in the efficiency both of energy systems in general and individual components Reduction in electricity loss Prevention of emergencies through desynchronisation of energy systems Increasing the maximum tolerated flows on electricity networks
Mineral extraction	Algorithms and software to formalise and extract knowledge from poorly-structured and unstructured data Computer monitoring forecasting algorithms and software for dangerous climatic phenomena and geological natural disasters Geological prospecting software systems in difficult climatic and geological conditions Software for further prospecting of depleted and active deposits Geological prospecting software for non-traditional energy sources	High efficiency of formalisation algorithms High level model adequacy Short query response time Accuracy, high speed and timeliness of results

(continued)

Markets	Groups of innovative products and services	Characteristics
	Intelligent pipe transport flow management systems	
	Algorithms and software systems and assemblies for predictive modelling of events and phenomena (social, technological, climatic, seismic, geophysical, etc.)	
Transport	Software to model the transport-economic balance on regional and federal levels	Short query response time
	Intelligent agglomeration transport systems	Low algorithm resource-intensity
	Intelligent transport systems for transit transport corridors and federal routes	Low power consumption
	Intelligent transport systems for automated and automatic management of air transport, including remotely piloted vehicles, and groups of such vehicles	Reduced dimensions
	Algorithms and software to assess risks and plan measures to mitigate emergencies in transport infrastructures	Increased reliability
	Autonomous non-serviceable micropower robotic devices which can be programmed by radio	Universality
	Software to organise multi-modal transport and logistics processes on regional, federal and international levels	
	Transport service quality monitoring and control system	
	Systems to monitor, control and supervise safety on transport and transport infrastructure objects	
Science	Intelligence “smart laboratory” systems	High system resilience
	Grid-algorithms and software for distributed solutions to certain classes of complex computing tasks	Increased efficiency of task distribution across grid-system resources
	Algorithms and software to formalise and extract knowledge from poorly-structured and unstructured data	High efficiency of formalisation algorithms
	Models, algorithms and software to track scientific and technical results based on analysis of re-use of results and identification of hidden relationships at all stages of scientific products’ and technologies’ life-cycles	High level recognition and clustering adequacy
	Algorithms and software for machine learning, including drawing on grid computing supercomputer models	Short query response time
	Algorithms and software systems and assemblies for predictive modelling	High model adequacy
	Next-generation analytics systems based on efficient methods and algorithms to formalise and extract knowledge and process big data	

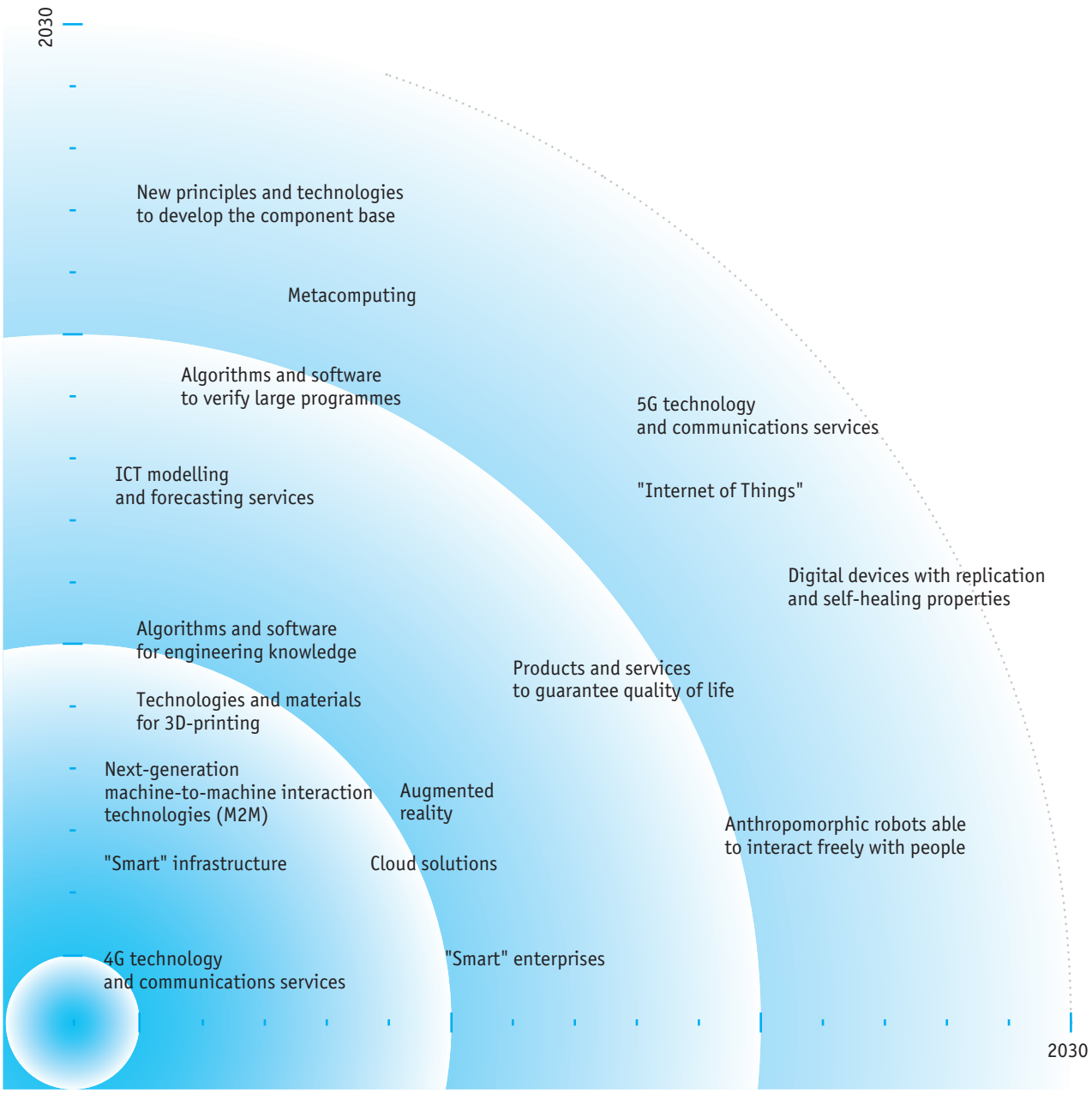
(continued)

Markets	Groups of innovative products and services	Characteristics
Administration	Platform to move public policy into the Internet space using crowd-sourcing to improve public administration and regulation Tools to create "cloud democracy" erasing the boundaries between civil activity and public policy Tools to guarantee a new level of protection for state secrets Algorithms and software systems and assemblies for predictive modelling of events and phenomena (social, technological, climatic, seismic, geophysical, etc.) Algorithms, devices and software to work with spatial data Multi-structure and multi-modal information storage	High level model adequacy Short query response time Accuracy of reported data Increased efficiency of formalisation algorithms High data capacity, speed and reliability irrespective of the type of data received
Education	Resources for distance learning, both in lectures or seminars and self-education Multimedia support for classroom-based learning, tailored to modern formats and requirements (from making texts available up to complex data query and processing tasks) Resources to train people with disabilities Both generally-evolving and profession-specific information bases Higher quality automated translation systems, able to translate both text and speech Profession-specific search and library systems Software for portable devices equipped with tutorials and resources Algorithms and software to process multimedia information in storage networks based on parallel semantic link computing operations Algorithms and software for self-training machine translation systems Next-generation analytics software Multi-structure and multi-modal information stores	High efficiency of algorithms to reveal semantic links Increased adequacy of translation and translation speed in real time High quality word processing Ease of adding new languages Acceptable level of universality Short response times to queries, changes in the situation and adequacy of event recovery High data capacity, speed and reliability irrespective of the type of data received
Health care	Algorithms and software for mathematical modelling of processes taking place in living organisms (for example, accelerating structure and macromolecule modelling processes)	High efficiency of algorithms to reveal semantic links Short reaction times to changes in the situation and adequacy of event recovery

(continued)

Markets	Groups of innovative products and services	Characteristics
	Algorithms and software to build complex 3D scenes using still and moving images in real time (computer vision) Models and software to develop detailed digital ontological profiles of patients, diseases, treatment options, etc. providing multi-dimensional records of medical and extra-medical parameters at a level not currently available Software to support decision-making in predictive medicine Wearable wireless sensors	Increased efficiency of formalisation algorithms Low power consumption Reduced dimensions High reliability Mobility, data transfer efficiency, application autonomy, interfacing with other networks
Individual demand for ICT products and services	Compact energy sources to provide mass-use digital devices with a long-term (weeks, months) power supply Augmented reality applications Intelligent "smart home" systems: optimal control of housing and communal services; digitalisation of consumer devices and combining them into a single network capable both of automatically maintaining optimal parameters and adapting them for remote control Robot assistants freely travelling and interacting with people Ways to increase quality of life for people with disabilities Knowledge-based tools of e-commerce and flexible management systems for delivery of goods to end users Ways to create virtual professional communities and new forms of employment, development of Internet businesses Personalised services linked to the consumer's situation, including personalised television broadcasting and news feeds Interactive museums and exhibitions which increase the accessibility of culture heritage sites and remove restrictions on attendance Multi-language (invariant to the source languages) and multi-modal (invariant to the content type: text, graphics, video) systems to extract and formalise data Devices to replace mass-produced products with home made products, including 3D-printers	Reduced dimensions Extended active use period High reliability Adequacy and high quality of virtual object presentation Short reaction time to human actions Convenience of receiving data in real time Fault tolerance Modularity Increased adequacy of behaviour in terms of operating conditions

Fig. 3. Innovative Products and Services with a Radical Impact on the Dynamics of World Markets in the "Information and Communication Technology" Priority Area



In the long-term a number of innovative products and services will have a radical impact on global markets (fig. 3).

"Smart" infrastructure in power engineering (smart grid) – an integrated self-regulating and self-restoring electricity grid system with network topology and covering all generating sources, trunk and distribution networks and all forms of consumer electricity, all together managed as an integrated set by a single network of automated devices in real-time – will undergo further development in the short term. The importance of sensory networks and sensor units will increase at the next stage in order to synchronise disparate industry systems for monitoring purposes.

Cloud solutions are already on offer on IT services markets. It is sufficient to note the dramatic growth and publicity accorded to services to store content in the "cloud" which are being developed and supported by all of the major companies in the segment, as well as the increasing trend of migrating towards Internet-based applications and leading global software manufacturers moving to business models geared towards a "thin client". According to recent research by McKinsey Global Institute, by 2025 the annual market potential of cloud technologies and applications according to various developmental scenarios for the global economy could range from 1.7 to 6.2 trillion dollars.

Fourth generation mobile communications (4G) are widely accepted as promising technologies which make it possible to transfer data at speeds in excess of 100 Mbit/s for mobile and 1 Gbit/s for fixed subscribers. The introduction of such networks has already started and in the near future there is expected to be widespread dissemination of 4G communications on a global scale and associated development of new forms of content services and business models.

The development of *machine-to-machine interaction technologies* (machine-to-machine, M2M) will lead to the emergence of more flexible opportunities for collaboration and distributed control of infrastructure objects and will become an important stage on the route to implementing the global concept of the "Internet of Things".

3D-printing technologies have been around for quite a long time and have been successfully applied in several industries. Thus, without their use, the activities of many leading companies in terms of creating mock-ups, models and prototypes of units, assemblies, products, buildings and structures would not be possible. Future improvements in 3D printing should be considered in the context of global developments in processing devices with computer numerical control (CNC) and in expanding their use among end users (creation of home and public Fab Labs). The future of such additive technologies is linked to the development of new production principles, the creation of new materials with increased functional characteristics (strength, rigidity, etc.) and reduction in costs.

There has been some development of *algorithms and software for knowledge engineering* at the juncture of learning system and cognitive psychology theories and research on artificial intelligence. Knowledge engineering extends concepts that were previously – in research on artificial intelligence – only applicable to computers (machine learning) to any learning system (where learning is understood to mean the acquisition and transformation of knowledge with a view to its application). New models for working with large amounts of memory (including semantic databases) are becoming increasingly abundant. The development of high-performance semantic analysis technologies is linked to the creation of promising hardware and software platform architectures, which take into account the specifics of semantic databases and procedures for their creation. Hardware support for shared memory and for large-scale parallelism computing models will help in achieving substantially new results in the very near future. Potential fields of application for such systems include business intelligence, bioinformatics, medicine, telecommunications, logistics, social network analysis and search engines. In the long-term the development of analytical software and knowledge formalisation systems will contribute to increasing the efficiency of research conducted in Russia in the field of preventing and reducing environmental pollution, processing and recycling man-made formations and waste; the environmental safety of deposit operations and mineral extraction; and technologies to reduce the risk of natural and man-made disasters.

The development of *algorithms and software to verify large programmes* for cloud and grid-based applications is one of the key fields of research and development in ICT. In the medium term, progress in software development technologies will set down a path of improving methods to verify industrial hardware and software systems. Theoretical bases for algorithms allowing for effective verification have already been developed and tested. In the foreseeable future,

these methods will become part of the technology cycle of companies which create programmes for critical applications. In a number of cases verification technologies are relevant not only for major software systems, but also to reduce the time take to develop various medium-complexity applications where reliability is a particularly high requirement (built-in computer technologies for on-board control systems in space and military equipment, medical equipment, mobile telephones, etc.).

The transition to the *5th generation of* mobile technology (5G) will lead, according to experts, to a 100–1000 increase in data transmission speeds and throughput efficiency compared to 4G technologies used today. Noticeable improvements in other technical characteristics are expected, such as in coverage area, number of simultaneous connections, cost of expansion and power consumption of infrastructure, energy costs on subscriber's device, and reliability and flexibility of connection. Despite the fact that the commercialisation of 5G technology is anticipated for 2020–2025 (shown by the dynamics of mobile communications in the last 20 years), corresponding standards and long-term programmes for research in the field are actively being developed now at international, national and corporate levels.

The model adequacy and query response time are key characteristics of *modelling and forecasting ICT services*. Mathematical and computer models based on the results of field and/or computer experiments applying predictive modelling concepts are "trained" based on multiple prototypes of input and output data and essentially simulate both sources to receive data and the models themselves, created on the basis of studies of the physics of corresponding processes. Using such approaches ("metamodelling"), it is possible to speed up calculations manyfold, all the while reducing the number of expensive field or computer experiments. In turn, this should lead to a drastic reduction in the timeframes and cost of design, improvements in the quality of engineered products, simplified use of such services and, as a result, a reduction in the need for qualified users. The use of such modelling to calculate the optical properties of metamaterials with complex geometries used in difficult-to-reproduce conditions makes it possible to optimise metamaterials and minimise production costs, which will lead to a transformation of the market for materials with new properties.

Growth in the market for *products and services to guarantee quality of life* will be linked to the emergence of specialist portals (both for various professional groups and for the population at large), as well as the development of continuous monitoring systems for important human physiological parameters based on mobile solutions. In terms of bioinformation technologies, the most in demand will be the results of innovative development at the juncture of micro-, nano- and biotechnologies, including algorithms and software to reveal the base mechanisms at work in the brain and memory and integrated systems to prevent health risks.

Resource-based services for distributed and parallel computing (metacomputing) allow the use of supercomputers to significantly increase the effectiveness of scientific research, as well as to increase the competitiveness of products across numerous sectors of the economy. Key directions in the development of metacomputing include grid-algorithms and software for distributed solutions to complex computing tasks; and algorithms and software to develop, verify and test large programmes. With the growth in demand for metacomputing services standard mechanisms will be developed for internal regulation of this services market and quality metrics will be created for these services which will make it possible to form business models for interaction between providers and consumers of the services. In the field of material production, thanks to e-science metacomputing services there will be a fall in the entry threshold for start-up companies onto knowledge-intensive product markets (microelectronics, pharmaceuticals, new material design, bioengineering). The development of this product group requires entirely new methods to solve the problems of energy consumption, component times between failures and the parallelism of the further movement towards increasing the real performance of metacomputing hardware platforms.

The concept of the development and communication of physical objects, referred to as the *"Internet of Things"*, appeared in the late 1990s. Its main idea was to fit as many objects as possible with interaction technology, creating a self-organising network of devices (objects) capable of working together to address these challenges and respond to changes in the environment. Such organisation of things (devices, objects) can restructure the corresponding economic and social processes and significantly reduce human involvement in these processes. The increase in the number of devices able to access the Internet, the growth in high-speed wireless networks, the development of machine interaction technologies and new types of sensors, the dissemination of cloud-based solutions and the start of the transition of client devices to IPv6 are all contributing to this. To realise the launch potential of the "Internet of Things" in terms of simple identification of objects in production processes, there needs to be a transformation in business processes in the majority of economic sectors.

Augmented reality technologies will be used as a basis for the creation of devices, which allow people to adapt the ways in which they interact with their environment through entirely new interfaces. A classic example of this concept is Google Goggles, which allows users to download information from the Internet on objects in their environment in real time. The most likely next step in the development of these technologies will be the appearance of special contact lenses imperceptible to others and able to transmit any information required from a variety of sources (including the Internet) to the user directly onto the retina of the eye. Thus, in terms of augmented reality the ways in which people socialise and perceive their surrounding environment could radically change, which in turn will bring about significant socio-economic effects.

Digital devices with replication and self-healing properties will become an integral part of the human environment in the long-term. A self-replenishing structure can produce copies of itself with equivalent functional properties. At present, one of the promising ways to solve this problem of self-replication and self-healing on a macro-level is layer-by-layer (additive) 3D-printing technology. To restore protective coatings and electronic circuits polymer capsules with carbon nanotubes are being developed which make it possible to reconstruct membranous constructions or conducting bridges if their integrity is violated. On a micro-level, the development of technologies and devices capable of self-replication, replication of external objects and self-healing will be inextricably linked to breakthrough achievements in nanotechnology, with the greatest impact in this regard coming from the development of molecular self-assembly technologies.

Abroad, there is currently considerable research and development into the creation of *anthropomorphic robots freely interacting with people*. In current versions, such robots are equipped with a control system including a number of key sub-systems: technical vision; voice control; voice messages; tactile sensing; spatial orientation; walking and stability control; and behaviour control. The possibilities of anthropomorphic robots are determined by their design and control system. On the whole designs involve compositional metal-polymer outlines with electromechanical drives to ensure mobility. Existing control systems have been built into onboard computer systems comprising universal central processors and peripheral micro-controllers, whereas their prospective variants – in the form of artificial nerve systems – will be built on the basis of a cognitive approach and a combined technology allowing for the use of neurological methods, technology to amalgamate sensory information, and intellectual behaviour and action performance control. In future breakthrough research into modelling the functioning of the human nervous system, the dynamics of its value system, and psychological and mental maxims taking into account external and internal factors will be crucial for robotics (and the creation of anthropomorphic robots in particular).

Maintaining the rate of growth in the ICT sector globally requires continuous increases in the performance of computer technology. At present, the technological process to manufacture

semi-finished products and materials reached the atomic level, which is where the Pauli exclusion principle, the Heisenberg uncertainty principle and other fundamental positions in quantum physics limiting the potential to control elementary particles come into play. So as to avoid a collapse of ICT markets caused by a slowdown in the development of the hardware component, which would result in negative effects for the entire global economy, there needs to be timely industrial development of *new technologies and principles to develop the component base*. The research priorities in this context should be focused on the areas of nanotechnology (electronics based on graphene, fullerene, etc.), photonics and memrister technologies.

For those products, which have a radical impact on the global markets in the long-term, leading research centres have been identified where there is active on-going work in these directions. For the most part they are organisations based in the USA, EU, China, Japan and Taiwan. In Russia there are certain competitive clusters which could collaborate as equals with recognised leaders (in particular with respect to adaptive infrastructures). The research of Russian scientists into large energy system and cybernetic energy system control theory has received high praise from the international scientific community. In the field of statistical modelling, text analysis, and expectation analysis, developments by Russian mathematical schools are on a par with global levels. There are centres with expertise in problems relating to the use of ICT in medicine and health care; the foundations have been laid in the development of next-generation analytics systems applied to health care and pharmaceutical problems, analysis technologies and natural language text processing combined with clinical knowledge bases, including genome data; and the ICT infrastructure of health care institutions is undergoing active development.

1.3. Promising Research Areas

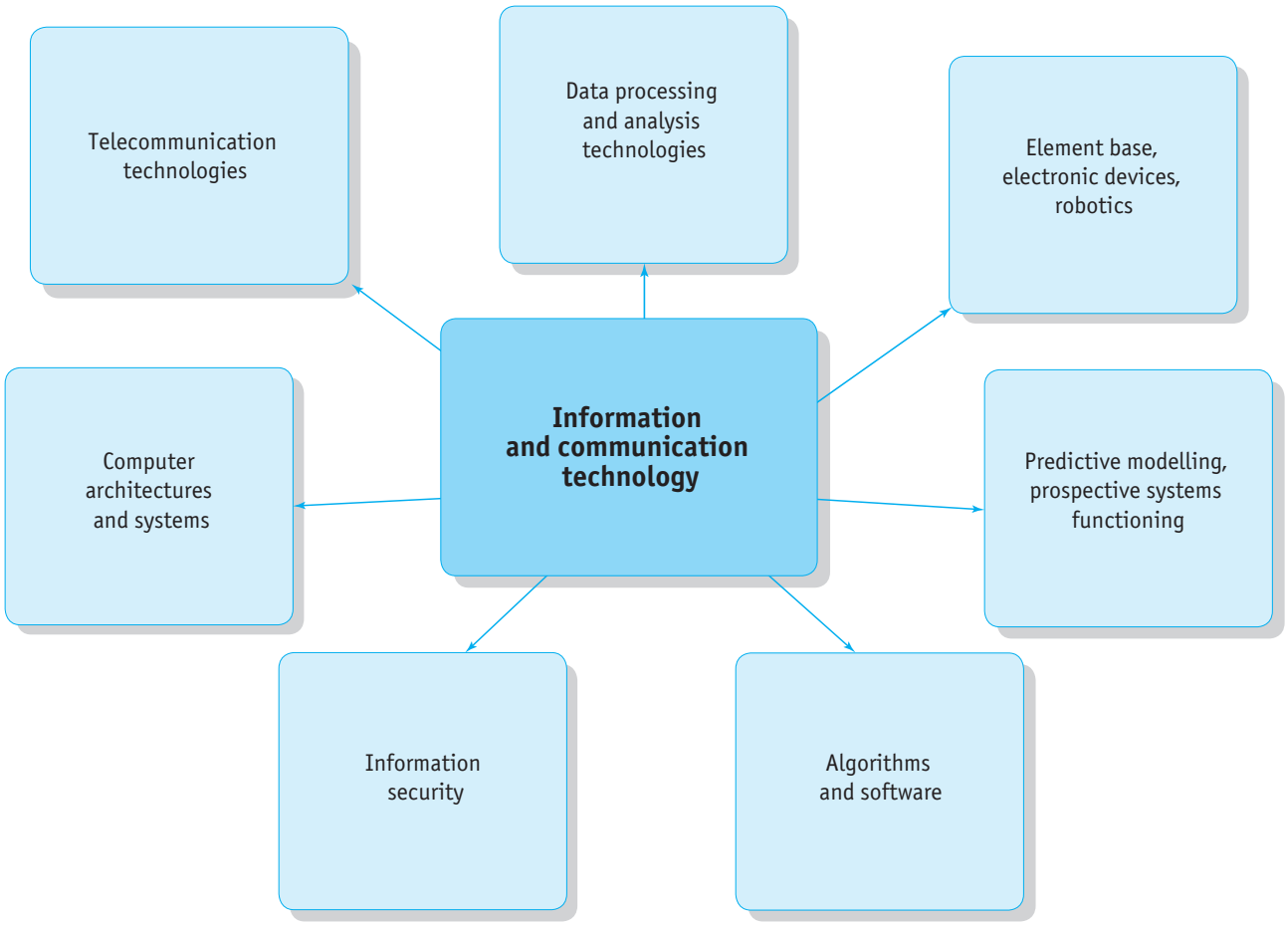
The emergence of the innovative products described above requires the development of corresponding scientific and technological groundwork. In this regard, experts have outlined the seven most promising fields in applied research for Russia for the period up to 2030 (fig. 4).

Among the most significant scientific and technological results which can be attained in this period are prototype systems based on new computational principles and prototype Multilanguage programming systems for knowledge extraction and formalisation; data processing technologies to solve big data problems; next generation business intelligence, including personal analytical systems, tools for real-time data processing, mobile analysis, etc.

The highest market growth rates for the aforementioned science and technology products are expected to be in health care, power engineering, mechanical engineering, transport, and in personal consumption of ICT products and services. In the medium term, experts expect the large-scale use of electronic health passports; the emergence of distributed networks of telemedicine centres; and the development of quality control and safety systems for drugs and medical services. By 2025, there is expected to be widespread distribution medical micro-devices implanted into the body to support its vital functions; technologies to exchange standardised data between transport vehicles; universal global positioning and identification techniques within the framework of the "Internet of Things" concept; and promising platforms for collecting, summarising and presenting content and knowledge. There may be possible integration of in-built digital devices into mechanical engineering products and the development of programming technologies for in-built systems.

The evolution of cloud computing and the development of new architectures and computational principles will lead to a transformation of software and the introduction of innovative IT solutions into the business strategies of companies operating across all sectors of the economy.

Fig. 4. Thematic Fields of the "Information and Communication Technology" Priority Area



The colossal growth in the volume of data available for analysis provides a basis for a radical growth in the effectiveness of managerial decisions, including in the business intelligence segment.

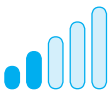
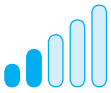
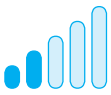
Despite certain achievements in the Russian sciences, the skill sets of Russian workers do not cover all of the areas of applied research required to achieve prominent positions in the prospective markets. Some of the more advanced areas include new data transfer, networking and content distribution technologies. However, in areas such as computer-aided element base design and new multimedia data processing technologies the level of Russian research does not score highly.

Computer Architectures and Systems

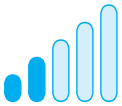
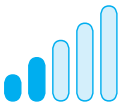
Expected results of future research:

- prototype systems based on new computational principles;
- prototype computer system elements based on novel data matching, storage, and exchange principles;
- research models and prototypes of computer architecture components based on new paradigms, including neuro-, bio-, optical, quantum, self-synchronisation and recurrence systems.

Table 2. Promising Research Areas in "Computer Architectures and Systems"

Research areas	R&D Level	R&D Priorities
Exaflop supercomputers		Development of high-performance and distributed ICT (exa- and zetaflop, server and personal petaflop supercomputers, parallel computing) Development of multicore computers based on standard general-purpose microprocessors Development of prospective communication supercomputer infrastructure, including hardware support for new parallel computing paradigms Development of energy-efficient devices, energy-saving and "intelligent power management" technologies Development of prospective data storage technologies as components of supercomputer set-ups: techniques for integrating data storage and computational systems; new approaches to data storage organisation; combining storage and partial processing; technologies for increasing data storage capacity, productivity, and energy efficiency Development of supercomputer monitoring and resource management systems Development of support infrastructure for very large systems: cooling, power supply, fire safety, ergonomics
Computational algorithms and software for ultra high performance systems		Development of automated parallel programming systems for various computer architectures Development of programming languages and systems, automated application building systems for unconventional (hybrid) architectures Development of data flow programming tools
Distributed systems and architectures		Development of distributed computation techniques and technologies (including those supporting grid technologies, metacomputing, network computing services, and cloud computing) Development of distributed data storage architectures with unlimited storage time and protected access control Development of new user login, authorisation and authentication technologies, services and resources for distributed computer systems Development of new Internet architectures (request networks, networks of networks, software-defined networking, etc.) Development of computer systems built by merging the resources of geographically distributed computer installations: computational resources, storage capacities, channel capacities, etc. Application of personal computer networks to distributed data processing

(continued)

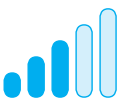
Research areas	R&D Level	R&D Priorities
New server and personal computer architectures		Development of computer installations using unconventional data processing and accelerator devices Development of low energy consumption and "intelligent power management" technologies for servers and personal computers Development of autonomous high-capacity power supply technologies for mobile devices Development of contactless power supply (recharging) technologies for mobile devices
Novel paradigms for the organisation and implementation of computational processes; new technologies to build computer devices		Organisation of multi-thread computations Organisation of dataflow computations Development of ubiquitous computing technologies Development of Processor-in-Memory Development of hybrid data processing complexes using components and systems based on different physics principles Development of prospective devices based quantum, neuro- and bio-computing principles Development of optical processors and systems

Telecommunication Technologies

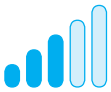
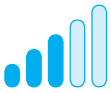
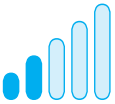
Expected results of future research:

- prototype networks and communication infrastructures' elements with terabit data transfer rates;
- prototype networks based on novel organisation principles, including cognitive, hybrid, adaptive, reconfigurable, and heterogeneous ones;
- prototype systems with guaranteed dynamic resource allocation;
- prototype new-generation research systems allowing transferring large volumes of data obtained through experimentation, performing distributed processing of research data, and offering distributed R&D teams an opportunity to work together.

Table 3. Promising Research Areas in "Telecommunication Technologies"

Research areas	R&D Level	R&D Priorities
New data transfer technologies		Researching the potential of optical networks, development of technologies allowing terabit data transfer rates Development of technologies for data transfer and interaction between various optical network devices without converting signals into electrical form

(continued)

Research areas	R&D Level	R&D Priorities
		Research and development of optical network security systems and techniques Assessing the limits of possible use of the allocated frequency spectrum, adaptive use of the spectrum, the development of new routing protocols for wireless networks taking into account the actual load of its specific segments, and energy-efficient wireless broadband access systems Research and development in innovative satellite-based data transfer and processing technologies and techniques, to ensure efficient use of radio-frequency bandwidth
Novel network organisation technologies		Research and development in programmable network technologies (Session Description Protocol), Service-Oriented Architecture, IP Multimedia Subsystems Research on self-organisation processes in computer networks, cognitive computer networks, adaptive interaction of heterogeneous networks Development of modelling techniques for complex telecommunication networks and systems, taking into account various aspects of dynamics, scaling, topology and heterogeneity Development of techniques to create multichannel mesh networks supporting guaranteed quality of service
New content distribution technologies		Development of systems and distributed networks for data delivery; development of content-oriented network architectures Development of prospective digital broadcasting systems: 3D TV, interactive TV, interactive and integrated multimedia video information systems, personalisation of broadcast content Development of guaranteed content delivery systems with dynamic change of users' location, network infrastructure, network delays, etc.
Digital reality technologies and systems, prospective human-ICT interfaces		Development of prospective human-ICT interfaces: control by gestures and facial expressions, "smart" clothes, brain-machine interfaces, etc. Researching technologies for and application of virtual reality

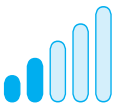
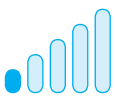
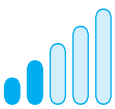
Data Processing and Analysis Technologies

Expected results of future research:

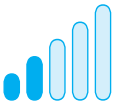
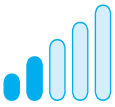
- prototype Multilanguage software systems for extraction and formalisation of knowledge out of unstructured or poorly structured data; prospective knowledge storage and analysis systems and tools;
- prototypes of software and systems of semantic analysis and computer semantic translation of information presented in natural languages;

- prototype software systems based on novel principles, for processing, searching, analysing and virtualisation, including decision-making support and situation identification software systems based on very large data arrays and flows;
- prototype software systems for real-time analysis of complex 3D scenes using still and moving images;
- research models and prototype software systems for storage, processing and analysis of very large multi-component data flows, including media data.

Table 4. Promising Research Areas in "Data Processing and Analysis Technologies"

Research areas	R&D Level	R&D Priorities
Techniques and technologies for collecting, processing, analysing and storing very large data volumes		Development of new techniques for maintenance and integration of information resources, electronic libraries and archives Managing extreme data flows Development of technologies for collecting data in natural environments; prospective sensor networks and monitoring systems (Internet of Things – IoT) Development of prospective technologies for collecting, converting, analysing and visualising very large volumes of unstructured or poorly structured data Extension of relational and object DBMS, development of new DBMS for scalable storage of research data Development of scalable systems for statistical analysis and processing of data; development of scalable algorithms and programmes for processing multiparameter, multidimensional, hierarchical, and multiscale very large data sets Development of new tools and protocols for managing input/output and selection of data, and transparent interaction requests for global data storage systems; wide-area data access, transfer and request tools Development of Russian Linked Open Data segments for various subject areas
New multimedia data processing technologies		Speech, images, and video recognition and synthesis technologies; machine translation of texts and speech Research in the area of efficient presentation of information, content and knowledge (3D ultra high-definition images, virtual and augmented reality, virtual immersion, multimedia, infographics, digital holography) Development of 3D visualisation technology (3D "display"); 3D browsers
New technologies for processing text-based and poorly structured data		Development of electronic dictionaries, search systems (including Internet search engines) automated text annotation and summarising systems, content filtration tools Development of semantic technologies, automated analysis of natural-language text documents to build knowledge bases by extracting data from web resources

(continued)

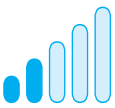
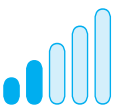
Research areas	R&D Level	R&D Priorities
		Development of machine translation models and technologies based on distributive semantics methodology
		Solving content compatibility problems in heterogeneous networks; ensuring semantic interoperability of data systems and services
		Development of technologies for the formalisation and extraction of knowledge out of unstructured or poorly structured data; creation of ontologies and knowledge bases for shared use
		Development of technologies for the selection and aggregation of data from distributed sources, in accordance with specific user preferences
		Development of technologies to design global data integration systems
Prospective web-based technologies and systems		Modelling the development of the "digital universe"
		Development of techniques to structure news flows in social networks
		Development of techniques to identify social networks' communities and connections between them
		Development of the IoT, including sensor networks at its lower levels, using sensors and actuators based on novel physics principles; "ubiquitous" positioning and "ubiquitous" identification of objects in the IoT; user interfaces for the IoT objects, based on cognitive principles
		Development of technologies for selection and aggregation of data from distributed sources in line with subscribers' specific preferences
		Development of context-oriented systems using location and profile data (social, emotional, cultural, etc.)
New data analysis technologies (Next Generation BI)		Development of self-service business intelligence (BI) and pervasive BI
		Development of In-Memory BI Analytics
		Development of BI for use with unstructured data (texts, speech, video, etc.)
		Development of BI components for DBMS
		Development of BI Cloud Solutions
		Development of Large Data Volumes BI
		Development of Mobile BI
		Development of Open Source BI
		Development of Search-Based BI solutions
		Development of Collaboration BI and Decision Making systems
		Development of Cyber Analytics information security BI solutions

Element Base, Electronic Devices, Robotics

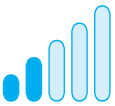
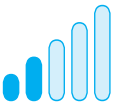
Expected results of future research:

- experimental designs and prototypes of extended-functionality integrated circuit blocks based on radically new features, including mutual influence of elements and the substrate;
- prototype microprocessors and very large communication integrated circuits, based on self-synchronising logic with locally asynchronous self-control and error management mechanisms;
- prototype element bases based on quantum effects, single-electronics, spintronics and photonics;
- prototype biosimilar and anthropomorphous robotic devices, self-learning robots, artificial robot nervous systems, robot group management systems.

Table 5. Promising Research Areas in "Element Base, Electronic Devices, Robotics"

Research areas	R&D Level	R&D Priorities
Prospective technologies for automated element base design		Development of mathematical, logical, circuit, topological and other formal models of devices, library elements and extended functionality blocks of integrated circuits with nanometre-range transistors, taking into account the elements' increasing mutual influence, the substrate's influence, temperature and electromagnetic fields Development of modelling methods for automated design of digital, analogue, mixed and radio VLSI with nanometric project standards Studying the dominating influence of wiring on the operating speed of small geometric size VLSI, including new wiring design technological solutions, such as 3D integration and optical wiring Development of algorithms and techniques to synthesise and optimise circuit solutions, taking into account topological and technological implementation Achieving interference immunity of digital and analogue-digital integrated circuits Integration of test sequence modelling tools and tools for rapid static analysis of operating speed, noise, current consumption, based on interval modelling techniques, on logic and circuit levels
Application of new element base to the development of prospective ICT		Development of a quantum computer; development of element base and control algorithms for individual elements to compute on the basis of quantum formalism Development of devices based on single electronics, spintronics, and magnetic moment quantisation effects Development of element base on the basis of nanophotonics, with energy transferred by single photons

(continued)

Research areas	R&D Level	R&D Priorities
		Integration of traditional CMOS devices and alternative data storage and transfer techniques (based on nanoconductors, nanotubes, memristors, quantum effects, etc.) Research into the properties of the prospective element base through studying electron-hole plasma of mainline elements: transistors, diodes Development of principles to design heterogeneous integrated circuits with micromechanical, optical-electronic, magnetic-sensitive and extended-functionality blocks
Technologies to make extended-functionality blocks for the element base		Development of efficient techniques to describe extended-functionality blocks, taking into account variations in technological parameters Development of parameterised extended-functionality blocks to ensure efficient adaptation to various system-on-a-chip architectures Development of techniques and hardware solutions for precision measurement of the temporary parameters of memory units inbuilt into a system-on-a-chip Selection of a technological basis for the development of precision high-speed analogue-digital devices Development of digital-to-analogue and analogue-to-digital converter architecture taking into account specific features of the technological basis and containing self-calibration and self-tuning devices, synchronisation systems with minimal temporal instability Development of prospective technologies for the integration of analogue-digital devices into system-on-a-chip, including techniques to mount the chip in the case minimising the mounting process' effect on the analogue-digital devices' parameters Development of prospective techniques to measure the characteristics of precision high-speed digital-to-analogue and analogue-to-digital converters
Robotics		Studying the purposeful behaviour of intelligent robots and robot groups, including on the basis of bionic principles Studying decision-making and control models in biological structures Development of techniques to build and support robots' artificial nervous systems Development of image and 3D scene recognition techniques and systems Development of technologies to make biosimilar and anthropomorphic robotic devices and systems

(continued)

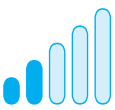
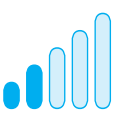
Research areas	R&D Level	R&D Priorities
		Development of mathematical support and software for problem-oriented information and control systems for intelligent robots of various types (micro-robots, household robots, unmanned aircraft and submarines, etc.) Development of contactless and markerless gesture and movement recognition technology, for remote control of robotic devices

Predictive Modelling, Prospective Systems Functioning

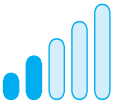
Expected results of future research:

- prototype software systems for predictive modelling of complex systems (technical, socio-economic, political, transport, etc.) and properties of physical, chemical, biological and other objects, with the level of predictive accuracy and complexity unattainable at the current stage;
- prototype software systems implementing new models of processes occurring in nature, society, humanitarian sphere, cyber space, etc;
- prototype software systems for automated management of large systems (socio-economic, technical, transport, etc.), based on novel principles, models and management processes;
- prototype software systems for implementing hybrid models of human cognitive mechanisms, speech and mental activities; technologies for modelling human intellect;
- research models and prototype devices to implement new principles of human-computer interaction.

Table 6. Promising Research Areas in "Predictive Modelling, Prospective Systems Functioning"

Research areas	R&D Level	R&D Priorities
Modelling complex systems and processes		Development of mathematical, logical, semiotic, linguistic and other formal language models of complex systems and processes Development of predictive modelling techniques for complex technical systems, physical, chemical, biological, economic, geological, climatic, social and other processes Development of models and prototype forecasting systems for various fields (economics, meteorology, seismology, geology, forecasting anthropogenic disasters, social phenomena, epidemics, etc.) based on intelligent real time data processing
Intelligent management and decision support systems		Development of techniques and tools for high-precision navigation Development of techniques for intelligent data processing and decision-making support Development of technologies to model human intellect, and to automatically make complex decisions

(continued)

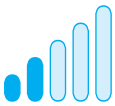
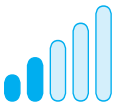
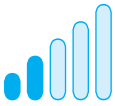
Research areas	R&D Level	R&D Priorities
		Studying decision-making models in biological structures (neuromorphic computing) Development of prospective sensor networks, “smart home”, “smart enterprise”, “smart energy grid”, “smart city” and other systems Studying ICT-based systems and tools to support the quality of life of senior citizens and people with disabilities Researching opportunities for industrial companies to apply ICT to reduce emissions of greenhouse gases (equivalents) Development of technologies for infrastructural support of subject-oriented ICT in the framework of mega research projects Development of subject-oriented ICT: e-government, e-health, e-banking, e-learning Development of an integrated management environment and integrated information space for transport infrastructure (to enable vehicles to exchange standardised data) Research in medical microdevices implanted into human body to monitor its health and support vital functions Creation of virtual offices without decreasing the efficiency of companies’ collective operations Development of technologies to enable wide-spread remote work in distributed mode
ICT design and maintenance tools		Development of tools and systems to identify technological and data objects during their life cycle Development of techniques and tools to automatically verify applied software Development of techniques and tools to automatically design complex ICTs

Information Security

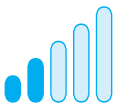
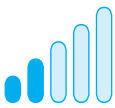
Expected results of future research:

- prototype computer infrastructure protection systems based on radically new paradigms, including quantum cryptography and computing, neurocognitive principles;
- prototype prospective tools and software for data protection systems taking into account new principles of data organisation and interaction of data objects, including global integration of information systems, ubiquitous access to applications, new Internet protocols, virtualisation, social networks, data from mobile devices and geolocation;
- based on novel principles, prototype software systems for biometric identification, procession, integration and analysis of multimodal biometric data, including for application in new areas (social web; applications using geocontext; protection of property; games; etc.).

Table 7. Promising Research Areas in "Information Security"

Research areas	R&D Level	R&D Priorities
Reliable identification and authentication technology in ICT		Research into the problems of strict authentication and trusted downloads in ICT using cryptographic conversion, including the use of quantum cryptography technology Development of a system to manage identification information with distributed processing on corporate and public networks Development of authentication and differentiated access technologies based on global identification systems
Reliable and trusted architectures, protocols, models		Development of new-generation protected communication channels based on quantum coding and data transfer effects, and an element base for such channels Development of models to ensure the security of distributed data processing systems, including grid computing and virtualisation of resource provision similar to cloud computing Building secure information systems using untrusted software and hardware components Development of trusted ICT based on analytical and imitation models (architecture, prospective technical solutions, procedures and operation protocols) Development of models to integrate data protection tools, basic components, specialised and superimposed, in the course of ICT design and targeted adjustment in accordance with data security policy Development of techniques to increase the reliability, viability and disaster resistance of ICT
Personal data protection technologies		Review and systematisation of Russian and international practices in the area of system situations and vulnerabilities in ICT of various levels and types, in the course of personal data protection Classification of informational resources' content through the inclusion of personal data; matching these classes with ICT types; development of a metric for levels of personal data protection on the basis of these correlations, and a methodology for their measurement Development of personal data protection technologies for large data arrays Development of user-centric privacy technologies Development of technologies for designing trusted architectures, protocols, and models Development of personal data protection technologies for distributed data processing systems

(continued)

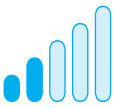
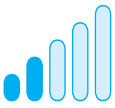
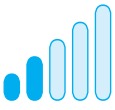
Research areas	R&D Level	R&D Priorities
Biometric personal identification tools and techniques		Application of integrated approaches to using various biometric characteristics for more reliable biometric personal identification Development of adequate models of biometric characteristics' images, and building efficient biometric data search algorithms Development of an algorithm and highly efficient technical solutions for personal identification which are low-cost and convenient to use with ICT
Meeting new challenges of the information war and cybercrime in ICT		Development of a system situations bank for new challenges concerning the information war and cybercrime in the environment of advanced and emerging ICT, and their description and classification for countering purposes Development of technologies to counter attacks in virtual computer networks of the Botnet type Development of new-generation intelligent data protection technologies, capable of adaptive adjustment to the changing nature and mechanisms of cyber attacks Development of new technologies to monitor the actual protection level of critical ICT data segments in situations of cyber impact Development of technologies for intelligent filtration of and access to web content Using public networks for covert data transfer

Algorithms and Software

Expected results of future research:

- prospective languages and prototype programming systems integrating novel and existing paradigms, including object-oriented, functional, logical, specification languages, "programming without programmer", subject-oriented, natural language programming, support of various software features' demonstrability;
- prototype prospective system software components, including those increasing data processing productivity, providing reliable evidence of meeting requirements, supporting prospective architectures, etc;
- research models and algorithms adaptable to new-generation computer systems;
- prototype software systems based on novel parallel computing models;
- prototype software systems based on novel distributed computing principles, utilising privately owned computers and mobile devices;
- prototype software systems and operating systems with locally asynchronous self-control and error management mechanisms;
- research models and prototype automated and automatic software analysis systems (including demonstrability of their various features), and software conversion systems (including their optimisation by various criteria, paralleling, inversion, composition and derivation of new software out of existing ones);
- research models and prototype machine learning software systems based on novel techniques and algorithms, including for processing very large and fragmented data sources.

Table 8. Promising Research Areas in "Algorithms and Software"

Research areas	R&D Level	R&D Priorities
Prospective programming paradigms and technologies, languages and systems		Development of high-level programming languages to be used with computer systems based on new architectures Development of automated programming systems facilitating analysis of software complexes, and conversion of software needed for their efficient operation, primarily at parallel computers based on new architectures Development of super-high-level programming languages integrating novel and existing paradigms and languages (object-oriented, functional, logical, specification languages, etc.) Development of analysis and conversion techniques for formal language models, including software (optimisation, specialisation, paralleling, verification, representation of software based on one paradigm into another, etc.) Development of human-machine systems for analysis and conversion of software and formal language models, integrated systems for designing reliable and demonstrably correct software Development of programming languages for unconventional architectures (including programmable logic and integrated circuits, graphic accelerators, dataflow computing)
Prospective technologies and solutions for operating systems, DBMS and interlayer software		Development of technologies to ensure reliability, safety and efficiency of operating systems for server, desktop, mobile and inbuilt systems Building kernels for operating systems which are reliable and resistant to harmful impact, demonstrably meeting data safety requirements Virtualisation of hardware and lower-level software Analysis and conversion of large data arrays Development of modular tools to verify and analyse large-scale component systems based on formalisation of components' semantics Integration of all major safety functions into basic component environment services Development of technologies for building scalable systems using paralleling, modelling, analysis and verification techniques Development of efficient automated programming technologies including new approaches to "programming without programmer", subject-oriented programming languages and systems close to natural language
Cognitive technologies		Research and cognitive modelling of intelligence Development of bionic principles, techniques and models for information technologies Development of collective intelligence ICT Development of technologies to model human intellect, and to automatically make complex decisions Research into personalised interfaces connected with human sensory organs

2 BIOTECHNOLOGY

Biotechnology, together with nanotechnology and ICT, is one of the most important and fast-growing "horizontal" technological directions. Based on forecasts by leading international organisations – the World Bank, OECD, European Commission, etc. – the growth rates of biotechnology product markets will continue to increase steadily. The intensive development of biotechnology can be explained not only by the advances achieved in biochemistry, bio-organic chemistry and molecular biology, but also by the crisis of traditional technologies (especially when considering the new trends, particularly environmental and energy-related), the need to guarantee food supplies, sustain the supply of resources, increase people's lifespan and support a healthy national gene pool. The presence of major scientific groundwork and empirical developments will make it possible within the next few years to significantly broaden the range of biotechnologies' uses in the mass production of products with new properties.

The development of various types of biofuels will contribute to the diversification of the fuel-and-energy balance and the reduction in greenhouse gas emissions. Cellular, genomic and post-genomic technologies will serve as a basis to prevent the spread of various types of human and animal diseases, obtain biomaterials from renewable raw materials to replace traditional industries (chemical, food, pulp and paper, etc.), develop new products with unique properties, revive rare and endangered flora and fauna, and protect the resources of the oceans. The improvement of bioorganic waste processing technologies will make it possible to solve the problem of waste disposal and reduce environmental pollution, while at the same time generating large amounts of biomasses for subsequent industrial processing. The introduction of new highly productive bio-objects and the application of efficient operating practices would enable us to significantly intensify production processes. The development of technologies to produce new varieties of agricultural plants and new breeds of animals with improved properties would allow for the production of sufficient quantities of high-quality food with balanced mineral and vitamin contents.

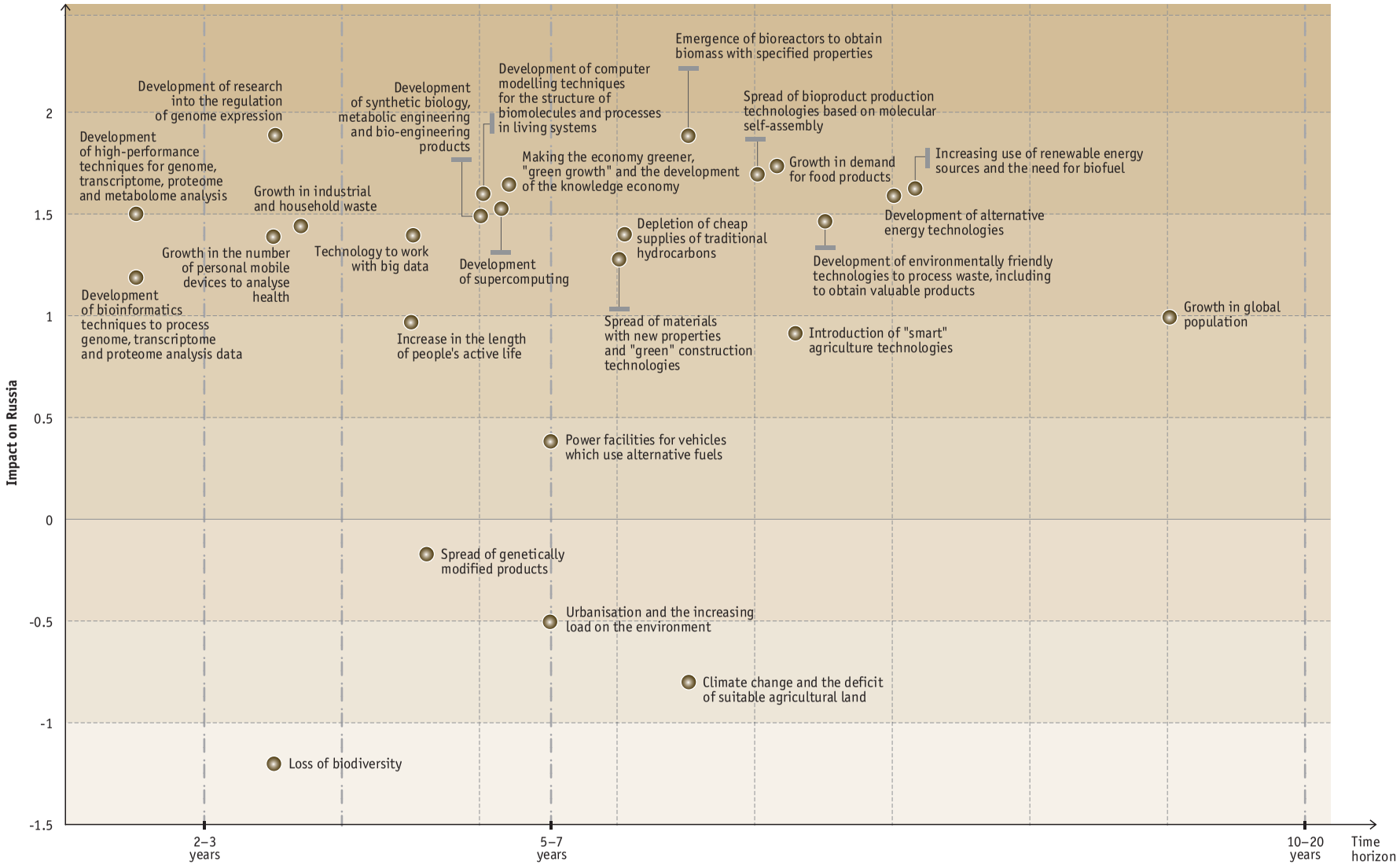
2.1. Challenges and Opportunities

The challenges and opportunities created by global trends, shaping the prospective development of the "Biotechnology" priority area, are shown in figure 5.

Thus, *the dissemination of genetically-modified (transgenic) products* is evoking ambiguous responses from society and the government, primarily due to the lack of objective information on their impact on humans and the environment in the medium and long-term and the risks engendered by this. At the same time, the development of this field could serve as a major impetus for the establishment of food and technical crops with improved or fundamentally new properties and often at a lower cost. As a result, we can expect significant growth in agriculture and increased land cultivation in regions which previously could not be worked due to unfavourable climatic conditions.

The depletion of cheap supplies of hydrocarbons is shaping the development of biotechnologies, making it possible to increase the effectiveness of the extraction and processing of raw

Fig. 5. Biotechnology: Challenges and Opportunities



Source: HSE ISSEK.

materials, which will ultimately lead to more active development of new hard-to-reach deposits at a lower cost and with greater output. With its substantial agricultural land and large volumes of agricultural, food and timber waste (250 million tons of concentrated agricultural and 50 million tones of timber waste annually), Russia could become one of the strongest players on the global biofuel market provided that there is effective organisation of scientific research, sufficient investment in the development of technologies and infrastructure, and the necessary institutional transformations are carried out.

The emergence of *bioreactors to generate biomasses with certain properties* will make it possible to develop recombinant production technologies for the food industry, agriculture, as well as the energy sector, which will make it possible to output new biotechnological products on industrial scales. The urgency of developing this field is conditioned by the increasing demand for deep biotechnological processing products for biomasses of various origins. Biofuel will be particularly in demand.

The convergence of ICT, nano- and biotechnologies could serve as an impetus to *develop "smart" agriculture* (diagnostic preparations, biosensors to gauge growth, optimising bio-devices, bio-robots, etc.). The introduction of new technologies will make it possible to increase the effective use of agricultural land, prevent erosion and the washing out of nutrients, protect the soil structure, and generally, reduce the negative impact on the environment.

The growth in the planet's population, which, according to UN estimates, will exceed 9 million by 2050, will open up new opportunities to export Russian agricultural biotechnologies and bioproducts (predominantly in developing countries). Consumers on high incomes will demand environmentally friendly food products. The leaders in terms of production and consumption will be rapidly developing nations, primarily China and India. With this, monitoring safety and quality in this field needs to be done by developed nations.

The progress in technologies to store, process and transfer large amounts of data (*technologies to work with big data*, production and support of supercomputer operations, supercomputing, development of new computer material and process modelling technologies) is highly important in terms of research into genomics, synthetic biology and bioengineering (primarily to decode and analyse genomes, and in the future, to mathematically model processes occurring in living organisms). The development of high-performance computing systems will contribute to the intensive development of molecular biology (speeding up processes to model the structures and dynamics of macromolecules).

Experts have outlined the following ***threats to Russia*** in this field:

- low productivity in agriculture;
- the critical lag in the scientific research and production technology base in biotechnology;
- low demand for practical developments;
- insufficient investment by businesses in the development of biotechnological industries;
- high barriers to entry onto the global biotechnology product market;
- risk of transforming a country in a raw materials source for leaders of the global biotechnology market.

2.2. Prospective Markets, Products and Services

Biotechnologies are actively used in biopharmaceutical and medical markets, allowing researchers to create biodegradable materials, diagnostic preparations, implants, vitally important drugs, cell lines, etc. These and other prospective biotechnology markets will be examined as part of the Foresight.

Prospective markets for the "Biotechnology" priority area[1]:

- industrial bioproducts;
- biotechnological agricultural products;
- biofuel and bioenergy;
- edible bioproducts;
- biological environmental systems;
- biotechnological systems and products for the forestry sector;
- aquabioculture.

As the analysis shows, in the near future biotechnologies will be most in demand in the agricultural sector, food industry and biofuel industry. In this regard, assessments of the possible proliferation of genetically modified organisms vary, due, as already observed, by society's mixed attitudes towards such products.

For each of the markets listed above, innovative products and services which will appear on mass in the period up to 2030 have been identified (table 9).

Among the innovative products and services, we have identified those which are capable of having a radical impact on the global markets in the period up to 2030 (fig. 6). In the field of biotechnology, radical development is chiefly characterised by the emergence of new properties in products, a multifold increase in their technical and economic properties and, as a result, a major transformation of markets and new potential to solve global problems and overcome various challenges.

In the short term *new varieties of crop plants and breeds of agricultural animals* could be achieved by using molecular markets in selective work, double haploid technologies, genetic engineering, and other methods. It is expected that new varieties and hybrids will have properties such as high nutritional content, increased productivity, and/or other benefits (size of fruit, ripening time), and resistance to diseases, pests and adverse environmental conditions. The development of genome selection technologies will make it possible to develop new, higher quality breeds of agricultural animals (for example, in terms of meat fat content) with faster growth which, in turn, will contribute to rational use of animal feed. The practical introduction of new products will lead to an increase in the efficiency of agricultural production and a reduction in crop losses.

Efficient technologies to generate *biofuels* (including motor fuels) will save non-renewable supplies of fossil hydrocarbons, allowing for a significant expansion in the current resource base of the economy, a reduction in greenhouse gas emissions and, ultimately, a reduction in the negative impact of the energy sector on the planet's climate. The main developmental directions in bioenergy technologies are increases in the energy efficiency of bio-conversion of carbon dioxide gas into motor fuel, reductions in the cost of biofuels, an expanded raw materials base for biofuels (for example, the development of technologies to convert lignocellulose into biofuel), and improvements in quality (stability, environmental cleanliness).

Biotechnological process to produce biomaterials and organic synthesis products out of renewable raw materials, to replace traditional chemical production and develop innovative products with unique properties would involve the development of the new strains of microorganisms and microbial consortia involved in these processes as well as the development of technologies to produce biosynthetic monomers and polymerisation methods. The replacement of chemical manufacturing with manufacturing based on biotechnological processes to produce materials and organic synthesis products from renewable raw materials will make it possible to create products with a high level of purity (including optically pure organic substances to synthesise drugs) and reduce the cost of their manufacture. New types of biomaterials will have a wide range of applications on account of their special characteristics. A number of products (bioplastics, etc.) will have

[1] Promising markets and innovative biotechnology products in medicine and pharmaceuticals will be explored in more detail in annex 3 "Medicine and Health Care".

Table 9. Prospective Markets and Product Groups for the "Biotechnology" Priority Area

Markets	Groups of innovative products and services	Characteristics
Industrial bioproducts	Fodder additives: – essential amino acids – vitamins – protein Enzymes: – industrial enzymes and biocatalysts – fodder and food enzymes Biochemistry, including monomers for biodegradable polymers: – organic acids, alcohols, diols – hydrocarbons Tools for biological protection of plants (biopesticides, bioinsecticides) Polysacharides and other tools for increasing oil extraction	Potential to create new products with unique properties Accelerated catalytic processes Slower unwanted processes Potential to eliminate the after-effects of pollution Reducing set-up and operation expenses Broadening the range of goods to make it possible to personify consumers Environmental neutrality and closed production cycle Increasing resistance to the "extreme" conditions of real bioprocesses (high temperature, acid or alkaline conditions, the presence of salts, organic solvents)
Biotechnological agricultural products	New varieties of crop plants New biotechnological forms of trees with predetermined features Microbial strains and consortia intended to create symbiotic plant-associated microbial communities providing required mineral substances to plants and protecting them from pathogens Plants and animals serving as "biofactories" to generate bioproducts for industrial and medicinal purposes New breeds of agricultural animals Fodder preservatives and silage ferments Combined feeds and premix	Higher yield/productivity Increased resistance to pathogenic and adverse environmental conditions Reduced ability to accumulate herbicides and pesticides Increase storage times Increase protein levels Improved taste Balanced nutrition, vitamins, amino acids, etc.
Biofuel and bioenergy	Biofuel and components from biomass: – pyrolysis products (bio oil, biogas) – biodiesel, bioethanol, biobutanol, bioether Energy products: – biofuel cells, energy bio-accumulators	Improved consumer properties Sustainability Environmental neutrality
Edible bioproducts	Sweeteners (sorbite, glucose and fructose syrup solutions) Products with pro-, pre- and synbiotic activity: – prebiotics, probiotics, synbiotics – starter cultures – highly concentrated enzymes	Safety Ease of use Possible prevention and treatment of diseases Personalisation

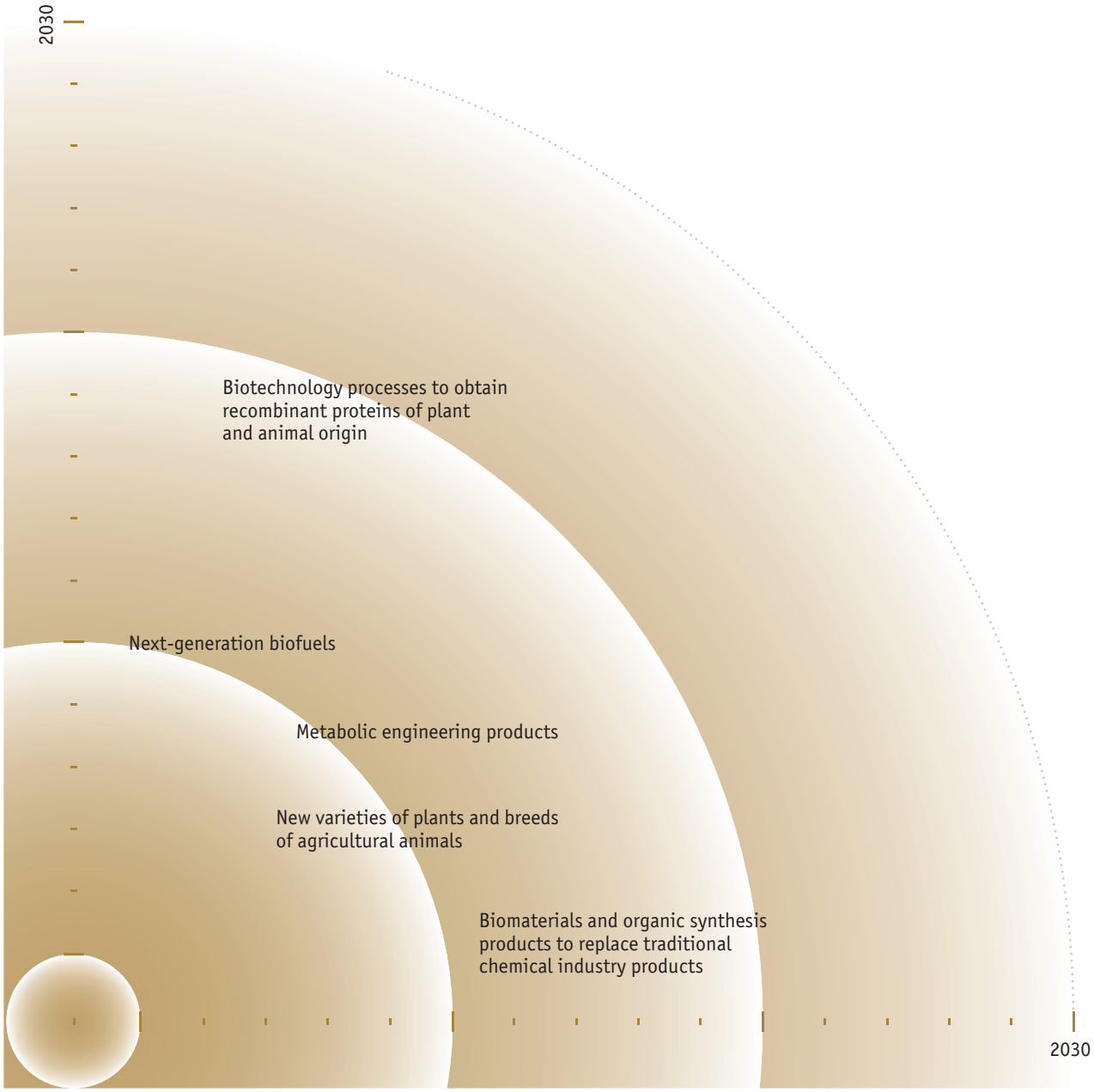
(continued)

Markets	Groups of innovative products and services	Characteristics
	Food protein: – protein products made from low-value waste – protein products made from by-products of processing vegetable and animal materials – protein products with improved properties Special food products: – plant or bacterial additives – vitamins, minerals – natural flavourings and colourings – enzymes and emulsifiers – amino acid additives – flavour enhancers – edible ingredients Functional food products: – functional therapeutic food products (prophylactic food products, special purpose products, products with reduced fat content, sugar content, organic production) – children's food products – biologically active additives Food products derived through deep re-processing of waste: – natural flavourings – colourings – new technological additives (ferments and emulsifiers) – starter cultures – vitamins – functional mixtures	Increased nutritional value Economically sound possibility of extracting from a wide range of primary products and waste Improved health, growth and development Improved storage times Balanced nutrition, vitamins, amino acids, etc. Resistance to the effects of an aggressive environment
Biotechnological systems to protect the environment	Methods to process lumber: – methods for low-waste lumber processing – methods to recycle lumber milling waste Treatment plants (methods to purify and process waste): – bio-decomposer organisms – methods to purify water, soil and the atmosphere using the metabolic potential of biological objects – biodegradants	Environmental neutrality High productivity High efficiency Potential processing Sustainability

(continued)

Markets	Groups of innovative products and services	Characteristics
	Environmentally friendly housing: – technology to create "zero" waste-free housing – biopositive construction materials (completely re-usable with biotechnological processing – new types of trees, wool, felt, natural maple and rubber) Bioresource centres and biocollections: – collections of microorganisms, fungae and algae – collections of cells of higher plants and animals	
Biotechnological systems and products for the forestry sector	Methods to reproduce and protect forests: – tools and methods to protect and reproduce arboreal genetic resources – biotechnological tree forms with specified properties – biological forest protection techniques – microbiological conservation products (biofertilisation)	Potential to reduce environmental costs Potential to increase the speed of forest reproduction Protecting biodiversity
Aquabioculture	Hydrobionts as a source of biomass: – new breeds and crosses of hydrocoles which are resistant to adverse temperatures and which have high growth rates and reproduction rates – recycled commercial hydrocoles and aquaculture products – cell lines of marine organisms and microbial symbionts which produce biologically active compounds Products derived from hydrocoles: – biologically active compounds – biopolymers and new materials – functional food products – biological raw materials, semi-finished goods, consumer products	Reduced environmental costs Increased nutritional value Increased storage times Improved taste Increased protein levels Balanced nutrition, vitamins, amino acids, etc. Increased resistance to the effects of an aggressive environment Availability Sustainability Environmental neutrality Biological activity
Biotechnological systems and products for the forestry sector	Methods to reproduce and protect forests: – tools and methods to protect and reproduce arboreal genetic resources – biotechnological tree forms with specified properties – biological forest protection techniques – microbiological conservation products (biofertilisation)	Potential to reduce environmental costs Potential to increase the speed of forest reproduction Protecting biodiversity

Fig. 6. Innovative Products and Services with a Radical Impact on the Dynamics of World Markets in the "Biotechnology" Priority Area



valuable properties such as biodegradability, and this, in turn, will provide an impetus for the creation of new biodegradable materials for medical and industrial purposes.

Biotechnological processes to produce biologically active compounds based on targeted modification of the producing organism's pathways using metabolic engineering techniques will make it possible to produce amino acides, vitamins, antibiotics, enzymes, recombinant proteins and other products. The increased effectiveness of new methods of metabolic engineering and bioengineering against the backdrop of traditional methods (random mutagenesis, etc.) reduces the cost of the product and creates the necessary conditions for mass application in various industries.

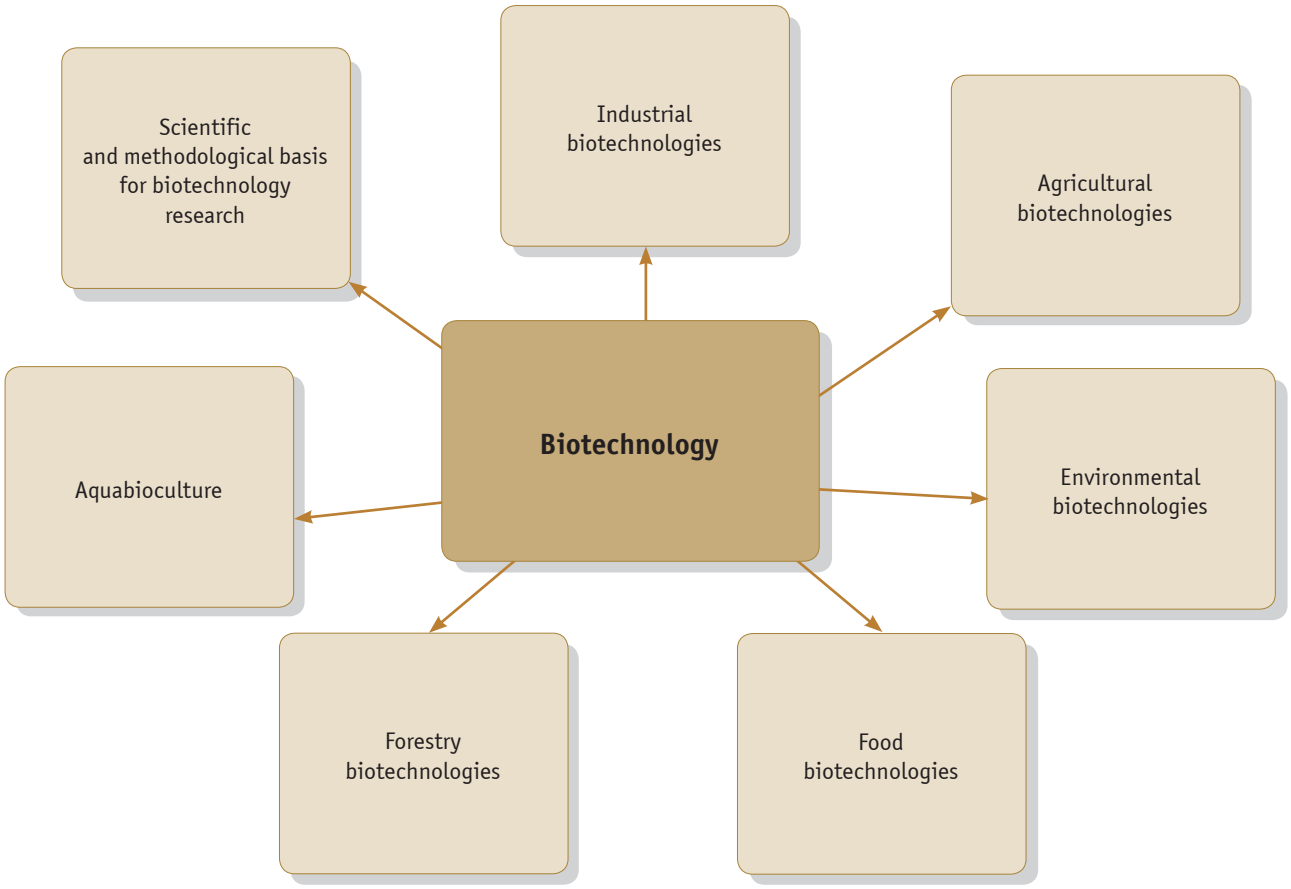
Biotechnological processes to produce recombinant proteins for industrial (enzymes, biopolymers, etc.) *and medical* (vaccines, antibodies, enzymes) *use in plants and animals*, or "biofactories", are cheaper and more effective compared with traditional technologies based on using microbial cultures and animal cells. Thus, technologies to produce recombinant proteins in plants using viral systems, and in the milk of transgenic animals, are one of the key prospective developments in this field.

The leading positions in the development of radically innovative products and services are occupied by scientists from the USA, Europe and Japan. In particular, the USA is actually the leader in the field of plant genetic engineering. Research into the development of biotechnological varieties without using transgenesis and biotechnological processes to produce recombinant proteins in plants and animals is receiving more attention in European countries. Biotechnologies to produce new types of motor fuels are being studied by a significant number of scientific organisations, universities and companies around the world. The Russian level of development in the majority of radical biotechnological products is seriously lagging behind foreign research, but a few Russian developments are in demand abroad (e.g. , genetic engineering strains – producers of aminoacids and vitamins).

2.3. Promising Research Areas

The practical dissemination of innovative products, as described above, largely depends on the level of scientific and technological groundwork, the role of which has grown markedly in recent years. Experts have identified seven thematic areas of applied research as being some of the most promising for Russia (fig. 7).

Fig. 7. Thematic Fields of the "Biotechnology" Priority Area



Achieving the above-mentioned effects of biotechnology development and securing a meaningful niche on promising emerging markets requires a radical improvement of Russian producers' skill sets, which currently are quite uneven. Among the most advanced applied research areas the experts identified are high-performance techniques for genome, transcriptome, proteome, and metabolome analysis; systematic and structural biology; and microorganism strains and microbe consortia to create symbiotic plant-microbial communities. On the other hand, in a number of other areas, such as biotechnological processes to make biomaterials, fine and mainline organic synthesis products from renewable raw materials, techniques to build genetic databases of plant varieties and seed certification, and environmentally safe biocides, the level of Russian research conducted in recent years remains insufficient.

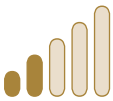
The priority directions for research and expected results for the period up to 2030 are shown below in the cross-section of integrated thematic fields.

Scientific and Methodological Basis for Biotechnology Research

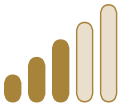
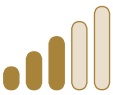
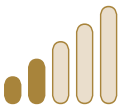
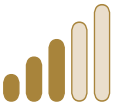
Expected results of future research:

- new methodological approaches to genomic and post-genomic technologies, systematic, synthetic and structural biology, bioengineering and bioinformatics.

Table 10. Promising Research Areas in "Scientific and Methodological Basis for Biotechnology Research"

Research areas	R&D Level	R&D Priorities
High-performance techniques for genome, transcriptome, proteome, and metabolome analysis		Development of multiparameter analysis techniques (on-chip technologies) Development of high-performance sequencing techniques Development of bioinformatics techniques to process genome, transcriptome and proteome analysis data Development of comparative genomics and proteomics techniques Development of high-performance robotic screening systems
Systematic and structural biology		Studying the structure of macromolecules and their complexes, cellular organelles, cytoskeleton elements, etc. on different levels of cell organisation Studying cell-to-cell interaction mechanisms of multicellular organisms, in organs and tissues Modelling in silico structures of biomolecules and bioprocesses taking place in living organisms; analysing them in vitro using bio-chemical and bio-physics approaches Analysis of regular DNA elements and epigenetic factors regulating gene expression in higher organisms' and procaryotes' cells

(continued)

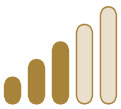
Research areas	R&D Level	R&D Priorities
Synthetic biology, metabolic engineering, and bio-engineering		Development of methodology for metabolic engineering, systematic and synthetic biology Development of techniques to modify cells' metabolic fates, and to create in microorganisms' cells de novo biosynthetic fates Development of models to create a synthetic cell Development of genetic engineering techniques and an expression system for biotechnologically significant microorganisms Testing reverse genetics techniques on lab animals, including transgenesis and mutagenesis Studying expression systems in eukaryote cells, including new genetic therapy vectors Regulating gene expression using RNA interference and related mechanisms Life-time visualisation of biological structures and processes in live systems Controlling biological processes using light and other electromagnetic fields
Immunological technology		Development of prototype bioactive complexes and sensors based on monoclonal antibodies Development of new immunoscreening techniques Development of new immunoprofilactic tools based on bioengineering technologies and immune response correction techniques Researching adaptive immunity
Cellular biotechnologies		Development of techniques to identify and assess the efficiency of oncological and infectious disease inhibitors in cell cultures Development of tools to prevent and inhibit tumour growth, based on bioengineering technologies Development of biotechnological techniques for targeted delivery of biologically active substances into organs and tissues
Studying natural biodiversity		Studying microorganisms not cultivated in laboratory environments Analysis of microbial community metagenomes

Industrial Biotechnologies

Expected results of future research:

- biotechnologies to make industrial, agricultural and medical products including traditional (biologically active compounds, food, forage, etc.) and new ones (recombinant proteins, biopolymers, organic synthesis products, biodegradable plastics, etc.), including:
  - laboratory-level processes for producing biologically active compounds (amino-acids, antibiotics, protein and peptide preparations, etc.) based on targeted modification of the producing organism's pathways using metabolic engineering techniques;
  - new ways to produce biomaterials and organic synthesis products out of renewable raw materials, to replace traditional chemical production and develop innovative products with unique properties, strains and associations of producer microorganisms;
  - prospective enzymes for application in biocatalytic processes, including those resistant to extreme conditions of real-life biotechnological processes (high temperature, acidity or alkalinity, presence of salts, organic solvents, etc.); artificial proteins with improved functional characteristics produced by rational design and/or directed evolution approaches;
  - microbial strains – producers of biologically active substances (bio-pesticides, bio-insecticides, etc.), to produce biological plant protection means;
  - prospective microorganisms and microbial associations for application in biotechnological processes, and for making microbial electric power sources;
  - prototype new sources of non-food biomass with improved properties for use as raw materials (fast-growing trees and water plants, microalgae, etc.), developed with the help of biotechnology;
  - laboratory-level biotechnological processes facilitating microorganisms' use of gaseous substrates, based on new strains and novel fermentation principles.

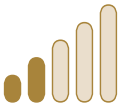
Table 11. Promising Research Areas in "Industrial Biotechnologies"

Research areas	R&D Level	R&D Priorities
Biosynthetic processes to produce biologically active compounds		Sequencing and annotation of microorganisms' genomes, primarily industrially significant ones Screening and studying microorganisms with specified biotechnologically significant properties Studying the regulation of metabolic fates including measuring carbon flows and activity of enzyme systems Studying the general regulation systems of microbial cells (molecular physiology) using transcriptome, proteome, and metabolome analysis Development of industrial microorganisms genetics – producers of aminoacids, vitamins, toxins, antibiotics, and other biologically active compounds; development of methodological basis for targeted adjustment of microorganisms' metabolism to achieve supersynthesis of cellular metabolites, with a high market potential (setting up cell factories)

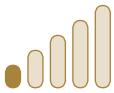
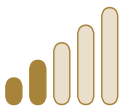
(continued)

Research areas	R&D Level	R&D Priorities
		Development of a methodology to integrate genetic material into microorganisms' genomes Development of cassettes to achieve adjustable gene expression at various levels Laying scientific and technological groundwork in the area of biosynthesis of biologically active cellular metabolites Creating new-generation producer strains Development of techniques for controlled cultivation of producer strains Exploring opportunities to create de novo biosynthetic fates using synthetic biology techniques Designing strains with adjusted or newly created de novo metaboloic fates to synthesise bioproducts
Enzymes and their use in biocatalytic processes		Screening enzymes with specified characteristics in natural populations and collections, and searching for enzymes in databases Studying biocatalysis mechanisms; identifying physical-chemical patterns affecting the acceleration of chemical reactions using biocatalysts Development of artificial catalysts based on biocatalysis principles Reseafch into biocatalysts' spatial structures using structural biology techniques (X-ray structural analysis, nuclear-magnetic resonance, etc.), and computer modelling Targeted evolution of enzymes and their rational design using directional mutagenesis techniques, to improve their properties: increase activity, stability, change specificity, etc. Development of recombinant enzymes with improved technological properties, including ones performing several consecutive reactions Studying mechanisms for secreting enzymes from microorganisms' cells, and optimisation of these processes Development of novel techniques for the isolation and purification of biocatalysts, their immobilisation and stabilisation, and use in nonconventional and non-aqueous environments Development of highly active strains – producers of industrial, fodder and edible enzymes which are particularly in demand: cellulase, beta-gluconase, xylanase, hemicellulase, phytase, pectinase, amylase, lipase, protease, nitrile hydrase, etc.

(continued)

Research areas	R&D Level	R&D Priorities
		Development of biocatalysts (oxide reductase, ligase, synthase, etc.) to make sensor devices through fine organic synthesis, to produce syntons etc. Identifying enzymes of specified classes, resistant to extreme conditions of real-life biotechnological processes (high temperature, acidity or alkalinity, presence of salts, organic solvents, etc.) Application of high-performance screening to identify mutant enzymes with unique catalytic properties; designing strains using genetic engineering techniques, rational design, and targeted enzyme evolution Development of techniques for controlled strain cultivation to achieve maximum possible yield of high-activity biomass Creation of prepared forms of enzymes for subsequent use in various fields
Processes to obtain biomaterials and fine and organic synthesis models from renewable raw materials		Development of approaches to new biosynthesis processes under extreme conditions (high or low temperature, acidity, etc.) to obtain industrially significant bioproducts Creation of highly productive strains of microorganisms synthesising polymers or monomers to subsequently obtain polymers which are suitable for finished articles which can decompose in the environment without generating any harmful products Establishment of scientific and technological groundwork and development of technologies to obtain biomaterials and fine and basic organic synthesis products from renewable raw materials, as well as to isolate and purify them
Industrial biotechnology resource base		Diversification of renewable biomass sources for use in biotechnological production and to improve the quality of renewable (vegetable) raw materials (prospective biomass sources include perennial fast-growing plants, single-cell algae, plants with adjusted cell wall structure, agricultural and municipal waste, etc.; a new raw material for biotechnology is synthetic gas, into which any biomass can be converted by pyrolysis) Identification and creation (using selection and genetic engineering techniques) of new plant and algae species and varieties (biotechnological/bioenergetics), for use as raw materials in biotechnological processes Development of microbiological transformation of synthetic gas Development of techniques for the cultivation, collection, pre-processing and biotransformation of renewable biomass (fast-growing plants, algae, etc.) Development of new techniques to increase bioavailability (pre-processing) ligno-cellulose raw materials, lignin utilisation and transformation

(continued)

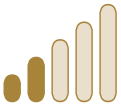
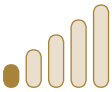
Research areas	R&D Level	R&D Priorities
		Development of technologies to use agricultural and municipal waste as raw materials to make high value-added biotechnological products
New technologies for the production, isolation and purification of bioproducts		Modelling separation processes in complex multicomponent biotechnological environments
		Development of new materials (membrane, chromatographic, etc.) used in separation and purification processes
		Development of continuous processes for separation, isolation and purification of bioproducts
		Scaling separation, isolation and purification processes; development of technologies, processes and equipment for use in biotechnological production
Biotechnologies		Studying the metabolism of microorganisms' strains, structure and dynamics of microbial communities and consortia used in biotechnological processes
		Modelling physical, chemical and biological processes occurring in microbial communities and external environment, for biotechnological purposes
		Identifying new prospective microorganisms for biotechnological purposes
		Development of biotechnological techniques for the intensification of metal extraction processes from ore, ore concentrate and rock
		Development of microbiological techniques to remove unwanted admixtures from extracted minerals
		Development of techniques to increase oil formation extraction
		Development of biotechnological techniques to control corrosion in various pipelines
		Development of technologies to reduce methane content in coal mines

Agricultural Biotechnologies

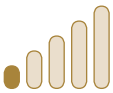
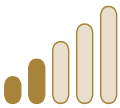
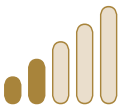
Expected results of future research:

- increasing the efficiency of agricultural production by applying advanced techniques to manage genetic resources of agricultural plants, animals, and microorganisms;
- innovative biological techniques to protect plants and increase their productivity;
- new industrial and medical bioproducts made using bio-factories – plants and animal.

Table 12. Promising Research Areas in "Agricultural Biotechnologies"

Research areas	R&D Level	R&D Priorities
Parent strains to develop new, high-yield, pathogens- and unfavourable environment-resistant varieties and hybrids of agricultural plants, produced using biotechnologies		Identifying genes and studying molecular-genetic mechanisms affecting economically valuable properties of plants (resistance to stress factors including phytopathogenes; increasing yield quality); identification of various pathogens' markers Decryption of mainline agricultural plants' genomes Development of techniques to produce high-yield varieties of agricultural plants using advanced technologies to produce initial homozygotic and recombinant material, genetic markers for plants' selection and genetic engineering Development of techniques for the transformation and efficient delivery of and constructs for the expression of heterological genetic material Development of techniques for haploidy and quick production of homozygotic initial strains
Algorithms to improve breeding technologies using genetic selection of agricultural animals; databases of agricultural animals' breeds' genome information, for application of cloning technologies and genetic databases to practical breeding		Analysis of genomes, identification of candidate genes - loci of useful quantitative attributes; studying molecular mechanisms of animals' productivity Development of molecular selection methodology and technologies for the separation and maintenance of biological material as a form of preserving unique genotypes and genetic resources Identifying and studying selection-significant polymorphisms associated with quantitative and qualitative production indicators Development of techniques to build genome databases and diagnostic testing systems making it possible to assess animals' breeding value at genome level Development of cloning techniques to replicate outstanding genotypes Development of a methodology for targeted modification of individual genomes, to create new breeding forms and extend product range Development of technology to breed animals producing recombinant proteins Creating new animal breeds using molecular technologies, systems to control the genetic production potential and quality of livestock and poultry products

(continued)

Research areas	R&D Level	R&D Priorities
Laboratory-level techniques to build genetic databases and certification of seed varieties		Development of techniques to build genetic databases of agricultural plants' varieties, based on using varieties' molecular markers Development of seed certification techniques, including molecular identification of varieties and detection of potential impurities (pathogens etc.)
Prototype innovation peroral drugs and candidate vaccines for animals		Analysis of genomes of disease agents particularly dangerous to productive animals Studying the evolution and channels of infectious agents based on the results of their isolates' phylogenetic analysis Designing DNA vaccines simultaneously containing DNA fragments of different agent strains, and development of techniques for their application Developing radically new prophylactic and therapeutic preparations based on research of molecular mechanisms of viruses' and bacteria pathogenicity, and their immune regulation repertoire Development of testing systems for high-performance instrumental measurement of animal organs' and tissues' tests, to detect agents of diseases which are particularly dangerous to animal and poultry farming Designing recombinant vaccines against agents of animal infectious diseases, and development of technologies for their production Application of mono- and bispecific monoclonal antibodies for serodiagnosis Development of systems for selective purification and concentration of infectious diseases' agents in veterinary monitoring facilities Studying new adjuvants and immunostimulants Improving techniques to assess the efficiency of antibacterial and antiviral chemotherapeutical preparations Improving oral vaccines to enable mass vaccination of domestic and wild animals
Novel molecular-genetic techniques to diagnose plant and animal pathogens; biological anti-pathogenic treatments		Identifying and studying individual markers of plants' resistance to pathogens Decryption of major phytopathogenes' genomes relevant to Russia's agriculture

(continued)

Research areas	R&D Level	R&D Priorities
		Development of testing systems to detect quarantine pathogens at all stages of agricultural plants production: from test tube to field Development of high-precision molecular genetic methods for diagnosis of pests and the development of new biological agents for plant protection Development of highly active strains – producers of microbiologic preparations Development of multifunctional biological preparations based on the association of beneficial microorganisms and recombinant microorganisms – producers of plant protection preparations Identification of new polypeptide toxins with selective effect on insects – agricultural plant pests Cloning the genes of selective insectotoxins, and obtaining their bacteria-based producers Development of technologies to make and use environmentally safe biological agents to protect plants from pests, disease agents, and weeds, for industrial production of agricultural products and for use in resorts and specially protected natural area, and water protection zones
Microorganism strains and microbial consortia to create symbiotic plant-associated microbial communities providing required mineral substances to plants and protecting them from pathogens		Understanding the genetic structure of microbial communities in mainline soil types to identify key gene and genome groups affecting basic soil formation processes (circulation of macro-elements, metabolism of humic substances, stability of biologic properties under effect of global climate change) and plant development (nitrogen and phosphate nutrition, protection from pathogens, ability to sustain homeostasis in situations of natural and anthropogenic stress) Understanding the structure of plants' symbiogenome, which enables integration of useful microflora to create environmentally efficient and self-sufficient microbial-plant systems Genetic construction and bioengineering of multicomponent and polyfunctional plant microbiomes, to mobilise trophic resources of the soil (optimal nitrogen and phosphate nutrition for mainline agricultural plants), their protection from pests and sustainable development amid global climate change (temperature and water balance, salinisation) and biospheric pollution Development of techniques for molecular monitoring of agricultural soils, to forecast the dynamics of their biologic potential's mainline parameters Development of a methodology for large-scale introduction of useful microorganisms into the soil, on the surface and into the tissues of plants cultivated in various Russian soil-climatic zones

(continued)

Research areas	R&D Level	R&D Priorities
		Development of new techniques to control the development and adaptive functionality of agricultural plants in environmentally stable agrocenoses, using signal molecules synthesised by microorganisms in industrial conditions Development of new enzyme forms useful for microbial-plant systems, to improve the adaptive potential of mainline agricultural plants Development of technology to cultivate producer strains, and designing new forms of biopreparations for farming (with growth stimulating and phyto-protection effects), to increase the competitiveness of products, sustainability of natural resources, and increase planted areas, based on organic farming principles Development of microbial preparations and technologies for their application to process and/or recycle agricultural waste
Laboratory-level biotechnological processes to produce industrial and medical bioproducts in plants		Development of new technologies to produce recombinant proteins (including vaccines) in plants-biofactories

Environmental Biotechnologies

Expected results of future research:

- biotechnology-based environmental pollution monitoring systems;
- restoration of ecosystems using live organisms – biodestructors;
- protecting materials and technological objects from biodamage and biocorrosion.

Table 13. Promising Research Areas in "Environmental Biotechnologies"

Research areas	R&D Level	R&D Priorities
New verified techniques for bio-testing and bioindication, with increased sensitivity and selectivity, to detect environment pollution; biosensor organisms' strains		Identification of new objects for biomonitoring and biotesting Studying organisms' indicator importance, their ability to adapt to existing pollutants under various conditions Development of techniques and criteria to evaluate bioindicators' physiological state and morphological changes in the course of ontogenesis Development and application of efficient biotesting systems, including express ones, based on biological material and live microorganisms Development of biosensors capable of quickly and selectively determining the quality and quantity of pollutants in natural ecosystems Development of techniques to detect the biosphere's response to anthropogenic impact on various levels of live systems: molecular, cellular, organism, population, and community

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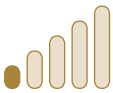
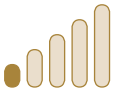
Research areas	R&D Level	R&D Priorities
New verified techniques for purification of water, soil, and atmosphere, using efficient organisms – bioremediators		Identifying new efficient live organisms – pollutant biodestructors; studying their biology Development of techniques for the production, storage and application of destructor biomass Studying the metabolic potential of biological objects allowing their ecobiotechnological usage Development of bioremediation technology: a complex of techniques for purification of water, soil, and atmosphere using metabolic potential of biological objects Development of biotechnological techniques to mitigate the after-effects of harmful environmental impacts, anthropogenic disasters (oil spills, radiation pollution, accidents at chemical production facilities, etc.)
Environmentally safe biocides to protect technological objects from destructor organisms		Studying mechanisms of specific macro- and microorganisms inflicting biological damage on materials, articles and installations Development of environmentally safe biocides and ecobiotechnological techniques to protect against biodamage and biocorrosion Studying the effects of biological factors on materials and technological objects Development of basic principles for accelerated laboratory testing of materials, articles and means of protection against biocorrosion and biodamage Studying the composition and dynamics of communities of organisms causing biocorrosion Development of techniques for biotechnological protection against harmful microorganisms, algae, fungi, invertebrates and other live organisms – destructors of technological surfaces

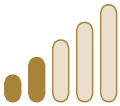
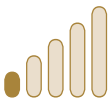
Food Biotechnologies

Expected results of future research:

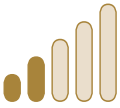
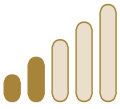
- safety evaluation systems for new and traditional food sources, ingredients, food processing technologies, functional food stuffs, baby food, diet and medical food, low allergenicity food, and biologically active additives, including:
  - prototype instruments for highly sensitive express detection of pollutants (xenobiotics, fungous and bacterial toxins, pesticides, veterinary preparations, etc) in food and food raw materials;
  - laboratory-level food authenticity control techniques based on detection of specific biological macromolecules (nucleic acids, proteins, etc);

- prototype new probiotics, prebiotics, synbiotics, enzymes and food ingredients; new strains of lactic acid bacteria and other technological microorganisms; microbial consortia with specified biological properties and optimised technological characteristics;
- laboratory-level biotechnological processes for making biologically active substances, useful protein products and ingredients from waste and low-value products obtained by processing vegetable and animal raw materials.

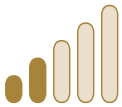
Table 14. Promising Research Areas in "Food Biotechnologies"

Research areas	R&D Level	R&D Priorities
Ensuring food safety		Studying the effects of new and unconventional food sources on human health, and interaction mechanisms between nutriome (macro-, micronutrients, minor biologically active food components) and the human body
		Identification of risks associated with new and unconventional foods based on high-performance metabolic process screening techniques ("omics" technologies)
		Development of techniques for multiparameter control of chemical pollutants' content in food and raw materials (fungous and bacterial toxins, pesticides, veterinary preparations)
		Development of techniques for express detection of bacterial contamination of food and raw materials
		Development of a set of techniques to confirm food authenticity, including identification of the raw materials' species based on identifying specific biologic macromolecules (nucleic acids, proteins, etc.)
		Studying the cumulative effect of sub-threshold pollutant concentrations, taking into account specific features of particular foods
		Development of methodological approaches to integrated safety evaluation of products containing several pollutants
Food protein technologies		Studying the physical, chemical and biological properties of food protein and protein compositions produced from vegetable and animal raw materials
		Development of techniques to test the biological properties of food protein and food compositions, on molecular, cellular and organismal levels
		Development of theoretical and methodological basis for targeted production of protein compositions with specified properties, and analytical platform for their testing

(continued)

Research areas	R&D Level	R&D Priorities
		Development of technological equipment for deep conversion of by-products and waste from processing vegetable and animal raw materials, to extract as many food proteins as possible and produce specific protein compositions
Biotechnological approaches to the production of probiotics, prebiotics, synbiotics, enzymes and food ingredients		Screening of microorganisms, identification of new probiotics and synbiotics, studying their physiological functions and metabolic fates; description of the structure and properties of biologically active compounds that they produce Studying genomes of lactic acid bacteria; identification, selection and production of highly active strains of lactic acid and other technological microorganisms with specified biological properties and optimised characteristics Development of biocatalytic and genetic engineering technologies for the production of food ingredients (including vitamins and functional mixtures), and techniques for assessing their safety and effectiveness Studying the functional properties of products based on biologically active compounds and biocompositions (foods, food additives, and functional food ingredients, biologically active additives, and medical biological preparations) Development of starter cultures and highly concentrated enzymes based on new probiotics for industrial and medical biotechnologies Development of new technologies to produce target products with specific properties based on biologically active compounds and biocompositions
Functional and specialised foods		Identification of effective biomarkers for objective assessment of the human body's provision with nutrients, and development of personalised diet recommendations Studying specific features of people's metabolism, nutrients and energy requirements in extreme conditions Development of a methodology for correcting pathological states using functional and specialised foods; formulating medical and biological requirements for their application in various population groups' diet Studying biological transformations of functional foods and ingredients; developing a strategy for studying their effects over vital bodily functions Development of techniques for assessing the safety and biological effectiveness of foods and ingredients, and for testing their functionality

(continued)

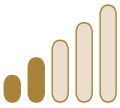
Research areas	R&D Level	R&D Priorities
		Development of a theoretical and methodological basis for targeted production of new foods and ingredients with specified properties Development of technological equipment for biocatalytic conversion and/or synthesis, to produce new food ingredients with specified properties, and food stuffs based on them
Processing food raw materials and waste		Screening prospective sources of biologically active substances (vitamins, antioxidants, polyunsaturated fatty acids, polyphenol compounds, biologically active peptides, etc.) out of low-value secondary products of vegetable and animal raw materials' processing Development and optimisation of techniques for deep processing of low-value vegetable and animal raw materials, to extract biologically active compounds, and/or for targeted modification of their structure to increase their functional and consumer properties and biological value

Forestry Biotechnologies

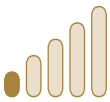
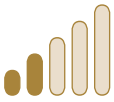
Expected results of future research:

- new forms of arboreal plants with specified properties, planting stock;
- assessing quality of seed material; monitoring of the phytosanitary state of nurseries and forest plantations;
- technologies for deep wood processing and recycling of sawmill waste;
- advanced forest plantation management system (including DNA labelling techniques);
- biological forest protection techniques.

Table 15. Promising Research Areas in "Forestry Biotechnologies"

Research areas	R&D Level	R&D Priorities
Parent strains for selecting new varieties of arboreal plants with improved properties (texture of timber, resistance to phytopathogenes, growth speed, etc.) produced using biotechnologies		Studying in vitro organogenesis processes and embryogenesis of arboreal plants; development of new techniques for in vitro cultivation of plant material Genetic analysis, mapping and sequencing of arboreal plants' genomes, including creation of inbred (homozygotic) collections using haploid technologies Development of techniques for molecular selection of arboreal plants Development of a theoretical basis for forest plantation management biotechnologies Studying physiological and genetic aspects of arboreal plants' dormancy in vitro

(continued)

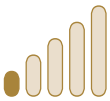
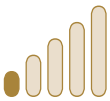
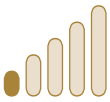
Research areas	R&D Level	R&D Priorities
		Haploids, homozygotic diploids and polyploidisation as a technique to produce new genotypes and forest plant varieties
		Development of in vitro banks of rare and endangered forest plant species
		Clonal microbreeding of rare and endangered species of forest arboreal and other plants, to create reserves of genetically valuable tree forms, to increase the quality of plant material
		Monitoring the current state and assessing the genetic variety of forest resources based on DNA analysis
		Targeted molecular (DNA) labelling to accomplish practical objectives of the forestry sector: development of forest planting zoning principles and techniques; creation of seed databases and seed certification; monitoring of nurseries' and forest plantations' phyto-sanitary state; control of timber origin's legitimacy
		Development of biotechnological tree forms with specified properties: reduced lignin content, resistance to herbicides, etc.
Microbiological protection of forests from pests and pathogens		Clonal microbreeding of plants (including gametic and somatic embryogenesis), for selection and production of pest- and pathogen-resistant forms of high-quality planting material
		Production of sustainable forms of forest plant species, and genetic engineering-based pest- and phytopathogenes control techniques
		Development of technologies to monitor the phyto-sanitary state of forest plantations
		Development of technologies for large-tonnage production of biological forest-protection preparations
Laboratory-level promising biotechnological processes for integrated processing of timber biomass and its individual components		Development of new-generation fibrous semi-products and cellulose composite materials
		Separation of lignin and hemicelluloses, with subsequent synthesis of high value-added products
		Development of environmentally safe technology to produce nanosize cellulose and manufacturing composite construction materials from it, with improved functional properties
		Development and application of technologies for integrated timber biomass processing to make products requiring deep processing (biofuel, biochemicals)

Aquabioculture

Expected results of future research:

- effective products from oceanic and internal water reservoir hydrocoles (fish, ostraceans, shellfish, echinoderms, algae, plankton);
- hydrocole deep processing systems, and their application to produce food, forage, and veterinary and medical products that are in demand.

Table 16. Promising Research Areas in "Aquabioculture"

Research areas	R&D Level	R&D Priorities
Identification of new, hydrocole biomolecules which are valuable for their practical applicability (enzymes, proteins and peptides, secondary metabolites, bacterial polysaccharides, archaea, algae, fatty acids and algae lipids) using genome and post-genome technologies; techniques for making biopolymers and new materials from hydrocoles		Studying specific hydrocole proteins and enzymes Application of bioinformatics techniques to identify new biomolecules in hydrocoles (biocatalysts, proteins and peptides, secondary metabolites, bacterial polysaccharides, archaea, algae, fatty acids and microalgae lipids Metagenomic research into water-based micro- and macrobionts
Laboratory level techniques for cultivating cell lines of marine organisms and microbial symbionts – producers of biologically active compounds		Development of innovative techniques for cultivating cell lines of vertebrate and invertebrate marine organisms, and microbial symbionts for producing biologically active compounds Development of hydrocole molecular selection techniques Development of new and improvement of existing biotechnologies to forage and breed valuable fish and seafood Studying marine ecosystems, detecting new objects for cultivation Development and testing of new forage and new feeding techniques for fish and other hydrocoles
Hydrocole molecular selection techniques to make highly productive aquaculture objects		Development of selection and breeding techniques to breed highly productive aquaculture objects Genomic analysis of hydrocoles and marine microorganisms Identifying microalgae strains optimal for biofuel production and techniques to breed them Development of integrated industrial closed-cycle technology to produce biologically active substances from little-used hydrocoles and industrial waste, directly at points of catching Making biopreparations from hydrocoles to increase the human body's resistance to unfavourable environmental factors, treat and prevent various socially significant and dangerous diseases

(continued)

Research areas	R&D Level	R&D Priorities
		Conducting medical and biological research, preparing technical documentation for peptide preparations made of hydrocoles' organs and tissues, with immunostimulating, antioxidant and other properties
		Development of biological substances and compositions, functional foods and biologically active food additives based on hydrocole raw materials
		Studying the properties of polysaccharides produced from shellfish and other hydrocoles, for practical medical and agricultural application

3 MEDICINE AND HEALTH CARE

The increasing quality and length of life among the population is a critical priority in public policy as an effective indicator of the socio-economic development of the country and its national security.

The ageing population, increasing numbers of oncological, cardiovascular and infectious diseases, deficiency diseases and brain pathologies and heightened mortality indicators linked to these are key factors in the development of medicine and health care. These challenges call for the emergence of new markets guided by the need for new methods of diagnosis and treatment, non-invasive reliable and rapid at-home monitoring technologies, and remote medical assistance methods geared towards prophylaxis, safety and high-performance.

There is already strong demand around the world for increased quality of life, including in terms of restoring lost functions of the body, organs or body parts. The consequence of this is the active growth in markets for biotechnologies and high-tech personalised medical services. Further progress in the field of bioinformatics, post-genome and proteome technologies will allow medicine to personalise therapeutic effects: the purpose of the required medicine will be determined based on an analysis of the patient's individual circumstances. According to experts, at least half of new drugs which are due to appear on the global market by 2015 will have pharmacogenetic characteristics.

The development of technologies to analyse the structure and functions of biological molecules and cells have brought about high growth rates in the development of biomedicines. The technological vector is aimed at the productivity of processes, precision and authorisation for devices and equipment to obtain the required information of the specified quality. This is giving rise to the need to develop information technologies, primarily in terms of metadata analysis.

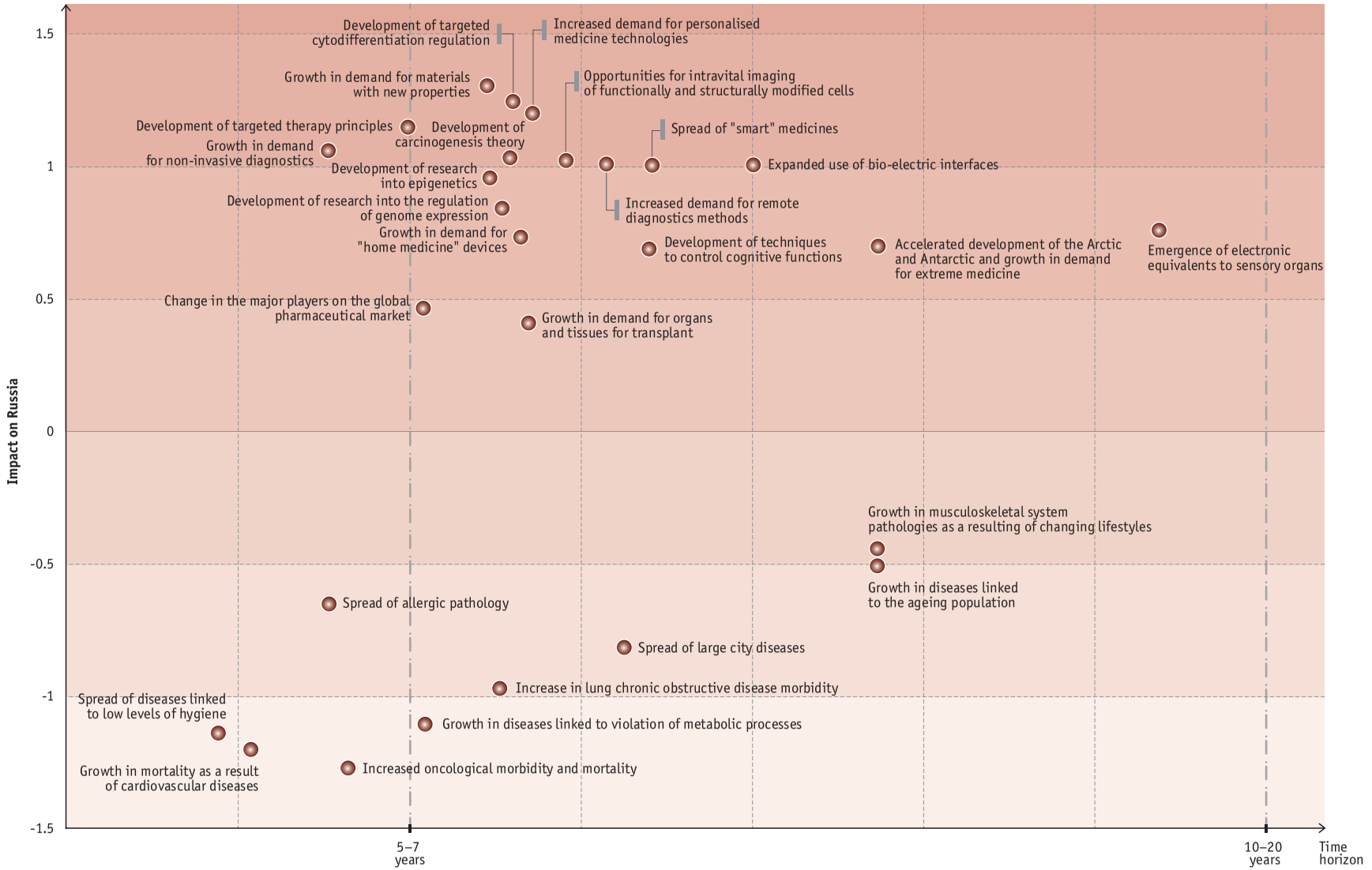
3.1. Challenges and Opportunities

Figure 8 summarises the challenges and opportunities which shape the prospective development of the "Medicine and Health Care" priority area in the context of the corresponding global trends.

Affected by the *growth in oncological diseases and mortality* around the world, there have been active developments in technologies for early diagnosis of oncopathologies. Modern diagnostic methods and equipment allow diseases to be identified at the early stages of development meaning that there are increased chances of a patient's recovery. The further intensification of this challenge will stimulate demand for new technological solutions in the field of diagnostics and therapies for oncological diseases which, in turn, will lead to an expansion of existing product groups and the emergence of new groups.

The challenges linked to the *growth in mortality rates as a result of cardio-vascular diseases* will become increasingly important. Patients diagnosed with these diseases require constant

Fig. 8. Medicine and Health Care: Challenges and Opportunities



Source: HSE ISSEK.

monitoring, and correspondingly there is expected to be development of the market for remote monitoring systems, increased demand for services and methods to prevent their situation becoming worse and to eliminate any after-effects. In the medium and long-term, there is likely to be a drop in the proportion of these diseases in mortality figures, but to achieve the desired levels there needs to be some consolidation of efforts in science and technology, as well as certain institutional changes.

The spread of diseases linked to poor hygiene has caused an increase in the density of the population, its way of life and a poor production culture. The development of simple diagnostic test systems and diagnostic equipment for clinical laboratories is extremely important under these conditions, in particular to identify tuberculosis and helminthiasis, diseases which are encountered in Russia at levels above the global average.

Large-scale urbanisation and the changes linked to this in the environment and living conditions are having a negative impact on humans, causing the *spread of diseases across major cities*. This problem is particularly acute for developed countries with a high pace of life. The reduction in physical work and psychological stresses has come to be a prerequisite for the pathogenesis of a large number of diseases. The "major city" factor itself creates a series of risks, the size of which grows year on year. The development of prophylactic methods to counteract stress-conditioned pathologies is considered to be one of the most important tasks of biomedical sciences.

Increasing life spans are leading to the emergence of a new group of *diseases linked to the ageing population*. The further intensification of this trend will contribute to the growth of markets for life-long use preparations and the dissemination of technologies and products to remotely monitor a person's health. It is expected that there will be increased demand for new materials, primarily for orthopaedics, and in the long- term expansion in the market for biodegradable materials.

Personalised medicine requires changes to key paradigms in medicine: "treatment of the patient" will come to replace "treatment of the disease". This refers to new monitoring, diagnosis, prophylaxis and treatment techniques. In diagnostics, the personalisation of approaches will give rise to demand for high-performance laboratory technologies for molecular screening and to analyse the structure of biological macromolecules. Genome screening technologies will be particularly in demand in the near future, and in the medium and long-term, high-performance protein profiling technologies.

In terms of treatment, there is expected to be significant growth in markets for drugs based on antibodies, as well as *targeted drugs*. Moreover, new hybrid techniques for targeted treatment are being developed using cell and genetic approaches. In general, personalised medicine will stimulate the development of high-performance and highly specific technologies.

Further *growth in demand for materials with new properties* is expected: artificial materials are often the only way to restore the functions of a particular organ or system (shunting, stenting, replacing heart valves, vessels, endoprosthesis, etc.) and they are actively used when producing medical instruments and equipment. There is likely to be work to develop the scientific and technological groundwork in the field of biositalls – materials with high levels of biocompatibility and the ability to be spliced with live bone tissue thanks to its biological activity and "form memory" effect.

The growing demand for remote diagnostics methods and monitoring in the medium term could be satisfied through the active introduction of ICT, in particular telemedicine, to provide consultations, manipulation and procedures from afar (the doctor and patient could be located in different cities or even countries). Progress in diagnostics will allow for the creation

of a system to continuously monitor certain groups of patients to provide them with first aid, including with the use of "home medicine" devices. With the widespread implementation of new systems, the timeframes for observing outpatients and their stays in hospital could be reduced. The development of remote technologies is especially important for Russia with its vast territory, uneven population distribution and concentrations of leading specialist health-care professionals in major cities. The development of non-invasive monitoring systems which eliminate the need to take biological specimens will become particularly important.

Experts have outlined the following ***threats to Russia*** in this field:

- high mortality rates due to cardio-vascular and oncological diseases, trauma and poisoning;
- ineffective existing measures to prevent infectious diseases;
- ineffective rehabilitation system;
- high cost of drug treatment for socially significant diseases;
- high level of alcoholism among the population, including youths;
- parallel surge in "beggar diseases" (tuberculosis, pediculosis, etc.) and "rich diseases" (stress, nervous pathologies, personality disorders, etc.) caused by increasing social stratification;
- the inclination of Russians to self-treatment and the high level of distrust towards "official medicine".

3.2. Prospective Markets, Products and Services

The greatest growth in the short term is expected to be in the pharmaceutical and diagnostic systems sectors. The product groups created by these sectors will continue to grow irrespective of the overall framework to develop the health care sector. Progress in technological fields such as cell technology, tissue and organ engineering, and genetic engineering will be guided by internal forces and global economic challenges. The least upward momentum will come from non-biodegradable materials: its growth will slow in the long-term. After 2020, development will intensify for market groups covering laboratory and functional diagnostics systems, implants, medicines and targeted delivery systems. In the longer term, there is expected to be a gradual merging of the pharmaceutical and medico-biological sectors and active use of biotechnologies to develop new drugs and medical devices. Biomedical research in the medium and long-term are due to focus predominantly on regenerative medicine, molecular and functional diagnostics.

Prospective markets for the "Medicine and Health Care" priority area:

- regenerative medicine;
- biodegradable materials;
- non-biodegradable materials;
- diagnostics systems;
- complex implants;
- surgical equipment;
- medicines and targeted delivery systems;
- live non-invasive visualisation systems.

For each of the markets listed above, innovative products and services which will appear in the period up to 2030 have been identified (table 17).

Table 17. Prospective Markets and Product Groups for the "Medicine and Health Care" Priority Area

Markets	Groups of innovative products and services	Characteristics
Regenerative medicine	Tissue and organ equivalents created using genetic engineering and cell technologies Targeted biologically active substances for damaged tissue regeneration Active molecular stem cell components for tissue regeneration Technologies and preparations based on modified cell systems for competitive treatment of auto-immune, oncological and neurological diseases Inorganic and organic materials of non-animal origin for targeted regeneration of organs and tissues	Increased likelihood of full patient recovery Increased quality of patient rehabilitation Minimising patient after-effects and complications
Biodegradable materials	New surgical materials based on biodegradable polymers Complex macromolecular complexes for mobile parts of implants and bio-organic systems to speed up osteo-integration of bone implants Bio-replaceable materials for orthopaedics imitating bone tissue architectonics	High efficiency High level of safety High reliability
Non-biodegradable materials	Composite ceramics and medicinal cement Dressings and transdermal plasters Mimetic materials for prosthetics	High efficiency High level of safety High reliability
Diagnostics systems	High-sensitivity sensors for human body's physical and physiological parameters Reagents Hardware and software to analyse statistical macromolecular markers Diagnostic systems for multi-factor statistical analysis of qualitative and quantitative data on low- and high-molecular marker molecules Proteome and genome biomarkers	Increased life expectancy Opportunities for early diagnosis
Complex implants	Individually-compatible ("smart") implants based on metals, ceramics or polymers which do not require periodic replacement Implants with bioactive coatings to speed up osteo-integration and meshing with tissues Bioresorbant implants to reconstruct damaged vessels Stents	High level of safety High reliability Increased quality of life

(continued)

Markets	Groups of innovative products and services	Characteristics
Surgical equipment	Invasive visualisation systems, including remote control Robotics Surgical lasers Micromanipulation systems (for high-precision surgical manipulation)	High reliability High level of safety Minimising patient after-effects and complications
Medicines and targeted delivery systems	Recombinant protein preparations Preparations based on nucleic acids, including gene therapy Preparations based on monoclonal antibodies providing highly specific actions Components and systems for targeted delivery of drugs, including based on inorganic nanomaterials	Minimising patient after-effects and complications Increased likelihood of full patient recovery High level of safety High reliability
Live non-invasive visualisation systems	Positron emission tomographs and contrasts for ultra high resolution visualisation Ultra high resolution magnetic resonance imaging Visualisation systems based on the biophysical characteristics of the internal environment (Doppler effect, etc.)	Minimising patient after-effects and complications Opportunities for early diagnosis of diseases High level of safety High reliability

In the field of medicine and health care the radical nature of products and services is determined by the presence of new properties and the ability to have an effect on solving current problems and to lead to radical changes in existing markets. A range of innovative products and technologies meet these criteria (fig. 9).

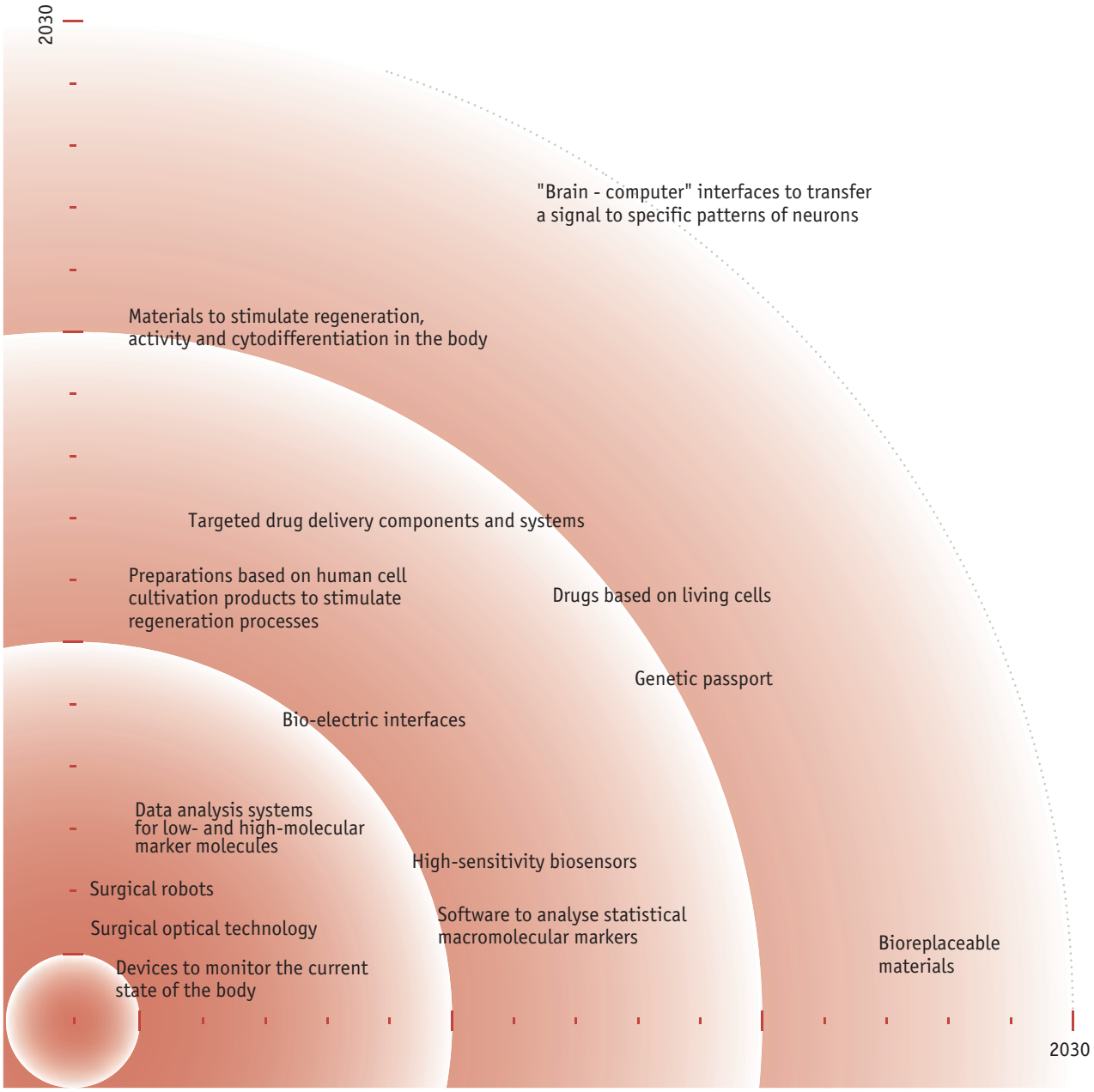
The use of *devices to monitor the current condition of an organism*, including remotely, will make it possible to simultaneously monitor a large group of patients, continuously monitor the parameters of an organism and the state of health of a patient (and where necessary take any urgent support measures), the correctness and timeliness of doctors' instructions, and enable communications between individual monitoring devices and the remote work location of the doctor.

Systems to analyse data on low- and high-molecular marker molecules are hardware and software systems offering high-performance analysis of proteins, nucleic acids and low-molecular metabolites using miniaturised mass-spectrometers. The unique feature of these systems lies in their ability to quickly identify the structure of molecules, which makes these technological solutions highly in demand in biochemical diagnostics.

The result of the practical introduction of new *surgical optical equipment* to replace (or complement) traditional medical equipment will be a reduction in tissue trauma and a fall not only in the time required for operations, but also the duration of a patient's stay in hospital. The development of minimally invasive surgery and the creation of complex hybrid systems consisting of nanotechnology and micro-electromechanical systems (including 3D and 4D multi-modal visualisation systems) will make it possible to use robotics in minimally invasive endoscopic procedures.

The emergence of new *surgical robots*, as well as nanorobots, will make it possible to reduce the level of trauma, wound infection and avoid the need for blood transfusions. Operations

Fig. 9. Innovative Products and Services with a Radical Impact on the Dynamics of World Markets in the "Medicine and Health Care" Priority Area



carried out using robots will see reduced soreness in the post-operative period, accelerated rehabilitation times, minimal risks of the complications common in traditional surgery, increased oncological and functional results from operations, and improved cosmetic effects due to the lack of large post-operative scars. The introduction of such surgical technologies will reduce the impact of the human element during the operation and in terms of its outcome.

Bioelectronic interfaces make it possible to integrate electronic devices with biological tissues (often membranes of nerve cells) to carry out vital processes and bodily functions under various conditions and environments. From a medical viewpoint this is necessary to achieve

connections between implantable chips, bionic prosthetic limbs, implanted artificial sensory organs, and the electrodes of various biotechnical systems and medical devices. Electronic sensory organs are likely to be developed, as well as prosthetics made from new materials with increased compatibility.

Highly sensitive biosensors to measure physical and physiological paramaters of the body will be able to diagnose and identify deviations and faults in the functioning of various organs and physiological systems in the body based on changes in objective operational indicators (physical, chemical, etc.) using instrument-based or laboratory research methods. Multi-component measurement systems will appear which will be integrated with analytical programmes based on chemometric approaches and artificial intelligence drawing together several diagnostic and visualisation technologies.

Software systems to analyse static (contextual) macromolecular markers will make it possible to carry out more in-depth genetic diagnostics (primarily for hereditary and orphan diseases). The expansion of the market for this product group will contribute to minimising the analytical processes in clinical laboratories and the emergence of specific personalised approaches to diagnostics. New systems which do not require expensive equipment and components could successfully compete with mass-spectrometers and other modern analytical techniques.

The use of *preparations based on cell cultivations stimulating regeneration processes* will make it possible to overcome diseases which were previously seen as incurable through the potential for a patient to reproduce their own cells or have cells introduced into the body. By varying the cell cultivation conditions (for example, by placing them in a hypoxic environment), it is possible to change the relationship of factors according to the required results (stimulating or suppressing angiogenesis, apoptosis and the proliferation of receptor cells).

Targeted drug delivery components and systems will increase the effectiveness of treatments through the targeted conveyance of medicinal substances directly to the target organ (tissue). The use of these systems will help to reduce the level of toxicity and side effects of drugs, as well as making them most cost-effective. In the long-term, there is expected to be "smart" medicines capable of reacting both to internal conditions and to changes in the state of the patient's body. The systems being developed will find application in treatments for various types of socially significant diseases: oncological, infectious, chronic inflammatory, mental illnesses, hormonal disorders, etc.

An important step for the transition to predictive and personalised medicine is the widespread dissemination of *genetic passports* containing data from a DNA analysis of the individual. Based on the genetic information provided, a doctor can not only correctly put forward a diagnosis and select the most appropriate treatment, but also – prior to revealing the real picture of the pathological process – to warn of any possible developments of a particular disease with a view to providing timely prophylaxis or treatment.

The introduction of *medicines based on living cells* (autologous, donor, primary, cultivated, differentiated and modified) will form a basis for cell therapy and tissue engineering for transplanting stem cells into certain parts of the body, as well as equivalents engineered on the basis of stem cells, which could be able to restore the structure and functions of damaged tissues and organs. Technologies to obtain stem cells from patient tissues will make it possible to make treatment materials within a matter of hours. The techniques used to selectively cultivate and differentiate this type of cell will allow for rapid and effective treatments for various pathologies. A new and fundamental property of these technologies is the complete compatibility of the stem cells taken from the patient's own differentiated tissues with the patient's body. In this regard, it is possible to rule out infections: the cells have reduced (compared with embryonic) capabilities to differentiate into unwanted directions.

New *materials to stimulate the regeneration, activity and differentiation of cells in the body* offer the potential to cure pathologies in the musculoskeletal system, wounds of various aetiolo-

gy, cardio-vascular diseases, etc. Innovative techniques are based on bioengineering "grafting" technologies in this field and are required, with the necessary speed, to regenerate cells and to subsequently form various tissues and organs directly in the body on the basis of those cells. At the end of the prescribed timeframe, the biodegradable polymer materials leave the body, breaking down with natural metabolic products. New technologies will help to speed up the healing of all types of tissue, prevent the formation of adhesions, and reduce the number of complications after operations, thus providing a significant increase in patients' quality of life.

The expected social effect of *bioreplaceable materials* for orthopaedics, replicating the architectonics of bone tissues and making it possible to heal bone defects, lies in the reduced level of disability in the population, the reduction in periods of incapacity, and the reduction in the length of hospitalisation and rehabilitation periods. Together with this, there is expected to be a fall in the risk of repeated prosthesis replacements. Within the existing technological base, a pool of innovative techniques is being developed which could offer radical medical care to restore bone tissue.

In the long-term, there is expected to be *"brain-computer interfaces"* which are systems to transfer electronic impulses from the body's nervous system to an electronic device and back. This achievement would find wide application in neuroprosthesis, in particular when developing bionic sensory organs. The development of this field will subsequently lead to the creation of systems which are a functional part of the human intellect (exocortex) to further improve cognitive processes.

For those products which have a radical impact on the global markets in the long-term, leading Russian and foreign organisations undertaking research in these directions have been identified. According to the results obtained, the leaders primarily include major scientific research and industrial centres in the USA and EU, and certain specific strands are being actively pursued in South Korea and Japan too. Work to create surgical optical equipment is mainly being undertaken by small companies. The level of Russian scientific research in general is lagging behind global levels. In particular, in terms of materials stimulating regenerative process in the body, there are some competitive developments and serious groundwork is being done in fundamental medical materials engineering, although practical applications are relatively poor.

3.3. Promising Research Areas

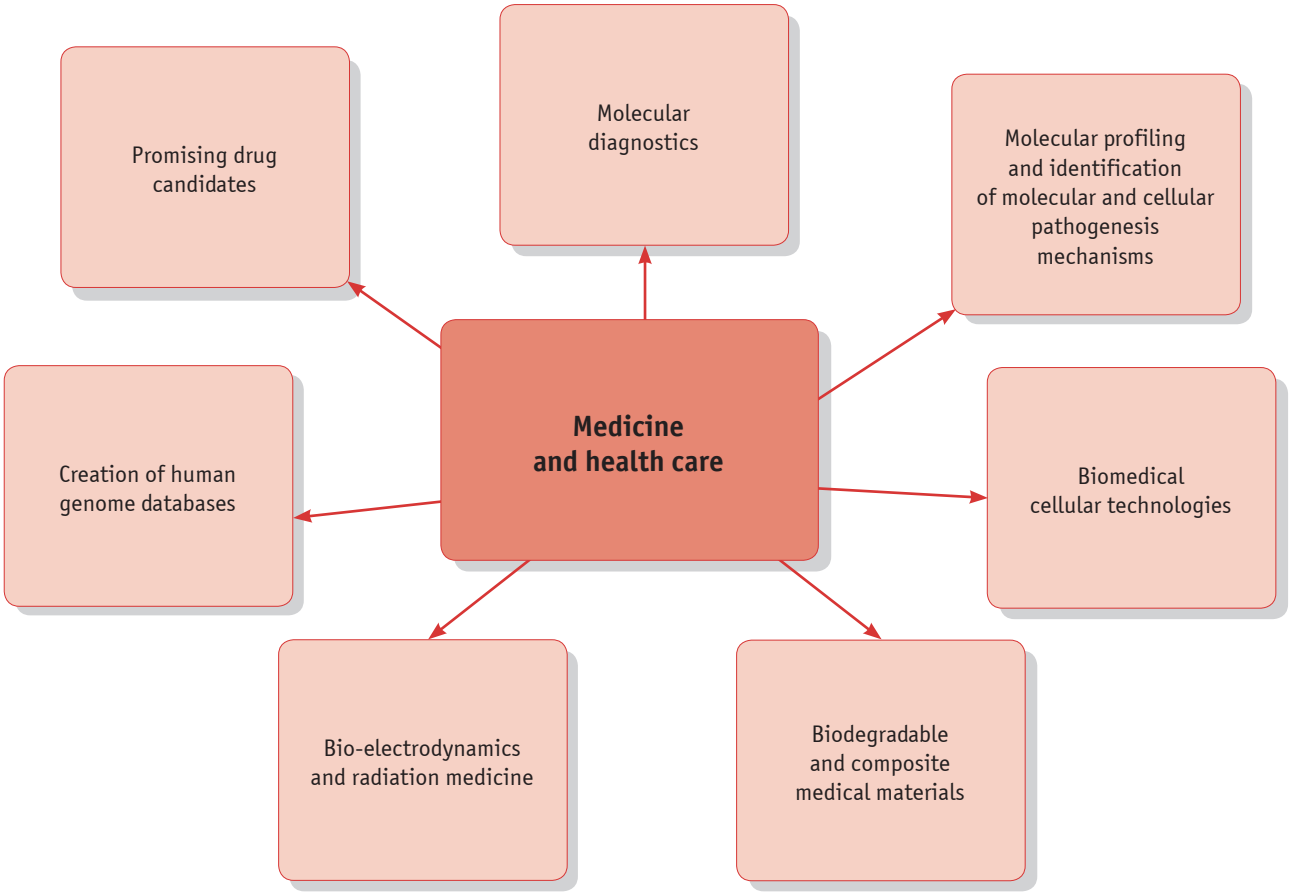
The emergence of the innovative products described above is determined by the state of scientific and technological groundwork. Experts have identified seven thematic areas of applied research as being some of the most promising for Russia in the period up to 2030 (fig. 10).

In the medium term, Russia can expect to achieve significant scientific and practical results in research and development fields such as biocompatible biopolymeric materials, self-sterilising coatings for medical applications, testing systems based on genomic and post-genomic technologies to diagnose cancer, systemic, infectious and hereditary diseases, biosensors and biochips for clinical diagnostics, based on new types of biological devices, and techniques for rapid identification of toxic substances and pathogens.

In other fields of research and development, including, for example, biodegradable materials based on gradient ceramics or medical textiles with unique therapeutic properties, the potential for Russian developments is already considered to be relatively high. Further advances in this field and the consolidation of existing advantages would require the development of existing and the creation of new translation medicine centres to develop pre-clinical technologies.

Regenerative medicine technologies form a key focus of modern research and development, designed to solve problems relating to brain diseases, the musculoskeletal system, and oncological and many other diseases. Leading countries around the world have already received some

Fig. 10. Thematic Fields of the "Medicine and Health Care" Priority Area



initial encouraging results in human organ regeneration, whereas in Russia there has been little groundwork in this area.

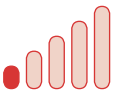
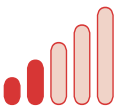
The successes of innovative pharmaceuticals – biotechnologies, chemical synthesis technologies, targeted treatment, the production of modern effective vaccine production – will enable Russian companies to break onto promising global markets and the government to raise the quality of Russian citizens' lives.

Promising Drug Candidates

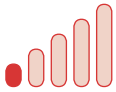
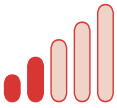
Expected results of future research:

- new drugs developed at the preclinical proof-of-concept stage, including preparations for prevention and treatment of a wide range of socially significant diseases (cardiovascular, neurological, oncological, haematological, autoimmune, endocrine, infectious, etc.), including:
  - new pharmaceutical molecules with valid therapeutic targets;
  - a collection of laboratory animals and cell lines for reproducing socially significant diseases; new highly effective vaccines including conjugate and DNA vaccines for prevention and treatment of infectious and oncological diseases, where traditional immunisation techniques are inefficient; drugs based on recombinant proteins and monoclonal antibodies; preparations for regenerative medicine; and highly effective drugs acting via new molecular targets.

Table 18. Promising Research Areas in "Promising Drug Candidates"

Research areas	R&D Level	R&D Priorities
Screening and increasing the safety of drug candidates based on new pharmacological targets and new research data on mechanisms relating to the emergence and development of human diseases		Creating new models to reproduce the most pressing human diseases (cardiovascular, nervous, digestive, endocrine, urogenital, immune and other systems, infectious and "rare" diseases) and understanding major mechanisms concerning their development Targeted screening of biotechnological derivatives to identify more effective and safe substances Identification, including via bio-modelling, of individual molecules, cellular structures and components of human body's regulatory systems, which can serve as biological targets for targeted effect, to influence pathological processes underlying widespread diseases Computer modelling of selected targets for subsequent construction of promising pharmacological substances capable of interacting with them Synthesis of new genetic construction coding products of selected regulatory proteins, and development of vectors for their introduction into cells – producers of biologically active compounds
Models based on cell lines and/or laboratory animals for pre-clinical research into human diseases		Development of mechanisms for targeted site-specific mutagenesis Development of targeted mutagenesis techniques for stem cells and somatic cells in adult organisms Development of a collection of cell lines and live animals as models for socially significant diseases (oncological, autoimmunological, neurodegenerative, infectious, etc.)
New drug candidates, including those with multidirectional effect, using both known and newly discovered targets via genetic engineering, biotechnological computer modelling and medical chemistry techniques		Identifying substances related to target molecules and activating or blocking specific targets by specific binding Creating cells – producers of bioactive compounds or bioengineering constructs, for introduction into the patient's body to produce biologically active compounds Defining optimal systems to produce specific substances, including procaryote and eukaryote cells, plants and animals; developing technologies for their cultivation, increasing productivity via hybrids Development of nanostructured biologically active substances and techniques for targeted delivery of protein preparations to specific organs, tissues and organelles, including with the help of nanotechnologies Discovering new biological objects – potential producers of protein substances and monoclonal antibodies Screening of biotechnological derivatives to identify the most effective and safe pharmacotherapeutical substances

(continued)

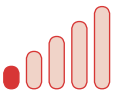
Research areas	R&D Level	R&D Priorities
Components and systems for targeted drug delivery to increase effectiveness, improve pharmacokinetic parameters, and decrease drug candidates' toxicity; and laboratory protocols for their production		Identification of new biological targets, including cytokines, hormones, enzymes, receptors, signal intracellular molecules to be affected by synthetic molecules to prevent or contain pathological processes Studying intermolecular interaction to develop delivery systems Target-oriented chemical synthesis of compounds with specific biological activity Discovering ways to increase bio-accessibility, and developing systems for delivery of these compounds inside the body Computer modelling of substances related to target molecules Development of new chemical synthesis techniques and equipment Screening and selection of substances with the highest effect and lowest toxicity out of the line of synthesised compounds with particular pharmacotherapeutical orientation
New vaccines, including combined ones		Studying the development mechanisms of infectious and oncological diseases; understanding the role of immune system and specific features of its functioning under pathologies Understanding the roles of immunocompetent cells, antigen-recognising and antigen-presenting structures, individual cytokines, end-organs, signal intracellular molecules in pathogenesis of tumorous diseases, in development and resolution of infectious processes Identifying factors underlying inadequate immune response to oncological and infectious (tuberculosis, malaria, AIDS) diseases Synthesis of new genetic constructs to produce antigens of infectious diseases' agents and tumorous antigens, and development of vectors for their introduction into the body Identifying carbohydrate epitopes and carrier proteins providing an optimal level of immune response to conjugated vaccines Discovering ways to avoid the development of autoimmune side effects after application of conjugated and DNA vaccines Improving existing and developing new biological systems to produce vaccines Screening of vaccine candidates to identify the most effective and safe ones

Molecular Diagnostics

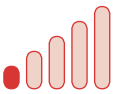
Expected results of future research:

- new diagnostic techniques and systems based on technologies to determine the structure and functions of biological molecules (nucleic acids, proteins, lipids, polysaccharides, low molecular compounds), including:
  - diagnostic techniques, testing systems and complexes primarily oriented towards the detection of socially significant diseases before their onset; new high-performance laboratory diagnostic techniques for the detection, quantitative and structural analysis of proteins and other macromolecular metabolites including lipids, glycoproteins, RNA, etc.;
  - techniques and tools for laboratory diagnostics of socially significant diseases (cardiovascular, oncological, haematological, infectious, endocrine, etc.), based on analysis of stated molecular markers;
  - new techniques and complexes for quantification of low-molecular metabolites, ions and microelements – markers of inflammation at different stages and chronic diseases;
  - tools for analysing individual predisposition to cardiovascular diseases, liver pathologies, diseases of reproductive systems and lipidic exchange disorders.

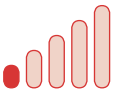
Table 19. Promising Research Areas in "Molecular Diagnostics"

Research areas	R&D Level	R&D Priorities
Hardware/software solutions based on technologies to analyse static (context-dependent) macromolecular markers to develop optimal treatment strategies and prepare personalised disease development forecasts		Large-scale population-epidemiological associative studies aimed at discovering stable combinations of nucleic acids' structural changes associated with diseases Discovering regulatory genes involved in disease development mechanisms Development of techniques for preclinical diagnosis of predisposition to diseases Discovering gene networks involved in the pathogenesis of diseases; development of algorithms to assess their associative importance Discovering DNA structure's polymorphisms associated with individual sensitivity to pharmacological preparations, and with specific features of their metabolism Development of special diagnostic reagents, automation systems, hardware/software solutions to diagnose socially significant diseases and new molecular mechanisms resistant to preparations applied for treating them, based on nuclear acids analysis Development of Russian hardware/software solutions to define nuclear acids' initial structure Development of data processing algorithms to identify clinically significant structural and functional changes in nucleic acids

(continued)

Research areas	R&D Level	R&D Priorities
		Development of algorithms and software for creating genetic information database of the Russian Federation's population
		Development of nucleic acid structural change detection and quantitative assessment systems, including recombinant and synthetic biology technologies
		Improving techniques to produce specifically immobilised DNA-probes, production and quality control techniques for very high purity deoxynucleoside triphosphates for sequencing purposes
		Development of systems to deliver solutions to sense chips' flow cells
		Development of interface devices for chips
		Development of sensor chip prototypes for full-genomic DNA sequencing
		Further development of colour single-nucleotide detection technologies
		Development of techniques for conjugation and specific sorption of nucleic acids on microspheres and specified surfaces
Hardware/software solutions, analytical devices and reagents to analyse dynamic (adjustable) macromolecular markers, and laboratory protocols for their application		Identifying protein molecular markers, their structure and functions, tissue affiliation, involvement in the pathogenesis of diseases
		Large-scale epidemiological research to establish associative and pathogenetic connections between molecular markers and diseases
		Discovering mechanisms of expression changes and/or activity of macromolecular markers
		Detection of connections between individual markers to analyse the macromolecular profiles of diseases
		Development of high-performance techniques to define the structure of dynamic macromolecular markers, including proteins, lipids, glycoproteins, and RNA
		Defining functions and number of dynamic macromolecular markers
		Development of algorithms and software to process data on the structure and functions of dynamic macromolecular markers
		Development of techniques for high purification of nucleic acids, proteins, lipids and glycoproteins, including nonspecific sorption, specific fixation of dynamic macromolecular markers, and automation of purification processes

(continued)

Research areas	R&D Level	R&D Priorities
		Discovering and/or developing novel techniques for speedy detection, quantitative assessment and definition of dynamic macromolecular markers' functions, including development of techniques and devices for non-instrumental diagnostics
		Development of hardware/software solutions for laboratory definition of dynamic macromolecular markers
		Development of automated laboratory diagnostics systems for dynamic macromolecular markers, including sample preparation and multicomponent analysis modules
		Development of express tests, including non-instrumental ones, to determine dynamic macromolecular markers for acute states, and markers for changing states of macromolecular background
Hardware/software solutions, analytical devices and reagents to analyse low-molecular compounds, and laboratory protocols for their application		Identification of new low-molecular metabolites involved in pathogenesis of socially significant diseases
		Determining pathogenic connections between the level of low-molecular metabolites and high-molecular disease markers
		Development of techniques for direct and indirect detection of low-molecular metabolites
		Determining mechanisms and techniques for biosynthesis of low-molecular metabolites in normal and pathological states
		Determining functionally looped marker groups of low-molecular metabolites in transitory, acute and chronic processes
		Identification of dynamic therapy efficiency markers
		Studying mechanisms for splitting metabolites associated with inflammation and chronic diseases
		Development of hardware/software solutions for detecting and measuring low-molecular metabolites, including ions and microelements
		Development of clinical protocols for detecting and measuring low-molecular metabolites using mass and charge detection technologies for low-molecular metabolites and their ionised components; development of new techniques for non-instrumental detection of metabolites
		Development of hardware/software solutions for dynamic tracking of the level of personalised-format low-molecular metabolites, and development of techniques and protocols to assess the quality of laboratory research on detection and quantitative analysis of low-molecular metabolites

(continued)

Research areas	R&D Level	R&D Priorities
		Development of technologies to synthesise special reagents for colour detection reactions and quantitative analysis of low-molecular metabolites
		Development of modified enzymatic complexes for colour detection of low-molecular metabolites
		Development of flow-through and non flow-through chips to detect low-molecular metabolites in multiplex mode
		Development of technologies to manufacture active surfaces for specific interaction with low-molecular metabolites
Infectious agent detection techniques, and laboratory protocols for their application		Development of prototype systems based on new computational principles
		Development of bioinformatics techniques to process genome, transcriptome and proteome analysis data
		Development of high-performance robotic screening systems
		Studying expression systems in eukaryote cells, including new genetic therapy vectors
		Development of new immunoprofilactic tools based on bioengineering technologies and immune response correction techniques
		Development of new techniques to identify and assess the efficiency of oncological and infectious disease inhibitors in cell cultures
		Development of molecular genetic techniques for pathogenic diagnostics of plants and animals
		Development of experimental models based on cell lines and/or laboratory animals for pre-clinical research into human diseases
Combinatorial molecular sensors, including aptamer-based ones, to develop all-purpose diagnostic and analysis tools for static and dynamic pathogenic states' factors		Bio-information analysis of diagnostically significant molecular static and dynamic factors, molecular docking
		Molecular engineering and development of biosensor molecules of various nature, including aptamers
		Modification of organic and inorganic surfaces with biosensor molecules; receiving, amplifying and registering signals
		Discovering genomic, proteomic and metabolomic markers and their combinations, reflecting the state and the dynamic characteristics of pathological processes
		Development of biosensors for express diagnosis of metabolic disorders; development of multidimensional chip implanting technologies

(continued)

Research areas	R&D Level	R&D Priorities
Molecular and cellular pathology, including studying changes of molecular-genetic component of intracellular signalling pathways, structural and functional disorders of specific cells and tissues in the context of pathological processes' development, to develop personalised medical technologies		Studying intracellular and intercellular cell activity mechanisms' disorders Discovering molecular-genetic factors affecting individual reactions of organisms Development of practices to control structural and functional states of effector cells; studying T-cell sub-populations; regulatory mechanisms of sub-populations' balance; their role in immunopathology development; discovering ways to directly eliminate autoreactive clones for therapeutic purposes Phenotyping, genetic typing, genomic and proteomic profiling reflecting individual reactions of organisms to pathologic processes Integrated modelling of organisms' reactivity

Molecular Profiling and Identification of Molecular and Cellular Pathogenesis Mechanisms

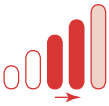
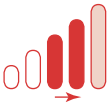
Expected results of future research:

- electronic catalogue (atlas) of human proteins, containing experimental data on tissue and organ proteome, and functional connections between proteins – disease markers;
- hardware/software solutions, reagents and materials for proteomic profiling;
- high-performance techniques for analysis and application of genetic material as a set of RNA molecules (transcriptome), proteins (proteome), and low-molecular compounds (metabolome);
- high-sensitive molecular detectors making it possible to detect single macromolecules in biological samples;
- proteome biomarkers – potential molecular targets of diseases;
- reagents for quantitative research of protein markers present in concentrations below 10^{-12}M.

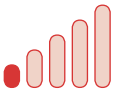
Table 20. Promising Research Areas in "Molecular Profiling and Identification of Molecular and Cellular Pathogenesis Mechanisms"

Research areas	R&D Level	R&D Priorities
Identification and quantification of transcripts, proteins, and their modifications (alternative splicing, post-translation modifications, single amino-acid polymorphisms) in human tissues		Development of experimental prototypes of highly sensitive molecular detectors making it possible to detect individual macromolecules in biological samples Development of multi-parameter analysis techniques (chip technologies) Development of bioinformatics techniques to process genome, transcriptome and proteome analysis data Development of comparative genomics and proteomics techniques Development of high-performance robotic screening systems

(continued)

Research areas	R&D Level	R&D Priorities
		Modelling in silico biomolecules' structure and processes taking place in live systems, and their in vitro analysis using biochemical and biophysics approaches Regulating gene expression using RNA interference and related mechanisms Development of prototype systems based on new computational principles Development of automated laboratory diagnostics systems for dynamic macromolecular markers, including sample preparation and multicomponent analysis modules
Increasing the sensitivity and productivity of clinical sample protein composition measurement techniques		Development of hardware/software solutions and specific reagents for snap analysis of dynamic biomarker arrays Complex bio-information solutions for proteome profile analysis Development of efficient automated proteome screening systems Studying expression systems in eukaryote cells, including new genetic therapy vectors Controlling biological processes using light and other electromagnetic fields Profiling the protein composition of biological samples to assess the risks associated with the emergence of socially significant diseases Building databases and knowledge bases on functional connections of proteins – markers of diseases
Obtaining, for each gene's products, experimental data on their presence in the bodies of patients with the diagnosed disease		Studying the structural and functional properties of proteome biomarkers – potential molecular targets of diseases Development of techniques to detect picomolar concentrations of biomolecules in biological samples Development of experimental reagent prototypes for quantitative research of protein markers present in concentrations below 10^{-12} M Analysis of genome and proteome profiles of socially significant diseases Development of databases and knowledge bases (atlas) of human proteome profiles Creation of a biomarker library for socially significant diseases Discovering molecular targets for development of new pharmacological solutions for the treatment and prevention of infections and parasites

(continued)

Research areas	R&D Level	R&D Priorities
Molecular foundations of cognitive function, including building signalling pathways; structural and functional description of tissues, cells and cell elements providing cognitive function; identifying molecular and cellular targets and effector molecules for diagnostics, prevention and therapy		Bio-information analysis of databases; modelling signalling pathways Structural and functional description of tissues, cells and cell elements providing cognitive function Studying the functional mechanisms of astrocytes and oligodendrocytes of various brain sections and zones, in normal and pathological situations Studying the adaptive evolution of mammals' brains Studying the roles of mobile genetic elements, lipoproteid and glycolipid complexes in the development of neurodegenerative diseases Identifying molecular and cellular targets and effector molecules for diagnostics, prevention and therapy Development of mechanisms to deliver effector molecules to various target cells' compartments, to regulate cognitive function

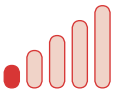
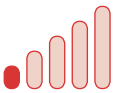
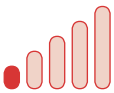
Biomedical Cellular Technologies

Expected results of future research:

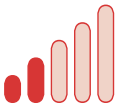
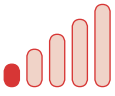
- products based on regenerative and cellular technologies to restore organ and tissue structure damaged by cardiovascular and oncological diseases, internal organs' functional disorders, burn disease, trophic ulcers, metabolic diseases, and traumas, including:
  - tissue equivalents to recover surface damage (burns, wounds, ulcers, etc.), for application in traumatology and treatment of cardiovascular diseases;
  - environments to produce cell-free products of stem cells cultivation;
  - tissue-engineering construct transplantation techniques, including their blood supply and innervation;
  - cell therapy clinical protocols for hereditary and metabolic diseases;
  - bio-replacement materials for application in regenerative processes along with cell-free technologies;
  - bio-replacement tissue-engineering constructs allowing emergency post-traumatic innervation and blood supply recovery;
  - human organ equivalents (pancreas, liver, visual and auditory analysers);
  - techniques for genetic correction of stem self-cells, and for using stem cells with induced pluripotentiality to treat cardiac insufficiency, for myocardium regeneration after heart attack, restoration of impaired blood circulation, peripheral nerves and nerve tissue;
  - new methods for researching neurochemical mechanisms of brain activity, the creation of behavioural reactions, and various types of dependency in humans;

- new methods for treating and managing the undesirable consequences of Parkinson's disease, schizophrenia, depression, alcoholism and substance addiction, as well as neuromuscular disorders;
- methods for partially or fully restoring sight lost as a result of abnormalities in the retina (amphiblestrodes);
- clinical protocols for treating diseases in the nervous system with the use of cellular photostimulation technologies (optogenetics).

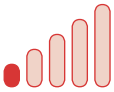
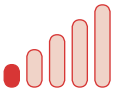
Table 21. Promising Research Areas in "Biomedical Cellular Technologies"

Research areas	R&D Level	R&D Priorities
Human tissue and organ regeneration techniques based on self-cells and donor cells, and tissue equivalents stimulating regeneration of preparations and cell cultivation products		Studying the role of contact interaction in activation and differentiation of stem cells Studying humoral and contact interaction's role in stem cells' regenerating effect Studying mechanisms regulating the migration activity of tissue-specific stem cells, and their intracellular mobility regulation mechanisms Development of techniques for application of tissue-specific stem cells to treat patients with ischemic, post-traumatic, and neurodegenerative conditions Development of approaches to using stem cells for treating patients with major burns and trophic ulcers Development of cellular therapy techniques for reproductive function recovery, treatment of diseases connected with connective tissue pathologies (varicose disease, prolapse of pelvic floor organs, parodontosis, etc.)
Human cells cultivation, modification and reprogramming techniques		Studying cells reprogramming mechanisms and factors
Systems for efficient cultivation of human cells, adjusting their properties, and targeted differentiation for tissue engineering and cell therapy purposes		Studying stem cells' differentiation ability, and molecular mechanisms affecting their differentiation Finding ways to achieve targeted differentiation of stem cells, to obtain active cells of required functionality (cardiac hystiocytes, liver cells, etc.) Development of safe techniques for patients to produce and grow their own stem cells from fat tissue, bone marrow, peripheral and umbilical blood, skin, and other sources
Tissue equivalents and artificial live human organs		Studying the mechanisms of stem cells' interaction with various tissue-specific matrices and their combinations Finding ways to induce cellular pluripotentiality

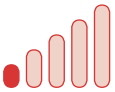
(continued)

Research areas	R&D Level	R&D Priorities
		Determining induced pluripotentiality mechanisms Determining the roles of DNA-modifying proteins and methylation of genome DNA in regulating cells' differentiation and pluripotentiality Studying the role of microRNA in regulating somatic stem cells' differentiation, and supporting their pluripotentiality Discovering optimal cell types, their combinations, volume density, differentiation state and activity, matrices of their properties and combinations thereof to create optimal tissue equivalents Determining the therapeutic potential of cells with induced pluripotentiality, and conditions excluding their tumorigenicity Development of techniques to produce tissue equivalents with 3D histotypic structure Development of protocols to reprogramme and differentiate cells with induced pluripotentiality, to produce specialised patient-specific cells for treatment of diseases and ensuring safety of their application
Biologically active substances for targeted regeneration of structure of human organs and tissues affected by disease		Finding new targets, the impact on which would stimulate recovery of organ and tissue structures Studying regeneration mechanisms impacting new molecular targets Discovering optimal ways to affect new regeneration-stimulating targets: selecting the optimal nature of the preparation (genetic engineering construct, recombinant protein, chemically synthesised compound); selecting impact mode (agonist, antagonist, inhibitor, allosteric regulator, etc.) Development of bioactive substances capable of stimulating the regeneration of cardiovascular, nervous, endocrine, respiratory, reproductive systems' tissues and organs, and of skin Development of techniques for targeted delivery of medicines into certain cells and tissues Development of techniques for therapeutic transfection of cells both outside the organism and inside the patient's tissues
Preparations to stimulate regeneration, based on human cell cultivation products		Studying the regeneration activity of combinations of components secreted by stem cells Selecting cell type, cell-free preparation, and a technique for its production, to stimulate regeneration in treating socially significant diseases

(continued)

Research areas	R&D Level	R&D Priorities
		Development of serum-free media for cell cultivation, techniques for using cell-free products as treatments, and their in vivo testing in models Development of techniques to step up production of cell lines and cell-free products
Controlling cell functions by affecting intracellular signalling pathways, transcriptional and translational complexes by various factors		Development of means to deliver various factors to specific compartments of target cells In silico modelling of intracellular and extracellular signalling pathways, transcriptional and translational complexes Experimental detection of knot molecules and critical states of intracellular and extracellular signalling pathways, transcriptional and translational complexes Studying intercellular interaction, including its effect on the regeneration of organs and tissues Controlling the expression profile of genes – regulators of cell differentiation Development of technologies for ex vivo and in vivo cell modification; cell reprogramming to control proliferation and apoptosis
Application of bioengineering, including tissue engineering, tissue equivalents and artificial organs, scaffolds of various nature, cell elements, cell and tissue cultures, for medical purposes		Development of various scaffolds modified with bioactive components, for in vitro production of external and internal organs' analogues using self-cells Development of technologies to produce tissue equivalents and artificial organs Development of technologies for 3D tissue prototyping Studying intercellular interaction
Artificial live systems, including artificial cell elements and chimeric cells		Creating "electronic" cells of various functionality Creating mitochondrions out of their constituent macromolecules produced with synthetic biology techniques Studying vesicular transport, and development of controllable vesicles Development of functional cell membranes Producing cells with specified properties, which don't have natural analogues
Techniques for safe conservation and storage of cellular products		Development of techniques and reagents, including environments, to stabilise stored cultivated cells and their products Techniques for cultivation, modification and reprogramming of human cells, and laboratory protocols for their application

(continued)

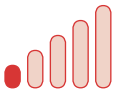
Research areas	R&D Level	R&D Priorities
Assessment of bio-safety of biomedical preparations and cellular products		Discovering key mechanisms of stem cells' regenerative effect on various organs and tissues, under various pathological conditions Studying the functional activity of cells produced via differentiation from cells with induced pluripotentiality, and assessing their biosafety
Optogenetic methods for controlling cellular functions		Development of transfection methods of specific expression of microbial rhodopsins into the structure of neurons Technologies for the synthesis of artificial light sensitive, transmembrane protein structures of varying degrees of sensitivity and reactivity to light fluxes of different wavelengths Mapping of neuronal systems in the human brain and development of algorithms of targeted photostimulation effects in certain pathologies of the nervous system Diagnosis systems for problems in the nervous system as a result of trauma or humoral (neural mediated) disorders

Biodegradable and Composite Medical Materials

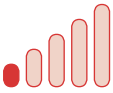
Expected results of future research:

- new-generation products made out of multicomponent biocompatible materials for applications in cardiology, oncology, orthopaedics, traumatology, dentistry and other medical fields, including metal-, ceramic- and polymer-based implants with bioactive coatings, for tissue and bone implantation; bioresorbable matrices; and hybrid scaffolds, intestinal and cardiologic stents, high-performance antiseptic dressings, etc.

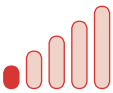
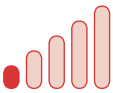
Table 22. Promising Research Areas in "Biodegradable and Composite Medical Materials"

Research areas	R&D Level	R&D Priorities
Special-purpose materials for external use		Development of basic approaches to the synthesis of, and structural principles for designing antimicrobial composite materials based on positively charged nanostructured particles, with selective bactericidal and antiseptic activity Modelling interaction processes in "particle – microorganism" systems Studying the mechanisms of nanostructured particles' affecting microbial cells, wound surface cells, healthy cells; studying biocompatibility processes Development of antimicrobial materials based on multicomponent nanoparticles containing nitride and metallic phases on the single particle level, and assessing their biologic activity

(continued)

Research areas	R&D Level	R&D Priorities
		Development of nanostructured sorbents, and studying sorptive activity in respect of microorganisms Development of experimental technologies to produce highly efficient wound healing and sorptive antimicrobial materials without any antibiotics or antiseptics, for surgery, burns treatment, dermatology and traumatology
Development of biomechanically compatible cardiological and intestinal implants and stents with functional coatings		Development of basic principles for creating biologically compatible surfaces and coatings, including with the help of electronic, ionic and plasma technologies, which would affect cells' proliferation activity Development of principles for creating new composite-polymeric biodegradable, environmentally safe materials, surfaces and coatings incorporating biologically active molecular structures Modelling bio-active constructs for the creation of biomechanically compatible implants and angio-surgical stents Determining the optimal combinations of chemical elements for making coatings for cardiologic and intestinal implants and stents, and assessment of their re-stenting Development of hardware solutions for making implant and stent coatings using electronic, ionic and plasma technologies, taking into account the specific features of particular individuals Designing new techniques for the purification and development of chemically and environmentally pure monomers to create new composite-polymeric materials, including deposition of hydrophilic or hydrophobic polymeric coatings on implants and stents Development of techniques for computer-assisted design of new materials and coatings, biomechanically compatible with hollow human organs Studying the biological efficiency of new cardiological and intestinal implants and stents using experimental disease models Development of minimally traumatic techniques for targeted delivery of cardiovascular and intestinal implants and stents, using experimental models
Functional-structure composite materials for dental and maxillofacial implants		Studying the mechanisms of interaction between new zirconium-based alloys, cells and tissues Studying zirconium-based materials' osteointegration patterns Optimising surface morphology in accordance with bone tissue structure, to reduce the time required for osteointegration Modifying composite surfaces using thin bio-compatible coatings

(continued)

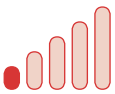
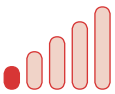
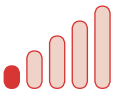
Research areas	R&D Level	R&D Priorities
		Development of composite surface sterilisation techniques using electronic and ion-plasma impact, and procedures for measuring the level of their sterility Designing new-generation dental and maxillofacial implants, enabling: more comfortable implantation procedures, reduced osteointegration periods, guaranteed reliable conjunction between implants and fixings used at the final stages of prosthetics, durable implantation and prosthetics, increased safety of implants' use
Orthopaedics materials imitating bone tissue architectonics		Development of principles for structural design of bio-ceramics, and production of high-strength porous ceramics for endoprosthesis of ossa in the structural phase state, similar to natural bone tissue and provoking it to proliferate into the ceramic framework Development of spatial structures optimal for three-dimensional new growth of bone tissue without suppressing its morphogenetic potential (ensuring osteoconductivity) Development of materials similar to natural bone tissue, and testing them using experimental models Development of techniques to modify interstitial surfaces of ceramic materials with bioactive calcium-phosphate compounds, to ensure controlled kinetics of bone tissue proliferation into the implant's pore space Development of technological approaches to shaping the spatial structure of porous ceramic frameworks using direct implant prototyping techniques, individually adjusted for specific patients Studying bio-compatibility and chemical stability of endoprostheses Assessing endoprostheses' strength against the background of the organ-and-tissue environment's influence, under static and dynamic loads
Materials stimulating regenerative processes in the body after transplantation, regulating cellular activity and differentiation in the body		Studying new composite materials for matrices – carriers of stem cells ("tissue bio-construction kits") based on biocompatible materials, including nanostructured metals, and coatings for Russian-made high-quality implants required to develop regenerative medicine In vitro and in vivo research to develop the concept of "tissue bio-construction kits" of various generations, based on the key "niche-relief" and "niche-energy" technologies for stromal and parenchymatous stem cells Research and development of 2D and 3D "tissue bio-construction kits" with artificial micro-territories of specified size and density, to stimulate growth of endogenous stem cells Development of protocols for the creation and upgrading of matrix panels – stem cell carriers ("tissue bio-construction kits"), and optimal ways of functionalising their structures and surfaces

Bio-electrodynamics and Radiation Medicine

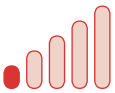
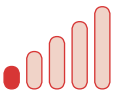
Expected results of future research:

- diagnostics and treatment techniques and hardware/software solutions based on targeted application of electromagnetic fields, high-energy radiation, electro-dynamic modelling of cells and tissues;
- new interfaces for registration and adjustment of organisms' states;
- laboratory protocols for application of electro-dynamic and radiation therapy techniques;
- handware/software for optogenetic diagnostics and treatment systems for neural diseases.

Table 23. Promising Research Areas in "Bio-electrodynamics and Radiation Medicine"

Research areas	R&D Level	R&D Priorities
Contact devices for interaction between cells and artificial systems, to substitute damaged organs' functions		Development of technology to use terahertz radiation for physiotherapeutic purposes Development of basic physics principles for low-traumatic microsurgery of various biologic tissues, using femtosecond laser pulses
Integrated electronic control devices to restore damaged functionality and monitor the body's current state, including remotely		Development of robotic and visualised surgery technologies Development of efficient techniques for the generation and registration of terahertz radiation waves, and for the creation of laser spectrum analysers with ultra-wide readjustment band
Ultra-high resolution internal structure visualisation systems		Development of visualisation techniques based on nuclear technologies combined with real-time image correction methods, by analysing complex 3D images Development of safety systems to use terahertz radiation waves Development of magnetic resonance spectroscopy techniques Basic research into terahertz radiation bio-effects, magnetic effects, bio-effects of optical range ultra-short laser pulses, magnetic fields, etc. Development of cellular and sub-cellular level visualisation tools Development of MRT technologies to obtain real-time extra-high-contrast images Development of functional MRT devices with specialised software Development of visualisation technologies based on combining high-frequency, ultrasound, and radio-frequency radiation sources, and information technologies, including in real-time mode Development of cellular and sub-cellular level visualisation tools

(continued)

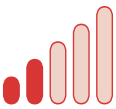
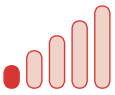
Research areas	R&D Level	R&D Priorities
High-sensitivity sensors for human body's physical and physiological parameters		Development of a technology to diagnose immunodeficiency in generally healthy individuals
Interfaces for neuronal photostimulation		Development of sources of monochromatic light wich can serve as microimplants Equipment for photostimulation of certain neuronal groups Development of software algorithms and systems for controlling the functioning of a targeted neuronal group Creation of hybrid optogenetic neuronal systems whose functions are determined by a number of physiological parameters

Creation of Human Genome Databases

Expected results of future research:

- national databases of genome information;
- a network of applied genome research centres;
- databank of potential biotargets.

Table 24. Promising Research Areas in "Creation of Human Genome Databases"

Research areas	R&D Level	R&D Priorities
Genotype database and knowledge base of the Russian population		Development of a system to monitor the state of populations
Database and knowledge base of clinically-associated single- and multiple-nucleotide polymorphisms, genes and gene networks affecting pharmacotherapy effectiveness		Development of a standardised national-level bio-bank system, and integration of these banks into international systems of biological samples banks Development of disease registries to support bio-banks Multicentre epidemiologic research on the population genetics of ethnic groups making up the Russian Federation population Development of prototype computer system elements based on novel data matching, storage, and exchange principles Development of prototype multilanguage software systems for extraction and formalisation of knowledge out of unstructured or poorly structured data; prospective knowledge storage and analysis systems and tools Development of integrated electronic control devices to restore damaged functionality and monitor the body's current state, including remotely

(continued)

Research areas	R&D Level	R&D Priorities
Prototype integrated hardware/ software solutions and lab protocols to use reagents for full-genome DNA sequencing, analysis of human proteome, transcriptional and epigenetic profiles		Development of prototype hardware/software complexes and their elements based on advanced molecular analysis principles Development of software systems to analyse the data of pathological processes' static and dynamic markers, and decision support protocols Development of new reagents and protocols for their application in integrated hardware/software solutions, to develop new molecular screening systems

4 NEW MATERIALS AND NANOTECHNOLOGIES

4.1. Challenges and Opportunities

In recent years, nanotechnologies have become all the more affordable both from an economic and technical point of view: modelling has become possible, as well as processes and process control on nano-levels.

The development of this field is stimulating a growing demand for new materials conditioned, on the one hand, by dwindling natural resources and, on the other hand, active introduction of nanotechnologies into the production of goods with fundamentally new properties. Thanks to nanosystems and materials created using nanosystems, in the near future there may come to be effective solutions for numerous problems in industries such as energy, health care and food production.

According to optimistic assessments, the first noticeable effects, primarily in nanoelectronics, photonics, nanobiotechnology, medical products and equipment, neuroelectronic interfaces, and nanoelectromechanical systems, can be expected as early as within the next five years. The largest breakthroughs of the next decade may include the molecular production of macroscopic objects ("desktop nanofactories") and the emergence of atomic design. The convergence of nano-, info-, bio-, and cognitive technologies may potentially lead to extending the active stage of human life.

The above-mentioned areas would potentially largely determine the level of technologies of the future. The greatest expectations are first of all associated with the development of hybrid structures combining organic and non-organic fragments, live tissues and synthetic components capable of giving them new properties; the development of nanocomposites, which would make it possible to make materials of unique strength, elasticity and conductivity – particularly important for achieving progress in alternative power engineering; and mathematical modelling of nanomaterials' properties, which is expected to significantly accelerate creation of new systems with useful properties.

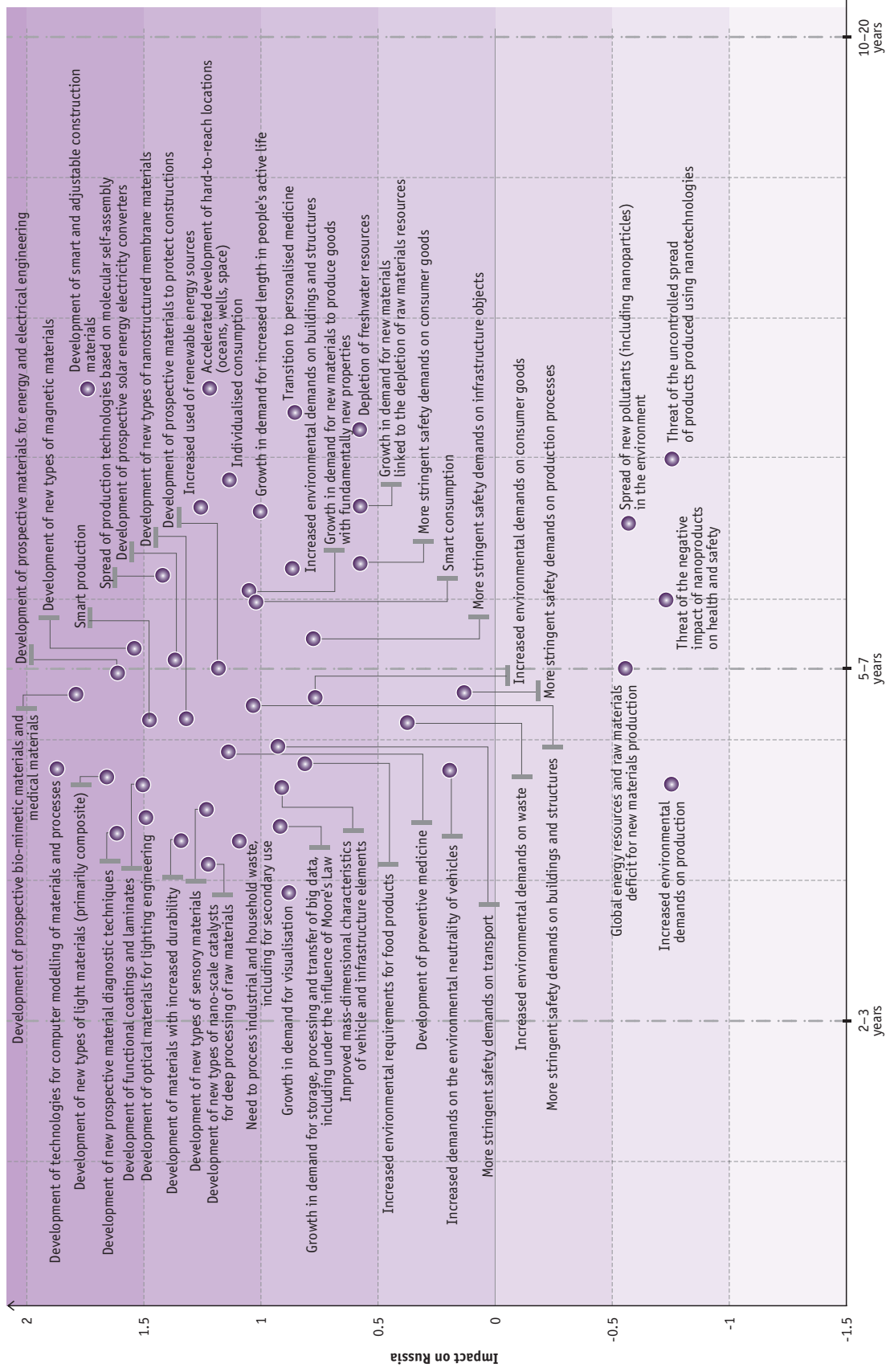
Nanomaterials will also play a major role in dealing with environmental problems, since they are at the core of advanced sensing and water treatment technologies, separation processes, and many "green chemistry" areas. They serve as a basis for the development of numerous drugs, targeted delivery systems for them, and express diagnostics technologies for live organisms.

The development of "New Materials and Nanotechnologies" in the medium to long-term will be determined by challenges and opportunities conditioned by global trends (fig. 11).

New *higher demands on production* linked, on the one hand, to safety and, on the other hand, to protecting the environment are in many ways shaping key vectors in the development of nanotechnologies in the future.

New types of light composite materials which are superior in strength and cost effectiveness over existing ones will take on a critical role. The scope for their application is extremely large: from the aerospace sector to the sports industry and medicine. Moreover, the use

Fig. 11. New Materials and Nanotechnologies: Challenges and Opportunities



Source: HSE ISSEK.

of composite materials will contribute to the development of high-speed transport which, in turn, will have a favourable influence on changes in people's lifestyles.

The use of *biomimetic materials and medical materials*, in particular surgical implants, will raise medical care up to a new level.

Technologies allowing computer modelling of materials and processes show great promise. Using such technologies it will be possible to model nanomaterial growth, aggregation, self-assembly and self-organisation processes, which will make it possible to achieve the desired structure and characteristics using a minimum number of actual experiments.

New opportunities are opening up in relation to the creation of *prospective electrical engineering materials*, including to develop fundamentally new telecommunications properties, elements of environmental and space monitoring systems, thermal imaging, nanodiagnostics, robotics, precision weapons, ways to combat terrorism, etc. Currently the nature and performance of electrical engineering, lighting technology, and device capabilities is undergoing fundamental changes thanks to the introduction of nanotechnologies and functional nanomaterials. The broadening scope for using nanostructures in the near future will make it possible to significantly reduce the dimensions of devices (for example, observation and recording methods), reduce their energy consumption, improve cost characteristics and benefit from the advantages of mass production of micro- and nanoelectronic components and systems.

The scope for application of *new methods of material diagnosis* which make it possible to monitor the status of complex systems exposed to physical and chemical influences will significantly increase. By using nanotechnologies new systems to visualise the surface of materials at atomic resolutions will be able to be developed.

The development and use of new materials and nanotechnologies will be a serious driver behind the modernisation and development of production methods, infrastructure and the social sphere. In particular, *the dissemination of production technologies based on molecular self-assembly* could come to be a major breakthrough. According to expert assessments, a relatively small molecular-precision device (a "desktop nanofactory") will be able to produce an object with a volume of approximately 1 litre and a mass of roughly 4 kg within about three hours.

Intelligent and customisable functional and structural materials with high levels of strength, plasticity, lightness, transparency and reflective properties could in future be used in current metals and plastics. There will be further increases in the demands placed on the technical properties of products, in particular with respect to resistance to radiation and corrosion, high and low temperatures, and material ageing.

There is expected to be active dissemination of *functional coatings and laminated materials* which will be used in the engineering industry (parts exposed to friction and high temperatures, etc.), the production of devices for various fields (medicine, metal- and wood-processing), etc.

Experts have outlined the following ***threats to Russia*** in this field:

- the scarcity of modern scientific and industrial equipment to develop and produce nanoproducts and new materials;
- barriers to importing technologies and materials;
- the lack of quality Russian raw materials to manufacture nanoproducts;
- the scarcity of highly-qualified personnel;
- acute competition from foreign manufacturers;
- the need for significant investment in the organisation of mass production to achieve economics of scale.

4.2. Prospective Markets, Products and Services

The changing face of the economy and society is in many ways linked to the widespread integration of new materials and nanotechnologies into production processes and the services sector. Like in the ICT sector, innovative markets for nanotechnology products and new materials are becoming an integral part of larger sectoral markets, many of which base a significant proportion of their production on nanotechnologies and new materials.

The experts were in agreement regarding the majority of application areas – future markets for nanotechnologies and new materials. In the short and long-term the main field of application for these materials is likely to be electronics. Functional nanomaterials will be used in virtually all computer and radio-electronic technology and in the vast majority of home appliances. However, according to expert assessments, if in 2015 the share of electronics on the nanotechnology market in Russia is likely to exceed three quarters, then by 2030 it will fall to one fifth. This will occur on account of the expanding use of new materials in the automotive and aerospace industries, shipbuilding, the food processing industry and housing construction. In the long-term, the emergence of markets which would combine large volumes and high growth rates is expected, specifically: mining and processing equipment, pharmaceutical and medical equipment, power engineering.

Prospective markets for the "New Materials and Nanotechnologies" priority area:

- aerospace technology and infrastructure
- motor vehicles and road infrastructure;
- nuclear energy;
- household chemical goods and perfumery;
- water transport (vessels and port infrastructure);
- renewable sources (solar and wind energy);
- rail transport (rolling stock and facilities);
- housing and utilities infrastructure;
- timber industry;
- oil and gas processing and petrochemical industries;
- equipment for extraction and processing industries;
- lighting equipment;
- food industry;
- instrument-making industry;
- agriculture;
- specialist equipment;
- sporting goods;
- machine tool industry;
- construction industry;
- textiles and leather products;
- pharmaceuticals and medical equipment;
- environment;
- electronics and communications;
- electrical energy.

For each of the prospective markets listed above, innovative products and services, which will appear on the market in the period up to 2030 have been identified (table 25).

For each group of innovative products and services, the key features guaranteeing their competitiveness have been identified (table 26).

Table 25. Prospective Markets and Product Groups for the "New Materials and Nanotechnologies" Priority Area

Markets	Groups of innovative products and services
Aerospace technology and infrastructure	Sensors to analyse the make-up of various environments
	Physical value sensors based on nanomaterials
	Fuel cells, catalysts for innovative energy sources
	New types of light and high-strength materials
	Heat-resistant nanostructured composite, ceramic and metallic materials
	Nanostructured composite and ceramic materials and coatings with special thermal properties (heat-conducting, heat-regulating)
	Nanostructured anti-corrosion coatings
	Nanostructured anti-friction and adhesive materials
	Nanostructured hydrophobic materials
	Radiation-resistant and radiation-protection nanostructured composite materials and coatings
	Nanostructured composite materials with special optical properties (photon crystals)
	Next-generation solar batteries
	Radiating elements (including lasers and organic light emitting diodes) based on nano-scale heterostructures
	Composite, ceramic materials and nanofluidics with special magnetic properties
	Electronic elements based on graphene, fullerene, carbon nanotubes, quantum dots
	Nanostructured composite materials with special conductive properties, including superconducting materials
	Nanostructured materials with form memory effects and "self-healing" materials
Motor vehicles and road infrastructure	Nanostructured materials for chemical sources of electrical current
	Fuel cells, catalysts for innovative energy sources
	Sensors to analyse the make-up of various environments
	Physical value sensors based on nanomaterials
	New types of light and high-strength materials
	Heat-resistant nanostructured composite, ceramic and metallic materials
	Nanostructured composite and ceramic materials and coatings with special thermal properties (heat-conducting, heat-regulating)

(continued)

Markets	Groups of innovative products and services
	Nanostructured anti-corrosion coatings
	Nanostructured anti-friction and adhesive materials
	Nanostructured hydrophobic materials
	Radiating elements (including lasers and organic light emitting diodes) based on nano-scale heterostructures
	Composite, ceramic materials and nanofluidics with special magnetic properties
	Nanostructured composite materials with special conductive properties, including superconducting materials
	Nanostructured materials with form memory effects and "self-healing" materials
	Gas-separating membrane nanomaterials
Nuclear energy	Radiation-resistant and radiation-protection nanostructured composite materials and coatings
	Nanostructured materials and reagents for water purification processes (water treatment)
Household chemical goods and perfumery	Physical value sensors based on nanomaterials
	Nanostructured materials and reagents for water purification processes (water treatment, raw food processing)
	Use of nanotechnologies and nanocatalysts to produce chemical products and perfumes
Water transport (vessels and port infrastructure)	New types of light and high-strength materials
	Heat-resistant nanostructured composite, ceramic and metallic materials
	Nanostructured composite and ceramic materials and coatings with special thermal properties (heat-conducting, heat-regulating)
	Nanostructured anti-corrosion coatings
	Nanostructured anti-friction and adhesive materials
	Nanostructured hydrophobic materials
	Fuel cells, catalysts for innovative energy sources
	Next-generation solar batteries
	Radiating elements (including lasers and organic light emitting diodes) based on nano-scale heterostructures
	Composite, ceramic materials and nanofluidics with special magnetic properties

(continued)

Markets	Groups of innovative products and services
	Nanostructured composite materials with special conductive properties, including superconducting materials
	Nanostructured materials with form memory effects and “self-healing” materials
Other renewable sources (solar and wind energy)	Fuel cells, catalysts for innovative energy sources
	Nanostructured materials for chemical sources of electrical current
	Composite, ceramic materials and nanofluidics with special magnetic properties
	Radiation-resistant and radiation-protection nanostructured composite materials and coatings
Rail transport (rolling stock and facilities)	Nanostructured materials for chemical sources of electrical current
	Fuel cells, catalysts for innovative energy sources
	New types of light and high-strength materials
	Heat-resistant nanostructured composite, ceramic and metallic materials
	Nanostructured composite and ceramic materials and coatings with special thermal properties (heat-conducting, heat-regulating)
	Nanostructured anti-corrosion coatings
	Nanostructured anti-friction and adhesive materials
	Nanostructured hydrophobic materials
	Radiating elements (including lasers and organic light emitting diodes) based on nano-scale heterostructures
	Composite, ceramic materials and nanofluidics with special magnetic properties
	Nanostructured composite materials with special conductive properties, including superconducting materials
	Nanostructured materials with form memory effects and “self-healing” materials
Housing and utilities infrastructure	Heat-resistant nanostructured composite, ceramic and metallic materials
	Nanostructured composite and ceramic materials and coatings with special thermal properties (heat-conducting, heat-regulating)
	Nanostructured anti-corrosion coatings
	Nanostructured anti-friction and adhesive materials
	Nanostructured hydrophobic materials
	Fuel cells, catalysts for innovative energy sources
	Nanostructured composite materials with special optical properties (photon crystals)

(continued)

Markets	Groups of innovative products and services
	Nanostructured composite materials with special conductive properties, including superconducting materials
	Nanostructured materials with “form memory” effects and “self-healing” materials
	Nanostructured materials and reagents for water purification processes (water treatment, raw food processing)
	Gas-separating membrane nanomaterials
Timber industry	Physical value sensors based on nanomaterials
	Heat-resistant nanostructured composite, ceramic and metallic materials
	Nanostructured composite and ceramic materials and coatings with special thermal properties (heat-conducting, heat-regulating)
	Nanostructured anti-friction and adhesive materials
	Nanostructured hydrophobic materials
	Next-generation solar batteries
	Radiating elements (including lasers and organic light emitting diodes) based on nano-scale heterostructures
Monitoring, protection and restoration of the environment	Sensors to analyse the make-up of various environments
	Nanostructured materials and reagents for water purification processes (water treatment, raw food processing)
Oil and gas processing and petrochemical industries	Fuel cells, catalysts for innovative energy sources
	Gas-separating membrane nanomaterials
	Nanostructured materials for chemical sources of electrical current
	Sensors to analyse the make-up of various environments
	New types of light and high-strength materials
	Heat-resistant nanostructured composite, ceramic and metallic materials
	Nanostructured composite and ceramic materials and coatings with special thermal properties (heat-conducting, heat-regulating)
	Nanostructured anti-corrosion coatings
	Nanostructured anti-friction and adhesive materials
Equipment for extraction and processing industries	New types of light and high-strength materials
	Heat-resistant nanostructured composite, ceramic and metallic materials
	Nanostructured composite and ceramic materials and coatings with special thermal properties (heat-conducting, heat-regulating)

(continued)

Markets	Groups of innovative products and services
	Nanostructured anti-corrosion coatings
	Nanostructured anti-friction and adhesive materials
	Nanostructured hydrophobic materials
	Nanostructured composite materials with special optical properties (photon crystals)
	Radiating elements (including lasers and organic light emitting diodes) based on nano-scale heterostructures
	Composite, ceramic materials and nanofluidics with special magnetic properties
	Nanostructured composite materials with special conductive properties, including superconducting materials
	Nano- and micro-robotics systems
	Gas-separating membrane nanomaterials
	Fuel cells, catalysts for innovative energy sources
	Nanostructured materials for chemical sources of electrical current
Lighting equipment	Nanostructured composite materials with special optical properties (photon crystals)
	Nanostructured composite materials with special conductive properties, including superconducting materials
	Next-generation solar batteries
	Radiating elements (including lasers and organic light emitting diodes) based on nano-scale heterostructures
	Nanostructured hydrophobic materials
Food industry	Sensors to analyse the make-up of various environments
	Physical value sensors based on nanomaterials
	Nanostructured materials and reagents for water purification processes (water treatment, raw food processing)
	Gas-separating membrane nanomaterials
Instrument-making industry	New types of light and high-strength materials
	Heat-resistant nanostructured composite, ceramic and metallic materials
	Nanostructured composite and ceramic materials and coatings with special thermal properties (heat-conducting, heat-regulating)
	Nanostructured anti-corrosion coatings
	Nanostructured composite materials with special conductive properties, including superconducting materials

(continued)

Markets	Groups of innovative products and services
Agriculture	Nanostructured composite and ceramic materials and coatings with special thermal properties (heat-conducting, heat-regulating)
	Nanostructured anti-corrosion coatings
	Nanostructured anti-friction and adhesive materials
	Nanostructured hydrophobic materials
	Radiating elements (including lasers and organic light emitting diodes) based on nano-scale heterostructures
Specialist equipment	Nanostructured materials for chemical sources of electrical current
	New types of light and high-strength materials
	Heat-resistant nanostructured composite, ceramic and metallic materials
	Radiation-resistant and radiation-protection nanostructured composite materials and coatings
	Gas-separating membrane nanomaterials
	Fuel cells, catalysts for innovative energy sources
Sporting goods	New types of light and high-strength materials
	Nanostructured composite and ceramic materials and coatings with special thermal properties (heat-conducting, heat-regulating)
	Nanostructured hydrophobic materials
	Nanostructured materials with “form memory” effects and “self-healing” materials
	Radiating elements (including lasers and organic light emitting diodes) based on nano-scale heterostructures
Machine tool industry	New types of light and high-strength materials
	Heat-resistant nanostructured composite, ceramic and metallic materials
	Nanostructured composite and ceramic materials and coatings with special thermal properties (heat-conducting, heat-regulating)
	Nanostructured anti-corrosion coatings
	Nanostructured composite materials with special conductive properties, including superconducting materials
	Physical value sensors based on nanomaterials
Construction industry	New types of light and high-strength materials
	Nanostructured materials for chemical sources of electrical current
	Heat-resistant nanostructured composite, ceramic and metallic materials

(continued)

Markets	Groups of innovative products and services
	Nanostructured composite and ceramic materials and coatings with special thermal properties (heat-conducting, heat-regulating)
	Nanostructured anti-corrosion coatings
	Nanostructured anti-friction and adhesive materials
	Nanostructured hydrophobic materials
	Radiation-resistant and radiation-protection nanostructured composite materials and coatings
	Radiating elements (including lasers and organic light emitting diodes) based on nano-scale heterostructures
	Nanostructured composite materials with special conductive properties, including superconducting materials
	Gas-separating membrane nanomaterials
	Nano- and micro-robotics systems
	Nanostructured materials with form memory effects and “self-healing” materials
Textiles and leather products	New types of light and high-strength materials
	Radiation-resistant and radiation-protection nanostructured composite materials and coatings
Pharmaceuticals and medical equipment	Sensors to analyse the make-up of various environments
	Physical value sensors based on nanomaterials
	Drug delivery systems
	Nanostructured bio-compatible materials
	Nanostructured anti-friction and adhesive materials
	Nanostructured hydrophobic materials
	Radiating elements (including lasers and organic light emitting diodes) based on nano-scale heterostructures
	Composite, ceramic materials and nanofluidics with special magnetic properties
	Nanostructured composite materials with special conductive properties, including superconducting materials
	Nano- and micro-robotics systems
	Nanostructured materials and reagents for water purification processes (water treatment, raw food processing)
	Gas-separating membrane nanomaterials
	Molecular self-assembly and self-organisation of nanomechanical systems

(continued)

Markets	Groups of innovative products and services
Electronics and communications	Nanostructured composite materials with special conductive properties, including superconducting materials
	Physical value sensors based on nanomaterials
	Radiation-resistant and radiation-protection nanostructured composite materials and coatings
	Nanostructured composite materials with special optical properties (photon crystals)
	Fuel cells, catalysts for innovative energy sources
	Nanostructured materials for chemical sources of electrical current
	Next-generation solar batteries
	Radiating elements (including lasers and organic light emitting diodes) based on nano-scale heterostructures
	Composite, ceramic materials and nanofluidics with special magnetic properties
	Electronic elements based on graphene, fullerene, carbon nanotubes, quantum dots
	Elements electronics based on memristors
	Nano- and micro-robotics systems
	Nanostructured materials with “form memory” effects and “self-healing” materials
	Molecular self-assembly and self-organisation of nanomechanical systems
Electrical energy	Fuel cells, catalysts for innovative energy sources
	Nanostructured materials for chemical sources of electrical current
	New types of light and high-strength materials
	Heat-resistant nanostructured composite, ceramic and metallic materials
	Nanostructured composite and ceramic materials and coatings with special thermal properties (heat-conducting, heat-regulating)
	Nanostructured anti-corrosion coatings
	Nanostructured anti-friction and adhesive materials
	Nanostructured hydrophobic materials
	Radiation-resistant and radiation-protection nanostructured composite materials and coatings
	Composite, ceramic materials and nanofluidics with special magnetic properties
	Nanostructured composite materials with special conductive properties, including superconducting materials
	Nanostructured materials and reagents for water purification processes (water treatment, raw food processing)

Table 26. Innovative Product Groups for the "New Materials and Nanotechnologies" Priority Area

Groups of innovative products and services	Characteristics
Fuel cells	High efficiency catalysts (fuel efficiency factor)
	Catalyst tolerance to CO
	Low fuel element start time
	Demands on combustible cleanliness
	Low costs of producing costly platinum group metals
	Stability of conductive membranes, their ability to work at high temperatures and low humidity
	Operating time without substantial drop in performance characteristics
	Recycling options
Catalysts for innovative energy sources	High selectivity
	High conversion
	High productivity (performance)
	Capability to regenerate
	Easily separable from products
	Low cost
Nanostructured materials for chemical sources of electrical current	High speed recharging
	Small scale and high unit electrochemical capacity of power source, cathode and anode material
	Stability of power characteristics at high charge and discharge speeds
	Stability of performance characteristics and high work resources (cyclability)
	Conductivity of electrode materials and electrolytes
	Possibility of working effectively at low temperatures
	Safety of operation
	Low cost
Sensors to analyse the make-up of various environments	High sensitivity
	Low error rate
	High selectivity
	Short response time
	Wide range of concentrations of detected substances
	Possibility of simultaneous detection of several substances (for multi-sensor "electronic nose", "electronic tongue", etc. systems)
	Small footprint

(continued)

Groups of innovative products and services	Characteristics
	Stable operations, possibility of self-calibration
	Low cost
	Ease of use
	Low energy consumption
Physical value sensors based on nanomaterials	High accuracy
	High sensitivity
	Efficient operations
	Fast acting
	Safety
	Possibility of use in large range of applications
	Compliance with special technical characteristics
	Low cost
Drug delivery systems	Targeted delivery
	High efficiency
	Lack of toxicity or side-effects
	Fast acting
	Prolonged effective use of preparation in an organism
	Wide range of applications
	Safe for humans
	Low cost of production
Nanostructured bio-compatible materials	Bactericidal properties
	Lack of auto-immune response and toxicity
	Bioresorption
	Regeneration properties
	High efficiency
	High unit strength and elasticity
	Compliance with set additional requirements (water-resistance, ability to incorporate living tissue, etc.)
New types of light and high-strength materials	High strength
	High heat and thermal resistance
	Cold resistance, ability to withstand sharp drops in temperatures while maintaining performance characteristics
	Low specific weight

(continued)

Groups of innovative products and services	Characteristics
	Mechanical properties (long-term strength, plasticity, hardness, resistance to cracking, resistance to fatigue and creepage, etc.)
	Mechanical properties (long-term strength, plasticity, hardness, resistance to cracking, resistance to fatigue and creepage, etc.)
	Mechanical properties (long-term strength, plasticity, hardness, resistance to cracking, resistance to fatigue and creepage, etc.)
	Special service or operational properties (resistance to wear, corrosion and radiation, stability for static and dynamic loads, etc.)
Heat-resistant nanostructured composite, ceramic and metallic materials	Thermal stability
	Low specific weight
	High mechanical strength
	High crack-, thermal- and erosion-resistance
	Presence of special properties
	Low cost
Nanostructured composite and ceramic materials and coatings with special thermal properties (heat-conducting, heat-regulating)	Heat-conductivity
	Reflective capabilities in terms of light and heat flows
	High strength and elasticity
	High destruction viscosity and specific shock viscosity
	Preservation of functional characteristics at high temperature intervals
	Low specific weight
	Low cost
Nanostructured anti-corrosion coatings	High chemical resistance during use
	Stability in aggressive environments
	Stability at elevated temperatures
	Ease of manufacture
	Low specific weight
	Anti-static properties
	Oil and petrol resistance
	Hydrophobic properties, moisture resistance
	High coating adhesion to pipe materials
	Low cost

(continued)

Groups of innovative products and services	Characteristics
Nanostructured anti-friction and adhesive materials	Low friction coefficient High adhesion to various materials Strength and durability High shock viscosity Structure stability Low production cost
Nanostructured hydrophobic materials	Hydrophobic properties Ease of manufacture Thermal and chemical stability Safety and ease of use Prolonged operation time Low product cost
Radiation-resistant and radiation-protection nanostructured composite materials and coatings	Radiation resistance Radiation protection qualities Mechanical strength Thermal stability Safety of use Durability Low cost
Nanostructured composite materials with special optical properties (photon crystals)	Optical and permittivity Thermal stability Selectivity of irradiation High-quality optical modes Low cost
Next-generation solar batteries	High efficiency factor Prolonged service Possible use of the infrared spectrum High power Ability to quickly deploy device Radiation stability
Radiating elements (including lasers and organic light emitting diodes) based on nano-scale heterostructures	High radiating element generated power Radiating element light range Prolonged service

(continued)

Groups of innovative products and services	Characteristics
	Possible regeneration Small footprint Possibility to give device special form (flat, raised, etc.) Light penetration Environmental neutrality Wide application Ability to scale and organise mass production (ease of manufacture) Compatibility with key elements of modern micro-electronics Low cost
Composite, ceramic materials and nanofluidics with special magnetic properties	High magnetism of nanoliquid saturation Coercive force High thermal stability Sediment and aggregate stability Low electricity conduction Combination of fluidity and magnetic manageability Low cost
Electronic elements based on graphene, fullerene, carbon nanotubes, quantum dots	Energy efficiency Conductivity Low prohibited zone width Minimal losses due to resistance Small dimensions Prolonged stable operation time Low cost
Elements electronics based on memristors	Sensitivity Large amount of data stored Reliability Safety Low cost
Nanostructured composite materials with special conductive properties, including superconducting materials	Electrical conductivity Transfer selectiveness Operation stability at low and high temperatures Elasticity Mechanical strength Environmental neutrality Low cost

(continued)

Groups of innovative products and services	Characteristics
Nano- and microrobotics systems	Low energy consumption Small footprint Low material intensity Fast acting Prolonged operation time Large amount of data stored Replicability Breadth of tasks solved Reliability
Nanostructured materials with form memory effects and “self-healing” materials	Speed of recovery / “self-healing” Ability to re-restore High strength, firmness and elasticity values Low cost
Nanostructured materials and reagents for water purification processes (water treatment, raw food processing)	Transfer selectiveness High productivity Resistance to poisoning (including biological) and obstruction Electrical conductivity Penetration in relation to filtered solutions and particles of various sizes Wide range of removable impurities High operating pressure Ability to concentrate deposits Membrane chemical stability Low cost
Gas-separating membrane nanomaterials	Transfer selectiveness High productivity Chemical and thermal stability Low energy consumption upon division Membrane resistance Wide application Low cost
Molecular self-assembly and self-organisation of nanomechanical systems	Small footprint High productivity Low energy cost Potential breadth of application

Fig. 12. Innovative Products and Services with a Radical Impact on the Dynamics of World Markets in the "New Materials and Nanotechnologies" Priority Area

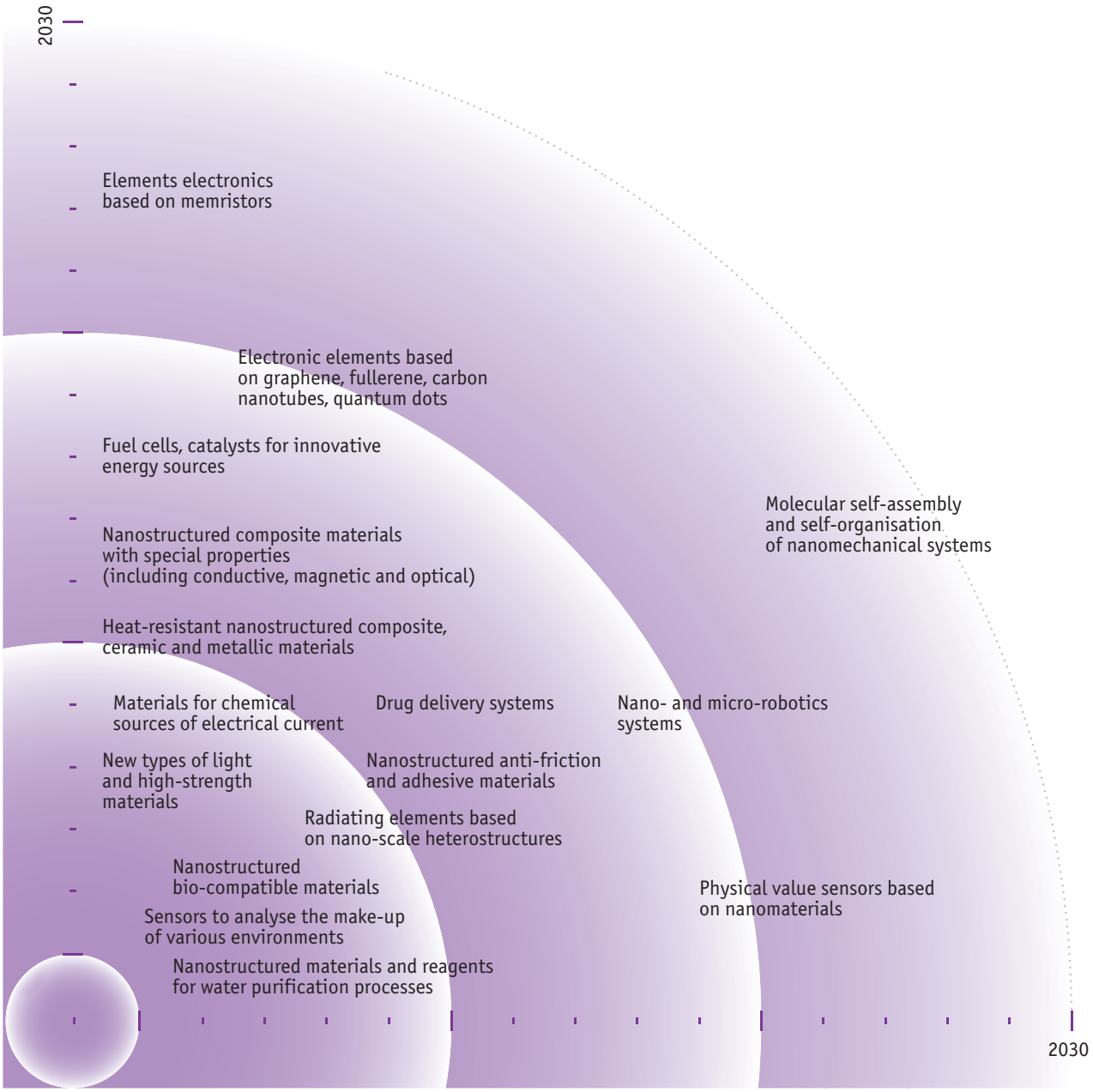


Fig. 12 shows products and technologies which could have a radical impact on the global markets together with the expected timeframes for their mass distribution.

Nanostructured materials and coatings can be applied to *sensors to analyse the make-up of various environments* so as to increase their responsiveness (by reducing the diffusion time in the sensitive layer) and increase sensitivity (by increasing the specific surface). Nanotechnologies can be used to develop new types of sensitive materials to miniature multi-sensor matrices (sensors) embedded in consumer electronics and clothing, and can also be placed in production and residential buildings.

Physical value sensors based on nanomaterials could be used in special measuring devices. They comprise two sub-groups of innovative products:

- electromagnetic wave measurement sensors: hard x-ray, ultraviolet, infrared, radio emissions, etc.;
- sensors designed to measure linear and angular displacement (produced using materials made from nanotubes with zero transverse deformation coefficient), acceleration (based on the tunnel effect with sensitive nanoelements), and terahertz radiation using planar nanostructures (based on ultra-thin metal films). This sub-group also includes optical nanosensors for mechanical stress (based on elastic inverted photon crystals), etc.

In the short term we can expect to see the emergence of *nanostructured materials and reagents for water purification processes* (water treatment, raw food processing). With the transition to these technologies, the problems of drinking water supplies and efficient purification of household and industrial sewerage will largely be solved, in particular by using various types of hybrid membranes with embedded nanoparticles. It is possible to significantly intensify water purification processes using membranes with an asymmetric (gradient) distribution of nanoparticles by restructuring membrane pore and channel structures. Such an effect can occur upon implementation of electromembrane technologies, allowing for an increase in the electrocatalytic activity of particles in a water dissociation reaction which enables higher speed electrodialysis purification of water in extreme currents. Ion-exchange and membrane materials containing nanoparticles of metals are used for further removal of dissolved oxygen from water, which is extremely important for a number of processes in today's electronics industry.

Ion-exchange and filter membranes will be widely used in food production and processing.

In the near future we can expect active development in technology to create *nanostructured bio-compatible materials* for medical use, primarily in two areas:

- developing materials to manufacture implants and substitutes for various tissues (for example, oxide or phosphate bio-coatings are applied to strong and relatively light titanium implants to prevent rejection by living tissues);
- the creation of materials with properties and structures similar to those found in the human body. One example is bone implants with a porous structure based on calcium phosphate. Ideally, medical materials should complement natural fabrics.

With the emergence of nanostructured bio-compatible and bioresorbable implants, the structure of the prostheses and implants market, together with the principles and approches to prosthetics, have changed significantly. The introduction of new technologies will make it possible to increase the active life of humans, reduce population disabilities, and improve people's quality of life.

The use of *drug delivery systems* will radically increase the effectiveness of drug treatments. Highly-porous nanoparticles or nanocapsules could be used as drug carriers. Targeted delivery systems are contributing to cost-effective spending on medicinal substances and reductions in their toxicity, as opposed to significantly levelling out their side effects.

New types of light and high-strength materials primarily relate to products based on carbon fibres. Their most important characteristics (high elastic and strength qualities, lightness, low friction coefficient, resistance to atmospheric effects and chemical reagents) and special features of their structure make it possible to combine carbon fibre materials with other types of fibres: boric, glass, and aramid. As a result, light and strong products can be created, combining the competitive advantages of two source materials. Such hybrid composites have already found application in the aerospace sector and sporting equipment industry. Other materials which meet the criteria of lightness and high strength can be

created on the basis of nanostructured alloys or aluminium, titanium and several other metals.

The most in demand will be the following products:

- high-strength mixtures based on nanostructured structural polymers;
- polymer composite materials with the addition of small quantities of carbon nanoparticles;
- stronger composite materials based on nanomaterials using wood;
- nanostructured composite materials based on light metals – Al, Ti, Mg – containing nanofibres made from super-high-molecular polyethylene, etc.

Many research groups are actively developing technologies relating to nanostructured *materials for chemical sources of electrical current*. Their use will make it possible to increase the specific capacity of electrodes, increasing the capacity of power sources and allowing for their miniaturisation and safety. An important parameter is also the increasing operating temperatures of these energy sources. Among the most promising chemical sources of electrical current are the following:

- lithium-ion batteries;
- fuel cells.

Fuel cells and catalysts for innovative energy sources will be able to use the large number of nanotechnological materials used to design various types of energy sources. In particular, these include:

- hybrid nanostructured proton-conducting membranes including nanoparticles which improve their transmission properties, and nano-scale catalysts based on platinum and transition metals (including "core in the shell" type catalysts) used to create fuel cells;
- nano-scale cathode materials with mixed electron-ion conductivty and nanostructured anode materials based on various forms of silicon and carbon, from which lithium-ion batteries are formed;

There will also be developed catalysts to produce innovative energy sources and chemical products many of which are already used in industrial production:

- efficient nano-scale catalysts for deep processing of oil and gas products;
- nano-scale catalysts for conversion of natural gas and associated gases into liquid petroleum, hydrogen and valuable organic products;
- nano-sized catalysts for processing renewable raw materials (biogas and biomass) into valuable organic products;
- a wide range of nano-sized catalysts for the production of innovative energy sources and processing of natural ones;
- nano-scale granular membranes based on complex oxides with a perovskite, spinel and fluorite structure, used in processes to partially oxidise methane and associated gases into synthesis gas at low temperatures, or nano-scale catalysts to convert biomass products into synthesis gas.

Broad prospects for the development of nanotechnologies are offered by radiating elements based on nano-scale heterostructures, including lasers and organic light emitting diodes. Organic light emitting diodes, one of the most cost-effective sources of light, are renowned for their unique slim design and high flexibility, offering a broad range of the light spectrum and light stream geometries to which humans are readily accustomed. They can be manufactured in any form, almost at will, and "fit" into working and residential premises of different scales. Lasers have already been widely used in medicine, mechanical engineering, construction and land surveying following the development of the printed circuit board and integrated boards. They are used to detect various substances (including weapons and explosives), for heating through thermonuclear synthesis and in astronomy.

Heat-resistant nanostructured composite, ceramic and metallic materials have considerable potential for application in numerous fields (in particular the aeronautical industry and electrical energy sector) thanks to their resistance to chemical decomposition at high temperatures.

Among this line of innovative products, the following are notable:

- carbon-carbon construction materials with maximum operating temperatures of up to 1650°C;
- light high-strength laminated composite metal-intermetallic materials suitable for use in high temperatures and at critical temperature gradients;
- heat-resistant composite coatings hardened with nano-scale silicides making it possible to increase the temperature and operating life of products, as well as their reliability by 1.5 times;
- carbon fibre composites with metallic matrices to produce heat-resistant construction items with a certain nanostructure.

Nanostructured composite materials with special properties (including conductiveness, magnetism and optical properties), intended to transfer and transform electrical currents, make up a large group of innovative products. The main applications for this type of materials are being developed to transfer high power currents and to miniaturise devices.

Nanostructured composite materials with special optical properties (including photon crystals) will be particularly in demand by 2030. In the medium term we can expect to see the use of systems with sensory properties, for example, the ability to change the range of intensity of emitted light in conjunction with certain reagents.

There may significant improvements in key functional parameters of fibre-optic communications lines providing safely screened multichannel methods to transfer data – speed and quality of the transfer – by using nanostructured materials, on the one hand, with extremely high levels of immunity to interference and, on the other hand, which are not a source of radiation. The application of photon crystal and micro-structured fibres opens up new opportunities to use fibre-optics in physical value sensors.

Nanostructured anti-friction and adhesive materials will find wide application in various industries. Among the most promising materials and products in this group are:

- separators of high-temperature rotating bearings capable of working without lubrication in aggressive environments;
- inorganic composites containing carbon nanotubes and graphene;
- bearings containing nano-scale modifying additives;
- wear-proof nanostructured composite materials generated using special powdered production methods;
- polymer lubricants containing inert nanoparticles (ZnO, SiO2, TiO2, SiC, carbides and nitrides of tungsten, titanium) to improve mechanical characteristics;
- multi-layer nanocomposite polymer coatings for interior finishing of pipes to reduce the friction coefficient, etc.

Nano- and microrobotics systems appear to be very promising in terms of their use in medicine, including to develop next-generation surgical devices. In this group, promising products include:

- movable elements of nano- and microrobotics systems based on laminated nanocomposite materials;
- integrated equipment based on mechatronic modules to machine complex parts;
- active nanostructures based on magneto-elastic materials and multiferroics with artificially created critical states, designed for micro-electromechanical systems;

- mechatronic modules used for spatial positioning of nanosystems and nanotechnological equipment based on incremental micromotors, roller drives and microprocessor control systems.

An important breakthrough in the electronics industry will be the development of electronic elements based on graphene, fullerene, carbon nanotubes and quantum dots. The electronic devices developed on the basis of these, with very small dimensions and weights, will have very high functional parameters. It is anticipated that after development of the frequency range up to several terahertz and significantly increasing the performance of computer systems, fundamentally new communications devices could be created with unprecedented broad-band channels.

This will open up a new niche for high-speed data transfer networks with small ranges and will make it possible to completely abandon the use of cables when connecting audio, television and video devices and home cinema equipment when transferring multi-threaded video at high resolution. Graphene photodiodes, used as photo receivers in the terahertz range, could be mounted in compact security systems (to detect arms, drugs, explosives, etc.).

New opportunities to create neuromorphic computer systems with a revolutionary new architecture will be opened up by memristor-based electronics. This drastically increases their performance when solving problems which have been poorly programmed on classic computers, and significantly reduces their energy consumption. In the field of "smart" electronics, it may be possible to make controlled changes to the electrical resistance of functional materials with long-term storage of the specified status, which will make it possible to use these structures as equivalents to synapses when setting up the hardware for neural networks and building neuromorphic computer systems.

As for the distant future it is worth mentioning molecular self-assembly. Products in this group will find the greatest use. Thus, self-assembling microchips will be especially cost-effective, productive and energy-efficient.

There is serious potential for medical applications, in particular to develop diagnosis methods and targeted drug delivery systems.

During the analysis leading Russian and foreign research centres which are actively carrying out work in this field have been identified for these products. The most notable successes in the field of new materials are seen among organisations from the USA, EU (primarily, Germany, the Netherlands, the United Kingdom), Japan and South Korea.

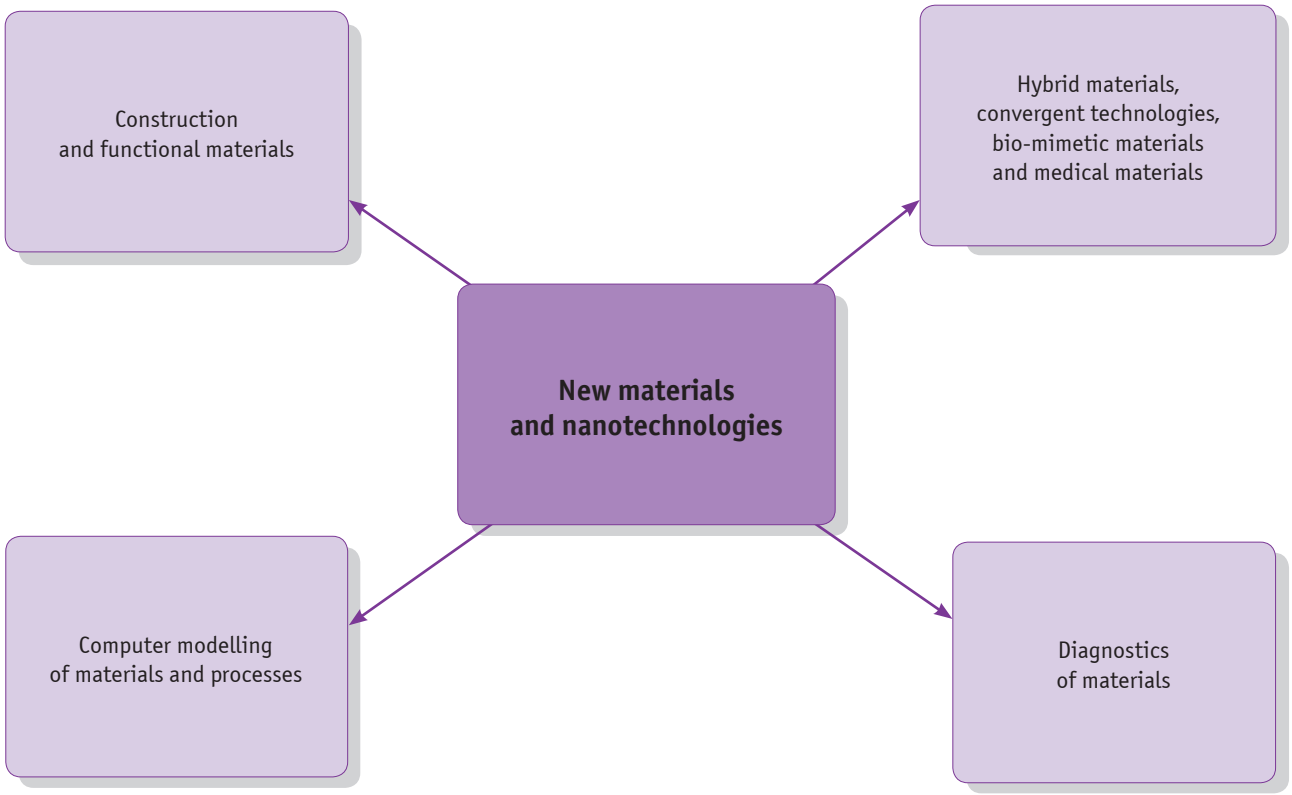
In Russia there are competitive teams in the Russian Academy of Sciences research institutes, as well as in state scientific centres and leading higher education institutions.

4.3. Promising Research Areas

Russia's opportunity to play a role in the trends outlined above and even to occupy a leading position in certain fields is in many ways determined by the level of scientific and technological groundwork, in respect of which four main promising areas have been identified (fig. 13).

The level of Russian research in nanotechnologies and new materials has been appraised relatively highly by experts, in particular in fields such as the development of nano-scale catalysts for deep processing of raw materials and the creation of nanostructured membrane materials. However, there are some "blank spots" where the results of the research carried out in the country have been recognised as poor. These include, among others, the development of construction materials for the energy sector.

Fig. 13. Thematic Fields of the "New Materials and Nanotechnologies" Priority Area



Construction and Functional Materials

Expected results of future research:

- gradient coatings based on nanocomposites, providing efficient protection to nodes and aggregates from external factors;
- composite intermetallic nanostructured coatings to protect constructions in extreme conditions;
- carbon fibre ceramic matrix composites based on high-strength high-module threads with reduced mass and increased thermal stability, for production of aircraft, rocket and space station construction components;
- new-generation construction materials with novel architecture and properties, primarily mechanical ones: increased durability, plasticity, hardness, fracture strength, resistance to fatigue, etc.;
- functional new-generation materials with new properties (optical, transport, radiative, etc.) achieved by introduction of nanosize structural elements;
- multiple-core processors based on photonic nanoswitches, increasing intra-chip connection throughput and reducing energy consumption;
- solar batteries converting up to 90% of luminous energy into electricity; batteries utilising infrared and short-wave ranges of the solar spectrum;
- new materials for alternative electric power sources, based on nanomaterials;
- super-powerful ceramic magnets for making high-performance electrical engineering equipment, components, etc.

Table 27. Promising Research Areas in "Construction and Functional Materials"

Research areas	R&D Level	R&D Priorities
High-strength materials		Development of high-strength and high-modulus composite materials, highly resistant to static, repeated-static and dynamic load Development of poly-matrix composite materials reinforced with nanosize fillings, with increased strength and heat-resistance Development of high-strength, high-modulus and heat-conducting carbon reinforcing fibre materials based on polymers and mesophase pitches
Durable materials		Development of crack-resistant layered metal-polymeric materials and metal-plastics, including reinforced ones Development of nanostructure-modified antifriction materials, high-strength and highly durable in aggressive gaseous and liquid environments Development of superlight impact-resistant composite materials based on heat-resistant gradient foam materials Development of materials to provide protection from vibration, noise and electromagnetic radiation Development of heat- and shock-resistant binding and tamping materials for construction and functional composite materials
Anticorrosion materials		Development of materials with increased resistance to oxidation and corrosion Development of functional coatings with low hardness-salts adhesion, low roughness, and high anticorrosion properties, to increase service life of heating networks and reduce their hydraulic resistance Development of layered, gradient, reinforcing and barrier coatings to protect metals from corrosive damage, mechanical and erosion-related wear, and heat impact, for use in various climates
Heat-resistant materials		Development of composite materials with regulated structures, for use at up to 1,700–2,500 ° Development of heat-resistant high-temperature carbon and carbon-ceramic materials, including nanoparticles-modified, and with multidimensional reinforcement Development of lightweight high-temperature intermetallic materials and intermetallic matrix-based materials, reinforced with refractory oxides and fibres Development of superlight foam materials, fibrous heat-shielding and heat-insulating materials, including durable and ablative ones

(continued)

Research areas	R&D Level	R&D Priorities
		Development of heat-shielding coatings with ceramic layer of reduced thermal conductivity and with composite barrier layers Development of materials and coatings for use at extremely high temperatures and under high dynamic load, for powerful long-life gas turbines designed for high-amplitude and high-speed variable loads, and for thermal energy installations with ultrahigh steam parameters
Radiation-resistant materials		Development of radiation-resistant and corrosion-proof materials, including dispersion-strengthened steels and alloys Development of radiation-resistant heat-shielding coatings
Smart and adjustable construction materials		Development of composite materials adaptable to external impacts (thermal and mechanical load, etc.) Development of memory materials, capable of restoring their initial shape after thermal or chemical impact Development of self-repairing and self-healing materials Development of materials with optical fibre and electric elements integrated into their structure, with self-diagnostics and wireless deformation-state monitoring functions Development of materials with piezoelectric-based actuators integrated into their structure, adaptable to external impacts (including changing their geometric shape and properties) Development of materials with high deformation and self-healing properties, including multidimensional reinforcement
Binding materials		Development of binding materials to serve as integrating basis for development of multifunctional construction materials
Sensory materials		Development of nanomaterials for miniature highly sensitive and highly selective chemo-sensors Development of sensing materials with biological structures' fragments, bio-sensors, bio-chips, and hybrid sensors based on such materials; and neuro-bio-interfaces
Materials with special electromagnetic properties		Development of carbon structures for nanoelectronics Development of organic high-molecular current-conducting polymers, including with mixed (electron-ion) conductivity Development of super-conductive materials, including high-temperature ones Development of nanomaterials for new-generation electrochemical current sources Development of functional nano-crystal coatings with special electrical and magnetic properties

(continued)

Research areas	R&D Level	R&D Priorities
		Development of materials to provide protection from vibration, acoustic and electrical impact, and to reduce visibility in optical- and radio-frequency bands Development of magnetic nanostructures, including molecular and magnetic nanomaterials Development of magnetically activated, magnetically-controlled materials and magnetic-rheological liquids
Catalytic materials		Development of catalysts for processing hydrocarbon raw materials, and production of higher-quality motor fuels Development of nanostructured and nanosize catalysts for petrochemical processes, including processing of black oil and extra-heavy crude oil Development of catalytic processes to convert natural and associated petroleum gas into liquid fuels, hydrogen, and valuable organic products Development of catalytic methods for processing sustainable raw materials (biogas and biomass) to produce valuable organic products Development of principles for application of catalytic processes to process organic raw materials
Materials with special optical properties		Development of materials for making organic LEDs, flexible solar batteries, displays and light storage devices Development of luminescent materials activated by ions of rare-earth and transition metals Development of light-emitting nanostructures, including quantum ones, for lasers and luminescent devices Development of nanostructured optical fibres and light guides, including Bragg lattices and photonic structures Development of nanostructured liquid-crystal materials Development of coatings changing light-absorbing and electroconductivity properties under external impact
Membrane materials		Development of membrane materials, membrane reactors and membrane catalytic processes to produce valuable chemical products Development of nanostructured membranes with improved transpiration properties, and devices based on them, for purification and separation of gaseous and liquid environments Development of hybrid membranes- and bimetallic catalysts-based nanomaterials for fuel cells

Hybrid Materials, Convergent Technologies, Bio-mimetic Materials and Medical Materials

Expected results of future research:

- bone implants based on bioresorbable nanoceramics and bio-composites supplying material to augment live tissues, fill in bone defects, etc;
- targeted drug delivery and cancerous neoplasm affecting systems developed using bio-compatible nanocomposites based on nanoporous compounds;
- nanocomposites based on plasmid DNA and interfering RNA, for targeted delivery of genetic material;
- devices for direct reading of nucleotide sequences, made using nanostructured coatings.

Table 28. Promising Research Areas in "Hybrid Materials, Convergent Technologies, Bio-mimetic Materials and Medical Materials"

Research areas	R&D Level	R&D Priorities
Hybrid materials and convergent technologies		Development of principles, techniques and technologies for making hybrid materials, structures, devices and systems, hybrid component base (biochips, hybrid detectors, hybrid actuators), hybrid sensors (microfluids, nano-chemo-sensors, bio-similar bionic sensors, hybrid sensor platforms) Development of principles, techniques and technologies for making synthetic (artificial) biological and bio-similar structures, devices and systems (proteins, protein complexes, artificial cells, "healing" virus) Development of neuro-bio-interfaces, bio-similar and anthropomorphic technological devices and systems, including robotic ones Development of new synchrotron-neutron diagnostic techniques for inorganic, organic, hybrid, and bio-similar materials and structures
Bio-mimetic materials and medical materials		Development of materials to make devices and technologies to stimulate the central nervous system Development of materials with special functional properties for use in invasive and non-invasive diagnostic systems Development of bio-composites and coatings based on polymers, nanostructured carbon, ceramic, metallic, and polymeric materials, bioactive glass Development of bioresorbable materials for bone and dental implants Development of implanted biodegradable and transdermal systems with controlled drug release Development of materials for nanocapsulation and targeted delivery of drugs, active substances and genetic materials Development of systems with high adhesion to various substrates, including biological ones, for use as protective coatings, packaging, wound and burn dressing, drug delivery systems, etc.

Computer Modelling of Materials and Processes

Expected results of future research:

- new concepts and programmes for predictive multiscale modelling of materials and processes (including testing the calculations on an array of experimental data);
- new techniques for multiparameter calculation of complex systems with biochemically active materials possessing biologic properties; smart materials for smart constructions; etc.

Table 29. Promising Research Areas in "Computer Modelling of Materials and Processes"

Research areas	R&D Level	R&D Priorities
Computer modelling of materials and processes		Modelling of materials' structure and properties as a function of their composition, to achieve required functional and construction properties of materials
		Modelling growth, aggregation, self-assembly and self-organisation of nanomaterials and supramolecular systems
		Modelling chemical deposition of thin films and coatings from gaseous and liquid environments
		Modelling transfer processes in nanoporous materials and membranes
		Modelling charge and energy transfer processes in nanostructure materials, including multi-layer
		Modelling biologically active receptor systems, molecules, and preparations
		Modelling new complex systems using compounds and nanostructures based on self-organisation effects to develop smart materials for making smart constructions
		Modelling new materials of artificial and synthetic origin reproducing certain functions of biological objects
		Modelling nano-, bio-, info- and cognitive technologies

Diagnostics of Materials

Expected results of future research:

- promising diagnostic systems;
- competitive technologies to achieve highly informative and reliable results to study objects' inner structures;
- new concepts for controlling the state of complex systems in the course of physical and chemical processes;
- new systems for the visualisation of materials' surfaces with atomic resolution.

Table 30. Promising Research Areas in "Diagnostics of Materials"

Research areas	R&D Level	R&D Priorities
Diagnostics of materials		Development of promising material diagnostics technologies, based on the principles of physical fields' interaction and yielding highly informative and reliable results Development of non-destructive techniques for diagnosing materials and processes in-situ and operando (synthesis, including self-assembly, modification and restructuring of nanoparticles, degradation, chemical processes involving nanoparticles, etc.) Development of nano-object visualisation techniques (atomic-force-, scanning- and transmission electron microscopy) Development of techniques to study nanoparticle and nanomaterial surfaces (high- and low-energy electron diffraction, X-ray photoelectron spectroscopy, Auger spectroscopy) Development of special techniques for local identification of a material's chemical composition, including nanomaterials

5 ENVIRONMENTAL MANAGEMENT

In the era of globalisation and rapid scientific and technological development the environment is becoming more and more vulnerable. Further pursuit of the established accelerative scenario with respect to environmental management poses high risks linked to human losses and curbs on economic growth. It is enough to mention that a large number of global challenges facing humanity in the near future are linked to the environment and unsustainable use of natural resources. This primarily concerns the depletion of a number of critical resources, climate change, the growth in the environmental footprint and pollution of natural environments, the lack of quality water resources, loss of biodiversity, etc. However, whilst the international community has already realised the importance of transitioning to environmentally oriented development ("green growth"), in our country this subject has traditionally been viewed as "peripheral".

Russia's need to establish scientific and technological undertakings in the field of environmental management is dictated not only by the opportunities to secure important shares of these prospective markets, but also by the threat of losing its position in traditional segments due to the constant tightening of international environmental quality standards for products and production technologies. The solution to this multi-faceted task requires domestic developers to have high skill sets for all areas of applied research.

5.1. Challenges and Opportunities

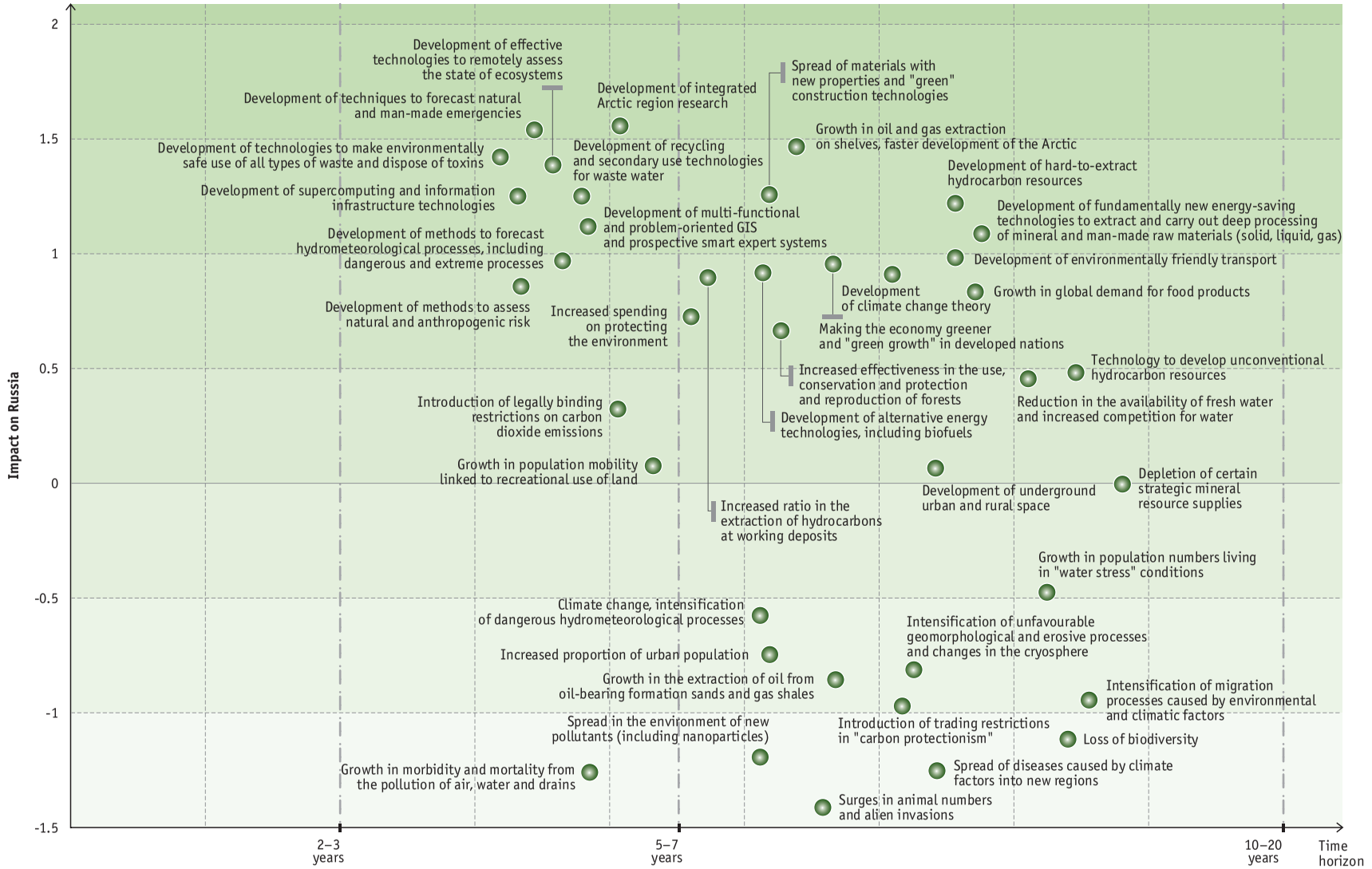
Figure 14 shows the challenges and opportunities which define the prospective development of the "Environmental Management" priority area.

Growth in morbidity and mortality from air pollution is one of the most important global challenges of the modern world. More than one billion urban residents on Earth have been subjected to dangerously polluted air, leading to irreversible harm to health. A reduction in polluting emissions into the atmosphere can be achieved by developing markets for environmentally safe technologies and products to effectively filter and detoxify the air, as well as new chemical materials, catalysts and absorbents for gas cleaning systems. A similar problem is posed by the pollution of water reservoirs and drains, caused by the lack of conformity between the quality of drinking water consumed by a large amount of the population and hygiene standards, as well as the limited access for many to centralised water supply systems.

In the long-term *the spread of diseases to new areas* (infectious and parasitic diseases spread through the air, water, soil and food) *caused by climate factors* will become a serious problem. To avert this threat the environmental services market needs to be developed, in particular a component such as medical and biological monitoring. The emergence of regions which are at risk of new diseases is possible based on modelling the changing boundaries of diseases' natural habitats using field data on vector numbers (requiring the development of new express methods and the improvement of existing methods) and laboratory findings on contamination levels.

Increasing the effective use, conservation, protection and replenishment of forests and ensuring that society's demands for resources and the mineral properties of woodland can

Fig. 14. Environmental Management: Challenges and Opportunities



Source: HSE ISSEK.

be fulfilled in a sustainable manner whilst guaranteeing the conservation of resource and environmental potential. The creation of conditions for sustainable and intensive use of forests while at the same time conserving their environmental functions and biodiversity are key objectives.

The proliferation of new pollutants in the environment (including nanoparticles) is leading to a deterioration in the state of the atmosphere, water basins and ecosystems. New nano-sized substances have a greater area of distribution, which makes it difficult to monitor them and determine the extent of pollution. Nanoparticles in the environment undergo transformation, degradation and bioaccumulation; the latter can have a specific impact on the human organism. Thus, the development of technologies to manage the release and emission of pollutants and the creation of barriers and filters making it possible to prevent micro- and nanoparticles from falling into the environment is a priority objective. In this regard, we need to develop microporous compounds capable of "absorbing" particles smaller than several micrometres. To carry out monitoring studies, firstly there needs to be an increase in the sensitivity of analytical instrumentation.

The loss of biodiversity witnessed today on a global scale in all respects – genes, species and ecosystems – is inevitably affecting the level of access to fresh water, food and medication, and is also having an effect on the state of the environment and protection from natural disasters. Serious measures are called for to reduce the use of substances which harm biodiversity, such as pesticides and herbicides.

The development of environmentally safe waste disposal and toxicant neutralisation technologies is seen as a key opportunity to solve global environmental problems. Research and development into the neutralisation of toxic substances and gases and cost-effective and environmentally sound technologies to recultivate, restructure and rehabilitate land play a priority role in this field. High growth rates are forecast for the market to recycle waste for re-use. The most in demand will be technology to reduce the resource-intensiveness of production, to make complex use of raw materials, and to prevent any adverse effects of pollutants on the environment.

The growth in shelf oil and gas extraction and the acceleration in the development of the Arctic region will allow an increase in available resources and raw materials and will increase opportunities for developing water transport in the region. The large-scale operation of mineral deposits in the Arctic presupposes the implementation of environmentally safe technologies, the development of which will require the mobilisation of significant financial resources. In addition, there are a number of unresolved issues surrounding national borders on the shelf. As technological prospects arise for the extraction of hydrocarbons, there may be some risk of increasing geopolitical competition in "disputed" regions. There also needs to be comprehensive development of mechanisms to compensate damages caused by potential incidents which, according to the estimates of a number of experts, at the present time cannot be covered by a single insurance company. Climate change is linked with serious risks, potentially causing the destruction of the extraction industry infrastructure in the Arctic, which will in all likelihood result in an environmental disaster. Ultimately, active development of the Arctic will have a significant impact on the situation of minority indigenous peoples.

Experts have outlined the following ***threats to Russia*** in this field:

- the unfavourable state of the environment (air, water, soil pollution, degradation of biotic compounds and ecosystems);
- the growth in waste production and consumption, culminating in environmental damage;
- the increasing negative impact of climate change, including dangerous hydrometeorological phenomena (floods, freshets, avalanches and mudslides, hurricanes, squalls, etc.);
- the lack of effective monitoring of the consequences of natural and man-made disasters;

- the lack of an environmental services market;
- the depletion of cheap stocks of quality hydrocarbons, as well as a number of strategically important natural resources (phosphorites, rare metals, etc.);
- the low level of material extraction when developing hydrocarbon deposits;
- the high proportion of archaic, environmentally polluting works with a low level of processing;
- a poor environmental conduct culture;
- insufficient volume and poor efficiency of exploration works.

5.2. Prospective Markets, Products and Services

Global trends in environmental management can fundamentally transform existing markets both through changes in key players (growth in secondary raw material and finished products markets based on waste and sewage processing, environmental conservation equipment, resource-saving technologies, etc.) and through changes in consumer preferences (development of environmentally friendly materials and products, "green" construction, etc.).

The development of the environmental management sector has strategic importance for Russia for a number of reasons. Firstly, in the near future there is expected do be a modernising leap to markets which are more attractive to our country, as a result of which, as stated above, there will be a drastic increase in the risk of losing competitive positions in traditional segments due to the steady tightening of environmental standards. Secondly, the worsening condition of the environment, which is inevitable without environmentally effective technologies, will lead not only to a fall in quality of life for the population, but also to the loss of the investment appeal of a number of regions, which will have a negative impact on economic development trends. Thirdly, the orientation towards "green growth" implies a transition from "brown" fuel and raw materials to innovative models for economic growth, requiring the introduction of eco-innovation and the establishment of the environmental industry as an independent sector of the economy. Thus, the formation of environmental management markets can be viewed as one of the most critical challenges facing the Russian economy.

Prospective markets for the "Environmental Management" priority area:

- *services to monitor and forecast the state of the environment, including early detection and forecasting of natural and man-made emergencies:*
  - environmental monitoring systems, including automated environmental control systems;
  - hydrometeorological observation and forecasting systems and hydrometeorology services;
  - water and land registers;
  - development of geographic information systems;
  - services to forecast emergencies and practices to manage the risk of emergencies;
  - practices to monitor and manage environmental quality;
  - work to model the climate and dangerous hydrometeorological processes;
  - services to provide information and analytical data for environmental conservation and for environmental safety, including preparing databases on the state of the environment;
- *effective and sustainable use and development of mineral and raw material resources:*
  - geological exploration in extreme conditions, equipment and materials for exploration works;

- equipment and materials to increase the percentage of mineral extraction from existing deposits;
- equipment and materials to increase the effectiveness of mineral processing, creation of zero-waste industries;

- *prevention and elimination of environmental pollution, as well as natural and man-made emergencies:*
  - work to eliminate the after-effects of natural and man-made emergencies, equipment and infrastructure for such work;
  - air scrubbing and detoxification services and scrubber systems;
  - services and engineering systems for water purification and re-use of water;
  - equipment to scrap, recycle and dispose of waste, secondary raw materials and finished goods based on the reprocessing of waste and sewage;
  - services to recultivate, restructure and rehabilitate land, equipment to recultivate natural environments;
  - environmentally friendly materials and products;
  - services to provide environmentally friendly waste management;
  - intellectual environmental services (consulting, audit, certification, etc.).

Expert assessments suggest that over the period 2015-2020 the most active development will be seen in markets such as those for early detection and forecasting systems for natural and man-made emergencies; environmentally friendly materials and products; geographical information systems; and equipment and materials to increase the effectiveness of mineral extraction and processing.

Over the period 2020–2030, the highest growth rates will be seen in markets for equipment to increase the effectiveness of mineral processing and extraction; environmentally friendly materials and products; water purification services, services to recycle water and the production of the corresponding equipment; and environmentally safe and economically sustainable waste management.

Innovative products and services which could appear on the market during the Foresight period are shown in table 31.

The expected time-scales for mass dissemination of products and services with a radical impact on the dynamics of global markets is shown in figure 15.

The role of *long-term weather forecasting with a large lead time* and a success rate exceeding climate forecasts will grow in environmental forecasting (in particular, dangerous natural phenomena) and economic planning (natural resources and economic risks affected by the climate, trends in climate dependent economic sectors, etc.), which will in turn contribute to the achievement of sustainable development and the security of the country.

The introduction of *remote monitoring systems using satellite systems* will ensure that qualitatively new information on the state of the land, land-based installations, and natural and anthropogenic processes is available. These data will serve as the primary source to create up-to-date thematic maps. Aside from this, prospective remote surveying technologies and computer data processing technologies vastly exceed the capabilities of traditional cartography both in terms of content and the diversity of the methods used to present the data.

The meso-scale model to forecast dangerous hydrometeorological phenomena is a software package incorporating an actual meso-scale atmospheric model; a unit to prepare input data, constraints and surface properties (pre-processing); and a post-processing unit to process modelling output data, additional calculations and visualisation. Such models, implemented for limited territories, already serve as a means to provide a detailed forecast of meteorological fields with various parameters (temperature, humidity, pressure, precipitation, wind), and the sampling resolution of the computer grids for operational weather forecasting does

Table 31. Prospective Markets and Product Groups for the "Environmental Management" Priority Area

Markets	Groups of innovative products and services	Characteristics
Environmental monitoring systems, including automated environmental control systems	Equipment to analyse and monitor micro- and nanoparticles in water, soil and the air Systems to control the state of the atmosphere, hydrosphere, cryosphere, landscapes, soil, biota, including monitoring emissions by industries and monitoring climate change Remote monitoring systems including using satellite systems	Increasing the effectiveness and operability of remote monitoring Increasing the effectiveness of monitoring the state of anthropogenically compromised land Increasing the effectiveness of preventing transborder negative impacts on the environment Increasing the effectiveness of public environmental oversight on federal and regional levels Increasing the reliability of information received Increasing the scope of monitoring, creating a global monitoring system
Hydrometeorological observation and forecasting systems	Long-term weather forecasts with a large lead time and a success rate exceeding climate forecasts Collective weather forecasts and methods for their likely interpretation Forecasts of the characteristics of the state and status of surface water objects	Increasing the effectiveness of short-term hydrometeorological phenomena forecasting Improving the responsiveness of warnings about dangerous hydrometeorological phenomena
Climate and dangerous natural process models	Meso-scale models to obtain the broad structure of forecast dangerous hydrometeorological phenomena Improving hydrodynamic forecasting models with high temporal and spatial detail, including joint models (ocean – atmosphere – land – biosphere)	Increasing the effectiveness of long-term climate change forecasting Improved abilities to adapt the population and economy to climate change Reducing economic losses caused by natural phenomena Increasing the forecasting capabilities of climate forecasting models
Systems providing early detection and forecasting of natural and man-made emergencies	Systems allowing the detection of conditions conducive to natural and man-made emergencies Systems to diagnose the state of natural and man-made systems Equipment to monitor, control the risk of occurrence, and reduce the effects of man-made and natural emergencies Methods to forecast natural and man-made disasters and their after-effects based on observation data and contemporary views on their preparation and development processes	Increasing the effectiveness of atmosphere pollution monitoring and early detection of conditions conducive to the occurrence of emergencies Reducing economic losses from man-made and natural emergencies Increasing the safety of industrial, energy, residential and infrastructure installations Increasing the forecasting capabilities of systems providing early detection of disasters

(continued)

Markets	Groups of innovative products and services	Characteristics
Land and water registers	Registers of land and water with the highest level of natural and man-made risk	Increasing the effectiveness of managing the state of land and water Increasing the accuracy and detail of register schemes
Geographic information systems	Software for supercomputers and information storage systems to model and forecast climate change and the state of ecosystems Specialist packets to process data from remote profiling of the Earth Web-servers (geo-portals) operating online	Increasing the lead time of weather forecasts and the reliability of assessments of future climate change Accumulating data from observations with a high degree of accuracy and sampling resolution Reducing the costs of obtaining and processing information in sectors related to the development of natural resources, transport and environmental activities
Databases on the state of the environment	Libraries of data on the long-term state of components of the environment Geographic information database of online data on forest fires, floods, leaks of hazardous substances, etc. allowing for a real-time assessment of the number, scale and distribution speed of disasters Databases on natural and man-made disasters, current observations on the state of the atmosphere and seismic and geophysical fields	Increasing information quality for administrative decision-making Increasing the responsiveness and reliability of information on the state of the environment
Emergency risk management methods	Environmental risk management methods when developing oil and gas deposits at sea, including in ice-covered regions Practices to assess and reduce the risk of loss for the population, land and infrastructure installations resulting from man-made disasters and natural disasters and the development of measures to reduce damage from such disasters Non-destructive control methods	Reducing economic losses and environmental damage from man-made and natural emergencies
Practices to manage environmental quality	Practices to optimise land planning in accordance with the landscape structure and the environmental and resource potential of the land Practices to conserve biological and landscape diversity (including specially protected natural regions)	Increasing the effectiveness of measures to conserve biodiversity Improving the population's living environment

(continued)

Markets	Groups of innovative products and services	Characteristics
	Practices to assess the state and dynamics of water and land ecosystem resources, restore the resource potential of land with a high anthropogenic load (soil, water and bio-resources)	
Environmental monitoring services	Environmental monitoring services	Increasing the effectiveness of monitoring the state of the environment Increasing the effectiveness of preventing transborder negative impacts on the environment Optimising decision-making in the public environmental oversight system on federal and regional levels
Hydrometeorological services	Hydrometeorological services	Effective short-term forecasting of hydrometeorological processes and phenomena Improving the responsiveness of warnings about dangerous hydrometeorological phenomena
Work to model climate change and dangerous hydrometeorological processes	Work to model climate change and dangerous hydrometeorological processes	Abilities to adapt the population and infrastructure to climate change Reducing economic losses from dangerous hydrometeorological processes
Emergency forecasting services and methods for managing the risk of emergencies starting	Emergency forecasting services and methods for managing the risk of emergencies starting	Opportunities for early detection of conditions conducive to the occurrence of emergencies Reducing economic losses from man-made and natural emergencies Increasing the safety of industrial and energy installations
Services to provide information and analytical data for environmental conservation and for environmental safety	Services to provide information and analytical data for environmental conservation and for environmental safety	Increasing information quality for administrative decision-making Increasing the effectiveness of measures to conserve biodiversity and maintain environmental quality Improving the quality of the population's living environment
Equipment and materials to carry out exploration works	Geophysical and drilling equipment for: – prospecting and searching for minerals in complex geological conditions – projecting the productivity of oil-bearing formations – searching for possible mineral occurrence areas	Increasing the effectiveness of prospecting for minerals

(continued)

Markets	Groups of innovative products and services	Characteristics
Equipment and materials to increase the effectiveness of mineral extraction	Deposit development systems based on combined physical and technical and physical and chemical technologies working together as part of a production programme in a single mineral, resource and technology territory of mining companies	Increasing the extraction level of minerals (including hydrocarbons) Reducing the resource and energy consumption of extraction
	Sea-based oil and gas deposit development systems	Increasing the environmental safety of extraction industries
	Equipment for super-deep (up to 15 km) drilling	
	Systems and methods to increase the output of formations, including a targeted change in their reservoir properties, including at depleted hydrocarbon deposits and low pressure gas deposits	
	Systems to make use of associated petroleum gas	
	Equipment to develop and extract non-traditional sources of raw materials, including hydrocarbons such as "heavy oil", gas-hydrates, shale gas, etc.	
Equipment and material to increase the effectiveness of mineral processing	Selective disintegration systems	Increasing the level of mineral processing (including hydrocarbons) Increasing the effectiveness of transporting minerals and processing products
	Useful component pre-concentration systems	
	Systems offering integrated and extensive processing of raw minerals	
Searching and prospecting for minerals	Searching and prospecting for minerals	Increasing the effectiveness of prospecting for minerals Reducing the economic costs incurred when searching for minerals
Mineral extraction	Mineral extraction	Increasing the extraction level of minerals (including hydrocarbons) Increasing energy efficiency Increasing environmental safety
Mineral enrichment and processing	Mineral enrichment and processing	Increasing the level of mineral processing (including hydrocarbons) Increasing the effectiveness of transporting minerals and processing products Reducing the level of waste from the mining industry
Equipment and infrastructure to eliminate the after-effects of natural and man-made emergencies	Mobile and stationary systems to clean up land and interior and marine waterways from hydrocarbon (oil) pollution	Reducing the negative after-effects of emergencies

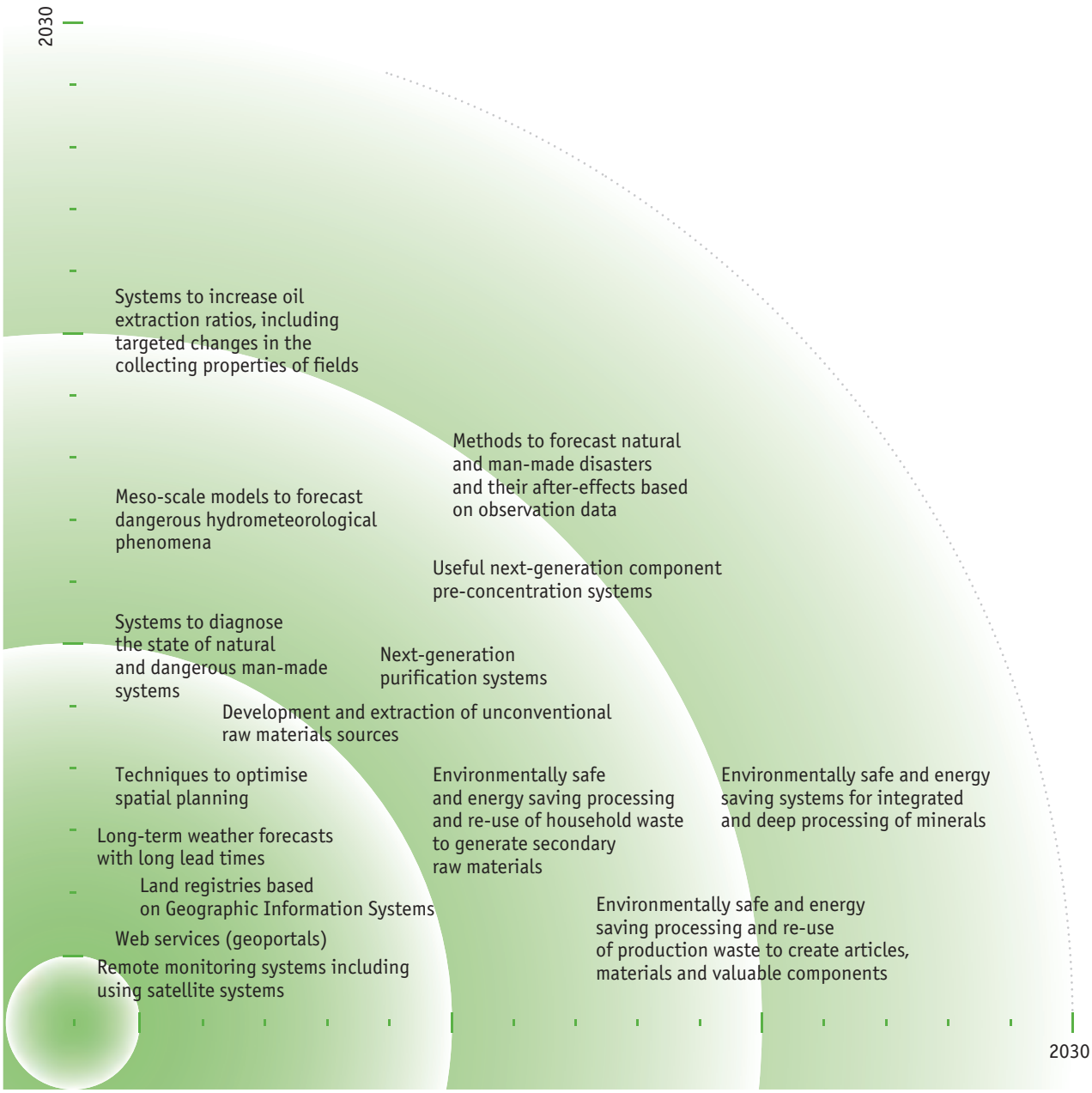
(continued)

Markets	Groups of innovative products and services	Characteristics
	Operative and dispatch management groups for various types of rescue work and work to eliminate the after-effects of emergencies	
Air scrubbing and detoxification systems	Specialist materials, catalysts and absorbents for air filtration systems Equipment for cost-effective and environmentally safe disposal of toxic substances in gas environments	Increasing the volume and improving the quality of air purification Reducing greenhouse gas emissions into the atmosphere
Water purification and water recycling systems	Equipment to process waste water sediment New generation purification systems (to remove new pollutants) Sorbents and reagents to purify waste water and prepare drinking water New resource-efficient environmentally friendly substances and materials to protect surface and ground water from man-made and anthropogenic effects	Increasing the volume and improving the quality of water purification The emergence of additional resources from waste water
Equipment to recycle, process and dispose of waste	Equipment to process and recycle various forms of sorted and unsorted waste (ballast and biodegradable parts) and generate secondary raw materials and finished products Equipment for environmentally safe and resource-efficient processing of production waste, generating goods and materials and valuable components (construction products and materials, lubricants and pastes, combustible gases, liquid fuel fractions and composite materials, concentrates of precious and rare metals, etc.) Equipment to process and destroy materials and raw materials containing hazardous and especially dangerous pollutants (including waste from the oil refining industry, medical and highly toxic waste)	Increasing the volume of industrial waste and other by-products re-processing Reducing the use of resources in production through the recycling of waste Reducing the level of environmental pollution Broadening the resource base of the economy and creating new products through the recycling of waste
Equipment to re-cultivate natural environments	Systems to guarantee environmental safety and the re-cultivation of sites, industrial and consumer waste processing installations (including highly toxic waste), landfills, tailings, land and water, including those polluted with oil and oil products, chemical and radioactive substances	Increasing the effectiveness of returning compromised land into economic use

(continued)

Markets	Groups of innovative products and services	Characteristics
Secondary raw materials and finished products based on the reprocessing of waste and sewage	Raw materials and products based on the reprocessing of solid household waste Raw materials and products based on mineral extraction and processing waste Fertiliser from waste water sediment Purified water for industrial, agricultural and other purposes	Reducing industry resource use Reducing the negative impact on the environment
Environmentally friendly materials and products	Organic products Construction materials with new properties (including energy-saving)	Improving health and quality of living, reducing morbidity caused by using synthetic food products Increasing the energy-efficiency of buildings and facilities
Work to eliminate the after-effects of emergencies, corresponding equipment and infrastructure	Work to eliminate the after-effects of emergencies, corresponding equipment and infrastructure	Increasing the efficiency of work to eliminate the after-effects of emergencies and reduce costs Increasing the effectiveness of rescue work
Air scrubbing and detoxification services	Air scrubbing and detoxification services	Increasing the volume and quality of air purification Reducing pollutant and greenhouse gas emissions into the atmosphere Increasing air quality in cities and industrial zones
Water purification and recycling services	Water purification and recycling services	Increasing the volume and quality of water purification Reducing water intake for industrial and utility needs
Services to re-cultivate, restructure and rehabilitate land	Services to re-cultivate, restructure and rehabilitate land	Guaranteeing the environmental safety of sites for solid household waste, landfills, tailings and other polluted land and water Returning rehabilitated land to economic use
Services providing environmentally friendly waste management	Services providing environmentally friendly waste management	Reducing resource consumption Reducing the negative impact on the environment
Intellectual environmental services	Environmental consulting, audit, certification, insurance, environmental education, measures to enhance environmental culture	Increasing the effectiveness of the environmental component of company activities Implementing market mechanisms to promote a cleaner economy Developing an environmental world view Improving the quality of "green" growth

Fig. 15. Innovative Products and Services with a Radical Impact on the Dynamics of World Markets in the "Environmental Management" Priority Area



not exceed 2 km^2. Improving these models will enhance the accuracy and scales of the forecasts of dangerous phenomena, both for "purely atmospheric" (storm wind speed, large-scale precipitation, etc.) and for series of hydrometeorological phenomena (storm surges, floods, rough seas, avalanches, etc.).

Systems to diagnose the state of natural and dangerous man-made systems are critical for the prevention of emergencies. These systems include not only an instrument base, but also a means to process and visualise the results. Their application means that the amount of time required for diagnosis can be reduced and accuracy can be increased, which would greatly reduce the possible damage and increase the safety of the technosphere. The development of systems to diag-

nose the state of natural and dangerous man-made systems based on innovative equipment will lead to the creation of new markets in the field of instrumentation and software.

Over the past two decades there has been active development in *methods to forecast natural and man-made disasters and their after-effects based on observation data*. For this, geographic information systems (GIS technology) has been used which, among other things, allows you to collect operational data, analyse the signs of brewing earthquakes and assess possible threats of their occurrence on a spatio-temporal scale. The prospective techniques that are being developed for earthquake regions will be based on detecting changes in the pattern of the solar-terrestrial structure (cloud seismo-tectonic indicators). To monitor and forecast earthquakes there needs to be space image data, including images at intervals of no less than 15–30 minutes, covering large areas and at a high sampling resolution.

Geoportals – a set of web-services (downloads, visualisation, editing, transformation, analysis, etc.) carried out on the basis of unrestricted access to geographic (geospatial) information – make it possible to improve efficiency and dramatically reduce the amount of time required to deliver public services. Moreover, they address the problem of investment openness and transparency. An important property of geoportals is the self-development of services. Thus, regional geoportals will be able to monitor the movement of state and municipal transport (snow-removal machinery, ambulances, etc.). This leads to the accumulation of data on average speeds along main city thoroughfares and makes it easier to find ways to optimise use of the road network.

Registers developed on the basis of geographic information systems are a system for quantitative and qualitative information on the state of natural resources, their economic and social value, as well as the breakdown and categories of users. All registers contain explicit and implicit spatial data; however, under the existing system the accumulation and storage of information on their "spatiality" is not in any way used in the procedures of services connected with the extraction and comparison of information stored in multiple registers. The creation of registers based on integrated GIS platforms will reduce the time taken to provide a service to a few minutes (currently, in Russian departments it can take days or weeks). During their development, there may be potential to allow for integration into other GIS platforms and databases. Moreover, keeping registers will open up a broad range of analytical capabilities and will become a key factor in the development of state and municipal services on an entirely different level.

Practices to optimise land planning in accordance with the landscape structure and the environmental and resource potential of the land imply the embedding of the landscape component in the land planning procedure. They will include GIS algorithms for landscape mapping, the development of generally accepted classifiers for various scale levels, and substantial GIS modelling of key stages of landscape planning: engineering and geological assessments of land, analysis of the capacity (vulnerability, resistance) of landscapes, calculation of eco-service systems, arrangement of the environmental framework and planning regional tourist and recreational systems.

The creation of equipment to *develop and extract non-traditional sources of raw materials* will guarantee the necessary conditions for the industrial development of new hydrocarbon sources. The application of these technologies implies a several-fold increase in the volume of reserves, the geographical expansion of extraction, and the transformation of the raw hydrocarbons market with an increase in the proportion of resources and alternatives to traditional oil and natural gas (gas-hydrates, shale gas, "heavy oil" and oil sands, coal mine methane, methane from high gas-bearing coal formations, etc.).

Systems and methods to increase the oil extraction ratio, including a targeted change in their reservoir properties, in particular at depleted hydrocarbon deposits and low pressure gas deposits, will play a crucial role. These involve a combination of technological solutions, instru-

ments and integrated groups aimed to have a chemical and physical impact on hydrocarbon-bearing formations in general and on individual components (hydrocarbons in beds, hydrocarbons themselves, water, etc.), leading to an increase in oil extraction. New technologies will not only help to increase the effectiveness of hydrocarbon extraction at operating deposits, but also to develop deposits with reserves which are hard to extract, including those which are currently regarded as exhausted. In the long-term, this will significantly increase the operating term of existing deposits and will push back the exhaustion of industrial stocks of traditional hydrocarbon raw materials by a decade. Some technological solutions will also be focused on recycling industrial carbon dioxide emissions.

The introduction of *environmentally friendly and energy efficient systems offering integrated and extensive processing of raw materials* to divide minerals into end products with the maximum quantity of mineral components will allow for substantial improvements in the effectiveness of mineral processing and a reduction in the volume of waste production. It will be possible to develop new affordable sources of raw minerals which, in turn, will lead to cheaper processing, changes in the geography of exporting and importing nations, and growth in competition on the market. There is expected to be a fall in capital expenditure and water consumption by 15–20% and expenditure on reagents and energy to process minerals by 30–50%; the productivity of processing and enrichment facilities will increase by 10–40% and the level of useful component extraction will increase significantly.

The application of *equipment for environmentally safe and resource-efficient processing of production waste, generating goods and materials and valuable components* will provide an opportunity to engage in the use of inactive reserves of minerals, poor ores, and metallurgy waste, and to reduce the amount of metal lost in dumps of unpayable ore and old waste from processing companies. Aside from this, the introduction of new developments will help to reduce the level of environmental pollution, in particular by minimising the area used for storing and disposing of waste on industrial land, which can eliminate the risk of highly toxic compounds entering the soil, waste water and the atmosphere.

New generation useful component pre-concentration systems are aimed at enriching minerals by various methods (gravitational, magnetic, electrical, flotation, bacterial, chemical, impulse, radiation and radio-thermal, concentrated and in-situ leaching methods, etc.). In particular, one of the technological objectives is to enrich material contained in man-made dumps and tailings up to an industrial concentration of a useful component. The further development of such technologies will create conditions to increase industrial supplies of mineral raw materials by bringing into service deposits with low metal content ores. Wider use of solid pockets of minerals will bring about an overall reduction in the value of extracted ore. The effectiveness of work by metallurgical and chemical companies which use enriched raw materials will increase together with the level of extraction of useful components of certain types of minerals; the amount of waste and raw materials loss will decrease.

New generation purification systems are based on nanotechnologies in water purification membranes. The availability of technology will lead in the long-term to solving the problem of drinking water shortages in a number of world regions and improving the effectiveness of closed-loop water processes in industry with prospects for optimising the sizes and increasing the mobility of existing treatment complexes.

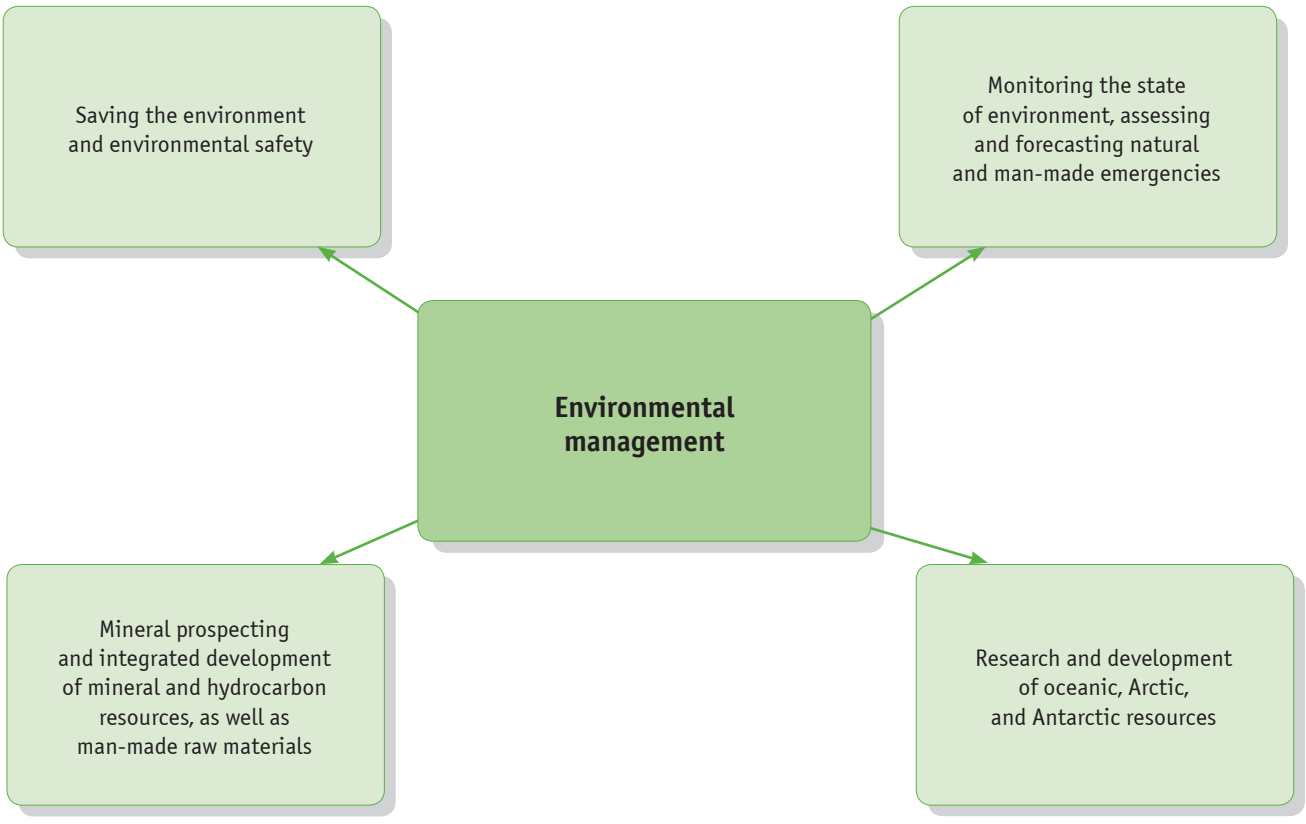
The introduction of *environmentally safe and resource-efficient processing and recycling of communal waste generating secondary raw materials and end products* will dramatically reduce the use of sites for the dumping of solid household waste, which will lead, on the one hand, to a reduction in greenhouse gas emissions on a global scale and, on the other hand, the replacement of a portion of traditional fuels. The waste processing and recycling market will grow actively, and correspondingly there is expected to be growth in the market for construction materials made from secondary raw materials.

Leading domestic and foreign organisations which are actively carrying out work in this field have been identified for these radical products. On the whole they are research institutes and production centres from the USA, EU, Japan, China and Canada. In terms of the development of remote environmental monitoring systems using satellites, national space agencies hold the leading role. The general development trend for supercomputer modelling of global atmospheric and ocean circulation around the world and meso-scale models is the gradual reduction in the number of organisations working in this field and the concentration of research in major leading centres; in some cases, studies are being carried out as part of international consortiums. The development of natural and man-made diagnosis systems is being undertaken by many organisations with many of them actively cooperating with one another, as a rule: some research centres are developing the instrument base, others software, and some are converting all of this into an automated diagnostic system. Studies to increase the efficiency of hydrocarbon extraction are under way in universities in practically all oil and gas extracting nations, as well as in research institutes owned by major mining companies.

5.3. Promising Research Areas

The level of scientific research and development plays a pivotal role in the development of innovative technologies and products. Four thematic areas of applied research have been identified for the "Environmental Management" which are deemed most promising (fig. 16).

Fig. 16. Thematic Fields of the "Environmental Management" Priority Area



The most significant scientific results which could be achieved over the period up to 2030 cover: the creation of monitoring, assessment and forecasting systems for the environment and natural and man-made emergencies; promising technology associated with searching and prospecting for mineral resources; and highly efficient safe methods to carry out sea-based prospecting and the extraction of hydrocarbons in extreme natural and climatic conditions. Their development and introduction will lead to more sustainable use of the country's mineral resource base and an increase in the effectiveness of its reproduction, a reduction in the level of environmental pollution, and the minimisation of damage from natural and man-made disasters.

In the medium term, there will be active research and development into environmentally friendly materials and products; software and geographic information systems; equipment and materials to increase the efficiency of extracting and processing minerals; and early detection and forecasting of natural and man-made emergencies.

Saving the Environment and Environmental Safety

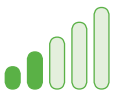
Expected results of future research:

- a reduction in the negative impact of economic activity (production and consumer waste, pollutant emissions into the atmosphere, discharge into water) on the environment and people's health;
- the development and application of environmentally friendly technologies on a global scale across the major sectors of the economy.

Table 32. Promising Research Areas in "Saving the Environment and Environmental Safety"

Research areas	R&D Level	R&D Priorities
Studying climate change and extreme climatic events using promising approaches to analyse climate-affecting factors		Understanding emergence and development mechanisms for dangerous and extreme hydrometeorological processes in the atmosphere and hydrosphere, including non-tropical cyclones, extreme precipitation, floods, droughts, and storms Studying the dynamics of atmospheric circulatory systems, including basic climate modes, non-tropical and tropical cyclones, and their roles in the emergence of atmospheric circulation anomalies Building data arrays on current and forecast climate change based on highly detailed observations and modelling experiments
Reconstruction of retrospective and assessment of modern cryosphere dynamics, including soil which has remained frozen for many years, and forecasts of possible changes		Building data libraries on retrospective and current states of the cryosphere, including soil which has remained frozen for many years, and glaciers, and the implications of global changes of the Earth's cryosphere in terms of climate, nature, and society Assessing the dynamics of the current cryosphere changes in polar regions
Development of forecasts for the transfer and transformation of environmental pollutants, including micro- and nanoparticles		Building data libraries on the migration of elements, obtained with the help of advanced technologies to research the geochemistry of landscapes

(continued)

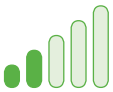
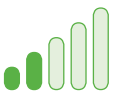
Research areas	R&D Level	R&D Priorities
		Developing systems to measure the effect of new types of pollution on waste water treatment processes
Assessment of changes in the environmental state of landscapes and their components, erosive streamflow processes, bio- and geochemical currents, bio-productivity and biodiversity, water reservoirs and their systems		Developing techniques to assess the state of landscape and its components to optimise territorial planning Building data libraries on environmental and geographical patterns of biodiversity formation; models of its evolution and environment-forming functions; invasions of alien species Building data libraries on geosystems' evolution patterns amid the climate change of the modern era and its palaeographic analogues Development of techniques to reduce anthropogenic pressure on water reservoirs – water supply sources
Assessment and forecasting of the overall impact of natural and anthropogenic factors on people's health and activities against the backdrop of the changing climate and environment		Assessing changes in public health Development of techniques to help the public adapt to changing climate and environment Development of techniques to assess environmental factors' effects on public health and medical and environmental conditions
Development of efficient environmental management systems for cities and urban agglomerations, economy and population distribution		Development of laboratory technologies for environmentally safe waste disposal, and resource-saving technologies to ensure compliance with environmental quality standards during waste recycling Development and application of multifunctional and problem-oriented geographic information systems, and prospective intellectual expert systems to support the environmental safety of various activities
Optimisation of territorial planning schemes in accordance with landscape structures, environmental and natural resources' potentials		Development of techniques to assess the environmental capacity of the natural environment, and to define critical anthropogenic pressures on the landscape and its components Development of techniques and technologies for regional monitoring of territories based on advanced remote geographic information technologies Estimating the necessary public expenditure on efficient environmental management in regional environmental and economic systems

Monitoring the State of Environment, Assessing and Forecasting Natural and Man-made Emergencies

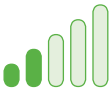
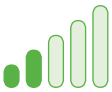
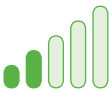
Expected results of future research:

- systems to monitor, assess and forecast the state of the environment, natural and man-made emergencies, and climate change, for subsequent application of advanced technologies to reduce any negative impact on the economy and public health.

Table 33. Promising Research Areas in "Monitoring the State of Environment, Assessing and Forecasting Natural and Man-made Emergencies"

Research areas	R&D Level	R&D Priorities
Assessment of the current state and dynamics of water and land ecosystem resources, and the restoration of the resource potential of areas experiencing high anthropogenic pressures (soil, bio- and water resources)		Development of scenarios concerning the flooding of Russian territories due to extreme rises in water levels; forecasting of the floods' impact on land, water and biological resources Development of innovative efficient approaches to modelling dangerous geomorphological processes, based on the concepts of morphogenesis systemic organisation
Monitoring and forecasting the state of the environment in large industrial cities, in protected coastal areas, bodies of water, and subterranean water reservoirs		Development of alternative drinking and industrial water supply systems Development of techniques for the assessment and environmentally safe development of cities' and villages' underground space
Technologies for instrument-based monitoring of pollutant emissions/dumping into atmosphere, bodies of water and soil		Development of highly efficient air and water environment detoxification technologies
Technologies to obtain, transfer and use data on the state of the environment and changes to the environment, using land-, air-, space-based and other systems		Development of cryosphere monitoring systems, including models for remote monitoring of glaciers Development of Earth magnetic field observation systems Space-based monitoring of rivers' hydrological states and systems Building libraries of retrospective and current data obtained by direct satellite observations of the environment and its components Development of systems to monitor and forecast the movement and deformation of the Earth's crust, volcanic and seismic activity
Technologies and systems for the early detection and forecasting of natural and man-made emergencies		Development of models to study the emergence of dangerous and extreme hydrometeorological process mechanisms in the atmosphere and hydrosphere Development of systems to monitor and minimise the impact of natural and man-made disasters on the population, infrastructure and environment, based on innovative geographic information, mapping and aerospace technologies Development of integrated physical and mathematical and complex models to measure the frequency, recurrence and regionalisation of dangerous hydrometeorological phenomena Development of technologies to assess the risks of various types of natural disasters

(continued)

Research areas	R&D Level	R&D Priorities
		Development of dynamic expert systems for seismic zoning Development of techniques for quick detection of dangerous natural and man-made processes, based on innovative geographic information, mapping and aerospace technologies Development of technology to protect forests from fires Building data libraries on the recurrence and intensity of extreme climatic phenomena Building data libraries on dangerous and disastrous biotic phenomena Building data libraries on natural and man-made geo-catastrophes of various spatial levels Development of novel approaches to the assessment and forecasting of geosystem stability under the effects of extreme natural and man-made factors
Technologies to ensure the safety of dangerous industrial and energy facilities, including chemical plants, oil refineries, mines, high-head dams, hydroelectric and nuclear power plants		Development of techniques for geodynamic monitoring of dangerous natural and man-made processes associated with deep mining of solid minerals Development of mechanical and mathematical techniques to forecast the states of complex environmental, technological, industrial, engineering, energy, transport, communication and hydraulic systems
Technologies to manage environmental risks at offshore oil and gas wells, including in ice-covered areas		Development of techniques for geodynamic monitoring of dangerous natural and man-made processes associated with offshore oil and gas production
Technologies to develop and update registries of land and water areas with the highest levels of environmental risks		Development of expert zoning systems based on the level of environmental natural danger and catastrophic phenomena
Technologies and systems to prevent any negative transborder environmental impact		Building data libraries on the current state of transborder water reservoirs and airspace

Mineral Prospecting and Integrated Development of Mineral and Hydrocarbon Resources

Expected results of future research:

- efficient management of natural resources and their reproduction using advanced prospecting technologies, including increasing hydrocarbon reserves, starting with oil.

Table 34. Promising Research Areas in "Mineral Prospecting and Integrated Development of Mineral and Hydrocarbon Resources"

Research areas	R&D Level	R&D Priorities
Prospecting work, including new mining areas meeting economic and environmental protection requirements; development of geophysical techniques for oil and gas prospecting in non-traditional geological conditions; assessment of oilfields' production potential; techniques for detecting potential mineral-occurrence areas		Development of ore-, oil and gas formation systems to predict those areas with the highest probability of discovering unique oil and gas fields and strategic metals deposits Development of research models for the geodynamic nature of major ore sites and oil and gas field provinces to identify common patterns of ore-, oil and gas formation processes in the Earth's interior Development of research models imitating the formation of ore-bearing magmas and fluids to develop technologies to discover productive complexes of erupted rock Describing lithological and geochemical analysis systems, and 4D modelling of sedimentary basins Development of installations using remote prospecting techniques based on laser and infra-red lidar technologies Studying the situational navigation processes of inclined, horizontal and branched wells in complex geotechnical conditions Studying the dynamics of explosions and shock wave propagation in mountain ranges Development of geographic information systems, aerogeophysical, space-based and lithogeochemical technologies for assessing closed areas and searching for "blind" mineral deposits Development of installations based on geophysical reservoir detection technologies Development of physical and chemical analysis techniques to discover distribution patterns of useful components in ore sites, including non-traditional precious metal compounds in new types of mineral resources, rare earth and rare metals Development of techniques to assess oil field resources, based on modelling naphthagenesis-related processes Development of special techniques to analyse the electrodynamics of geological environments to identify areas for prospecting Development of 3D sedimentary basin models describing connections between sediment accumulation and subsequent diagenesis and catagenesis processes with oil-, gas- and ore-formation processes; structural lithological factors affecting oil-and-gas accumulation and ore deposition to forecast sedimentary mineral sites

(continued)

Research areas	R&D Level	R&D Priorities
Techniques to increase oil extraction rates, including targeted adjustment of oilfields' collecting properties to increase hydrocarbon extraction rate, including at depleted sites and low-pressure gas deposits		Studying the plastic, rheological and geodynamic properties of oil formations with various dynamic, hydraulic, and thermal impacts Development of physical and chemical processes and state patterns for "rock – liquid – oil and/or gas" systems Development of basic elements of explosiveless low-bench hydro-well geotechnologies, and biotechnological techniques for increasing oil extraction Development of rock-crushing installations based on resonance force impact, electric and radiation pulses and fields Development of installations to adjust the rheological properties of bulk rock and fine dust mineral products using vibration mechanics Development of geotechnologies for mining minerals using robotic systems Development of experimental materials for explosive rock blasting and controlling the granulometric properties of explosions' products
Disposal of associated petroleum gas		Development of technologies and equipment for deep chemical treatment of associated petroleum gas
Identification and use of non-traditional raw material sources, including hydrocarbons such as "heavy oils", gas-hydrates, shale gas, etc.		Studying physical and chemical patterns of valuable component extraction processes from coal, shale, and industrial waste combustion products Development of hydraulic fracturing technologies for application on shale rock and formations
Physics- and chemistry-based technologies for processing highly gaseous coal layers, preventing possible emissions of mine methane, including for production of gaseous and liquid synthetic hydrocarbons		Development of hydraulic fracturing technologies for application to methane-containing shale and coal formations Development of processes for targeted adjustment of the state and properties of rock intergranular contacts Studying the structural, physical, chemical, and technological properties of minerals during combined application of geomaterials and mineral suspensions
Technologies for efficient processing of solid minerals, including energy-saving integrated processing of hard-to-enrich natural and man-made mineral raw materials with high concentration of mineral complexes		Development of specialised techniques to analyse the interphase interaction mechanism in the course of mineral complexes' opening and separation in force fields Development of natural and technological systems for integrated development of solid mineral sites Development of rock-crushing and mineral complex disintegration technologies, based on complex and combined energy impacts

(continued)

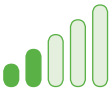
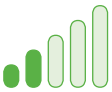
Research areas	R&D Level	R&D Priorities
		Development of technologies for targeted adjustment of mineral physical, chemical and technological properties Development of rock-crushing installations based on resonance force, electric and radiation pulse to preserve wholesome mineral components Development of installations to adjust the rheological properties of bulk rock and fine dust mineral products using vibration mechanics Development of installations to adjust minerals' surface properties and intensification of the flotation process Development of new classes of flotation reagents to improve the extraction of precious metals' particles from hard-to-enrich ores and man-made raw materials with a complex material composition, on micro- and nanolevels Development of techniques to analyse non-traditional precious metal compounds in new types of mineral resources, rare earth and rare metals, to develop innovative technologies to extract fine-dust, micro- and nanoparticles Constructing geotechnological and geomechanical models for the safe development of deep-water solid minerals sites Development of rock-crushing installations based on resonance force impact, electric and radiation pulses and fields Development of installations based on novel ore separation principles, using wide-frequency electric and electromagnetic fields Development of experimental materials for explosive rock blasting and controlling the granulometric properties of explosions' products
Use of mining and raw materials processing waste on industrial scales		Development of research models to reproduce the physical and chemical patterns of valuable component extraction processes from combustion products of coal and industrial waste of metallurgical and ore-dressing enterprises

Research and Development of Oceanic, Arctic, and Antarctic Resources

Expected results of future research:

- highly efficient, safe technologies for marine prospecting and the extraction of hydrocarbons in extreme climates and environments, including ways to prevent and manage the after-effects of accidental oil spills;
- technologies for prospecting and mining solid minerals from coastal and the deep-water shelf.

Table 35. Promising Research Areas in "Research and Development of Oceanic, Arctic, and Antarctic Resources"

Research areas	R&D Level	R&D Priorities
Environmentally safe marine prospecting and mining of various mineral resources in extreme conditions in oceanic, Arctic, and Antarctic environments		Development of technologies to prospect for and extract hydrocarbons and other minerals on the Arctic shelf Development of a model to reproduce the structure of oceanic and Russian seas' resource potential, including the Arctic shelf and coastal regions Studying the effects of hydrometeorological factors on the efficiency of prospecting and developing polar areas' resources, taking into account climate change Development of mechanisms for large-scale methane emissions at the Russian Arctic shelf and the biogeochemical methane cycle in the Arctic seas Assessing of geological and geophysical prospecting and development of mineral, hydrocarbon, and biological resources of the world's oceans
Technologies for seismic prospecting in ice-covered waters		Development of mineral site detection technology and equipment, based on passive seismic prospecting techniques
Technologies to guarantee the overall safety of the development of Russia's continental shelf in the Arctic and Antarctica, including monitoring and forecasting natural and man-made emergencies		Development of models to reproduce the emergence of extreme, dangerous, and catastrophic phenomena in the ocean and Russian seas; development of systems to assess their impact on marine industries and coastal enterprises Optimisation of marine environmental management and integrated management of marine and coastal ecological systems Hydrometeorological and geographic information support for marine industries to minimise risks and optimise marine economic activities
Preventing and managing accidental oil spills, primarily in icy conditions, including the development of technologies for under-ice oil prospecting		Development of technologies and equipment for efficient protection of marine environments from man-made pollution Measuring vessel pollution; development of prototype marine environmental control and monitoring systems for the world's oceans and Russian seas
Technologies for integrated hydro-meteorological and environmental monitoring of dangerous natural phenomena, and primarily the ice situation in the Arctic and Antarctica and in other ocean areas		Studying the ocean's role in climate change and the emergence of climatic anomalies on the continents Development of "ocean – atmosphere – sea ice" system, describing the dynamics of ice cover, wind waves and currents, including in polar seas Studying the structural changes and dynamics of the Arctic and Antarctic waters due to natural and man-made factors in the medium and long-term

(continued)

Research areas	R&D Level	R&D Priorities
		Development of climate change models for the world's oceans and Russian seas, including installation of sea-floor buoys, expedition observations and space data Development of climate change models for polar regions due to natural and man-made factors in the medium and long-term Assessing anomalies of climate-forming processes on the ocean surface, including energy exchange at the ocean-atmosphere boundary Assessment of natural and man-made processes occurring in coastal areas and waters adjacent to remote Russian seas Assessing migration dynamics and mammal and bird populations – indicators of climatic and anthropogenic changes Assessing pollution and environmental damage in the world's oceans, the Russian Arctic zone, and in the Southern Polar Region Development of technologies for hydrometeorological and hydrographic navigational support of marine activities Development of systems to monitor environmental pollution and biodiversity in the Russian Arctic zone Development of online climate change monitoring systems, based on vessels' expedition observations and measurements taken by stationary and drifting buoys
Advanced Earth Remote Sensing (ERS) technologies, including environmental monitoring, estimating resource reserves, and forecasting the environmental situation in the Russian Federation's Arctic areas, using the Russian "Arctica" multi-purpose space system; automated information gathering and processing systems for application in hard-to-reach Arctic and Antarctic areas		Development of a remote environmental monitoring system for the world's oceans, the Arctic and Antarctic, including Arctic Ocean seas Development of a system for long-term instrument-based monitoring of key climate change in the world oceans' circulation Development of a remote monitoring system for the migration of marine and ground mammals and birds in the Russian Arctic zone Development of techniques for satellite-based monitoring and analysis of seasonal and perennial changes in sea ice cohesion in the Russian Arctic and internal seas

6 TRANSPORT AND SPACE SYSTEMS

6.1. Challenges and Opportunities

The development of transport systems in the period up to 2030 will be characterised by a quite specific combination of global and national contexts. The key items of the national (Russian) context include providing transport connectedness, integration of the entire Russian territory, and a cardinal increase in the level of mobility of the population [President RF, 2012b]. These political statements by the President of the Russian Federation reflect the very difficult challenges that the Russian transport system faces and that are linked with science and technology, as well as societal and economic development issues. A significant part of Russia's territory, including area of traditional resettlement by people, has not yet been covered by proper transportation networks. The transport mobility of Russia's population is approximately 7,000 passenger kilometres per year; this is 3–4 times lower than global levels. No less than 30 % of the population of Russia can be categorised as 'archaically mobile', which means they make around 2,000–3,000 passenger kilometres a year.

The global context is characterised by a number of new trends emanating from the more traditional leading countries (USA, Canada, Japan, and EU countries) as well as new leaders (China). In the field of mass passenger transport, the key area for discussion is major breakthroughs in regional aviation and high-speed railways. These have a visible effect of 'shrinking the landscape' i.e. a subjective (from the point of view of the transport user) reduction in the distance between towns and regions.

In the segment of transportation of energy cargo, it is important to stress the clear tendency to use large (250,000 cubic metric tonnes and greater) liquefied natural gas tankers that have engines powered by gas from fluidised beds.

When it comes to cargo transportation for households, a future where many households widely use unmanned flying equipment to deliver an extensive range of goods ordered via online retail websites is becoming increasingly a reality.

We can talk with confidence about the creation, in the years leading up to 2030, of a new market segment of private transport, which is oriented on space travel.

In the market of households' self-service transport, we need to mention the appearance of the first (since mass produced light automobiles were launched in 1908) mass institutional breakthrough in urban and agglomeration mobility. Today not only do we witness 'weak signals' but also very clear signs that the era of the dominance of the car in global megapolises is coming to an end. Now, the ideology of car-dependent mobility is being replaced by the idea of sustainable mobility, which presupposes the construction of balanced, multi-modal transport systems.

One of the characteristic institutional innovations in such systems is the practice of car sharing, which involves the club (cooperative, rotating) use of cars similar to the use of trolleys in supermarkets. Moreover, it is planned to use both more traditional, small cars and exotic (for today) constructions including folding electric cars. In the last 20 years, car sharing has become a widespread commercial product which has possibilities of becoming mass-oriented.

For all the above mentioned trends, we notice a convergence of innovations in the technology sphere (materials, energy saving mechanisms, control systems) as well as in institutions

and business models. An idea that is increasingly put into practice is comprehensive multimodal transportation planning, implemented at global, national, regional, and urban agglomeration levels. As part of this idea, the corresponding legislative and regulatory framework is being developed, and practical examples and scientific schools are being compiled.

There is some justification to suppose that Russia is capable of addressing the problems in transport and space systems due to the realities of the country's national context while at the same time, following in line with global trends. Of course, solving these challenges is linked to carrying out a broad range of research across all the different areas of transport, including aviation and space. Moreover, research and development in technologies, materials, fuel, and control systems should be interlinked with research on institutionalism, transport planning, and modes of financing infrastructure projects.

An effective, modern, and comprehensive transport system can become the driver of the Russian economy, helping to create the conditions for the country's innovative development. However, setting this up requires significant financial resources which cannot come only from the federal budget. Thus, a key task for the transport sector is to make the country more attractive for investors – a task that can be achieved through reducing costs, increasing the effectiveness of construction and maintenance of infrastructure projects, and raising labour productivity.

For the "Transport and Space Systems" priority area challenges and opportunities have been identified which define the main vectors for its development (fig. 17).

The rapid development of the transport system will be assisted by the emergence of *new materials (including composite and nanostructured)*, micro-electromechanical devices, digital electronics and satellite navigation systems. These innovative developments will make it possible to optimise the construction of various means of transport: increasing their cost-effectiveness, reducing their mass, increasing their service life, facilitating their control, and creating more comfortable environments for passengers.

The continuous increases in environmental demands make it necessary to constantly improve air transport systems, and primarily propulsion systems. *The transition to next-generation aircraft engines* will make it possible to intensify the use of aircraft. Greenhouse and harmful gas emissions into the atmosphere will significantly fall as a result. A radical increase in the efficiency of aircraft engines will only be possible with the development of engine plans based on new thrust principles.

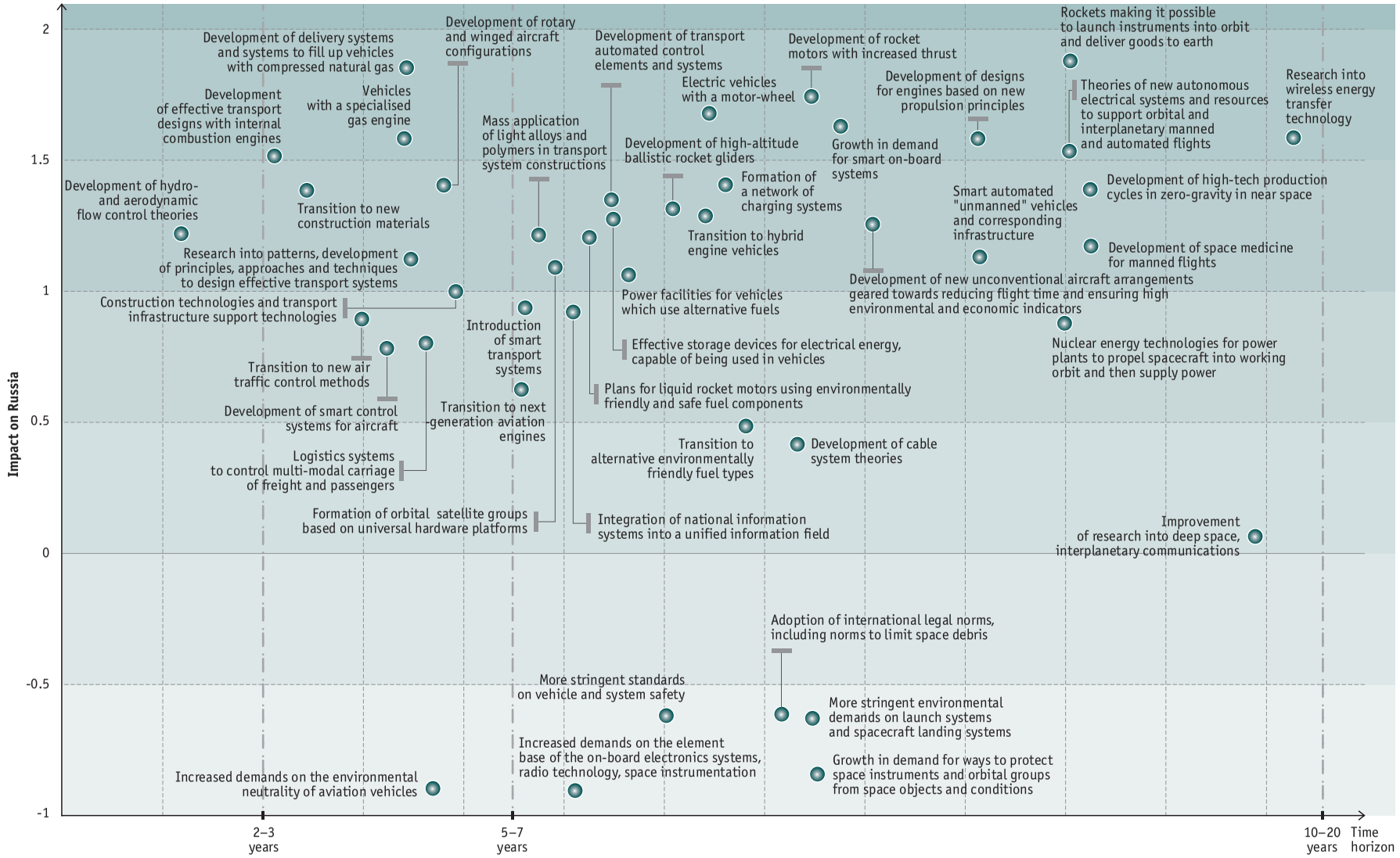
The development of a fundamentally new class of engines, including *liquid rocket engines with environmentally-friendly and safe fuel components* and *rocket engines with increased propulsive burn*, open up promising opportunities to develop space systems. Methods to increase load capacity will make it possible to place in orbit not only new heavy satellites, but also a range of space-based instruments, thereby reducing launch preparation costs.

The growth in demand for ways to protect space instruments and orbital groups from space objects and conditions is giving rise to the development of systems to monitor near-earth space and technologies to recycle "space debris".

The new impetus in this area will lead to the use of *alternative fuels*. The greatest prospects in the area of effective energy solutions for vehicles are linked to fuel cells using hydrogen or natural gas. In particular, the introduction of *vehicles with specialised gas engines* will be cost-effective and environmentally-friendly technological solutions. The transition to *hybrid power* will lead to lower fuel consumption, form a new market for electric motors and high-capacity batteries, and change the servicing system. Thus, there will be demand for synthetic fuel derived from renewable raw materials.

Finally, with regard to transport infrastructure, *the introduction of smart transport systems* will contribute to a significant increase in capacity on existing roads and a reduction in the number of road traffic accidents.

Fig. 17. Transport and Space Systems: Challenges and Opportunities



Source: HSE ISSEK.

Experts have outlined the following ***threats to Russia*** in this field:

- *space systems:*
  - short active timeframe of spacecraft;
  - lag in the development of orbital groups;
  - insufficient number of International Space Station modules available for use;
  - unfavourable geographical aspects of cosmodrome (launch pad) placement requiring the development of rocket systems with higher operating characteristics for guaranteed access to space from the country's territory;
  - remoteness of production companies from launch complexes, special demands on transport processes;
  - restrictions in export of spacecraft and special electronic components from developed countries;
  - use in space transport vehicles of toxic fuel components which may be prohibited under international agreements;
  - special demands on the number and quality of monitoring and telecommunications systems components in relation to the need to cover large areas of the country;
  - technological lag in the scientific, experimental and industrial segments of rocket and space manufacturing;
  - technical lag in ground infrastructure using space services and poor development of related instrument manufacturing sectors;
  - lack of qualified personnel;
- *air transport systems:*
  - lack of qualified personnel;
  - technological backwardness and high level of wear across the country's network of airfields;
  - poor integration into modern international logistics chains;
  - lack of skilled workers in the aviation manufacturing industry and aircraft technology operations;
  - existence of special climatic demands on aircraft and ground-based infrastructure;
  - mismatch between civil aviation technology and international environmental standards and agreements on safety and noise immunity;
- *road transport systems:*
  - insufficient development of transport infrastructure (including in urban areas);
  - need for system-level solutions to develop the transport infrastructure;
  - lag in the development of high-speed and smart transport systems;
  - growth in the negative impact of the transport industry on the environment;
  - poor development of national telecommunications and navigation systems;
- *water transport systems:*
  - technological backwardness of ship building companies;
  - perceptible dominance of military orders over civil orders, while globally the demand structure is the direct opposite;
  - horizontal integration of the industry, whereas the dominant structure globally is vertical;
  - poor development of specialist load transport technologies (liquefied natural gas, hazardous, unstable, active substances, etc.);
  - long repair and servicing times for vehicles;
  - unfavourable climatic conditions not allowing all-year-round loading at shipyards and giving rise to high energy costs;
  - high cost of prototyping when developing vehicles;
  - poor development of logistics technologies leading to barriers and gaps in transport chains.

6.2. Prospective Markets, Products and Services

The development of the prospective markets and innovative products in this field will be linked to progress in technologies and materials for vehicle building and construction, transport and logistics systems for goods and passenger transport, and space systems.

Prospective markets for the "Transport and Space Systems" priority area:

- modelling, forecasting and planning the development of transport systems based on a transport-economic balance;
- smart transport systems and new control systems;
- multi-modal transport and logistics systems;
- integrated modelling of transport flows;
- systems to increase the environmental neutrality and energy-efficiency of vehicles;
- transport safety systems;
- innovative materials and technologies to create transport infrastructure and vehicles;
- rapid and high-speed travel systems;
- prospective vehicles and systems;
- space systems and services.

According to expert assessments, the highest growth rates in the medium term can be expected for smart transport systems and new control systems, environmentally-friendly and energy-efficient transport vehicles. Particular attention should be paid to markets whose growth rates could increase after 2020. These primarily include: multi-modal passenger and freight transportation and logistics systems; new materials and technologies for transport construction; prospective transport vehicles and systems; and space services.

Table 36 shows innovative products and services for the aforementioned prospective markets.

Figure 18 shows examples of innovative products and services which could have a radical impact on global markets in the long-term.

New technical methods and *automated systems to monitor the state of vehicles and infrastructure* and oversee their maintenance and repair will make it possible to generate integrated analytical assessments of the level of technological safety and to create a single multi-level vehicle control system. By optimising repair and re-construction schedules for infrastructure it will become possible to reduce the risks associated with operating transport systems without appreciably worsening the operating conditions of traffic flows. The introduction of new products can help to significantly increase the level of safety on transport, optimise road traffic and reduce the degree of wear on key resources. Knowledge of the operations of transport systems and infrastructure in difficult climatic and geological conditions, including Arctic and sub-Arctic zones, could be a competitive advantage for Russian workers and manufacturers.

In the long-term there is expected to be dynamic development of the services market linked to *methods and models for situational management in smart transport systems* in urban areas. The introduction of such systems will make it possible to increase safety, commercial speed and the predictability of transport, as well as the capacity of the transport system by 15–20% without attracting capital investment to construct and re-construct infrastructure.

Progress in the field of *new materials for vehicles and infrastructure* is not possible without technological breakthroughs in material engineering. Special attention will be paid to developing composite materials, metal alloys and metal-ceramics with nanoadditives, nano-coated parts to be used in aggressive environments, metal-polymers and polymer composite materials, carbon fibres with enhanced strength, heat and impact resistance, as well as new types of synthetic lubricants. The use of innovative construction materials in the rolling

Table 36. Prospective Markets and Product Groups for the "Transport and Space Systems" Priority Area

Markets	Groups of innovative products and services	Characteristics
Modelling, forecasting and planning the development of transport systems based on a transport-economic balance	Transport-economic balance on a regional and federal level Statistical monitoring regulations, methodology and systems to build transport-economic balances Regional, municipal and federal transport system models based on a transport-economic balance Integrated system for modelling and planning the development of the country's transport system	Potential for scientifically substantiated planning of balanced transport infrastructure planning and development of an integrated transport space Increase in the quality of territorial transport access assessments and forecast traffic directions and volumes Completeness of statistics, high adequacy models and accurate algorithms for forecasting Potential to obtain required information from the minimal number of sources with the lowest possible time and labour costs Potential to build mathematical transport-economic balance models with various levels of aggregation, describing intraregional, interregional, foreign trade and transit transport and economic links Coverage of national territory or basic transport directions
Smart transport systems and new control systems	Smart transport systems for urban areas Smart transport systems for transit corridors and federal routes Smart transport systems for automated and automatic management of air transport, including remotely piloted vehicles, and groups of such vehicles Methods and models for situational and adaptive control in smart transport systems Methods and models to control movement demands in smart transport systems New control systems on rail, road, air, sea, and inland water transport	High efficiency of transport control Increased safety, commercial speed and predictability of travel along transport corridors Individual automated control of transport systems, increase in travel safety, fall in the impact of driver behaviour on congestion and situations preventing effective circulation High efficiency of flow control at transport network sites, automatic control mode without dispatcher input Potential to avoid congestion by informing traffic users, early redirection of traffic flows, changing travel modalities Optimising the transport process, improving energy efficiency and safety Increasing the capacity of air corridors, traffic safety and reducing overheads

(continued)

Markets	Groups of innovative products and services	Characteristics
Multi-modal transport and logistics systems	Highly-effective transport and logistics technologies Technical models and technological systems to organise transport and logistics processes High-level transport logistics systems	High commercial speed, delivery of goods exactly on time, synchronised control of transport and logistics processes in supply chains Technological compatibility of multi-modal transport and logistics process operations, unification of shipping documents
Integrated modelling of transport flows	Economic models of the competitive transport services market Social transport standards models Transport service life cycle models Transport service quality monitoring and control system	Increasing the effectiveness of transport market regulation by the state Identifying a minimum level (parameters) of availability and quality for transport services provided to the population, guaranteed by the State Establishment of market rules to motivate increases in the availability and quality of transport and logistics services with non-discriminatory access to commercial activities Statistical monitoring of service quality parameters, drafting corresponding analytical reports and substantiated recommendations to develop transport service quality state regulation mechanisms
Systems to increase the environmental neutrality and energy-efficiency of vehicles	Systems to monitor the negative impact of transport on the environment Methods and systems to reduce negative environmental impact on rail, air, sea, inland water, and road transport and the public road system Methods and systems to increase energy efficiency on rail, road, air, sea, and inland water transport	Assessment of the environmental situation in urban areas, including the impact of harmful emissions by vehicles and their noise impact Increased attention to environmental factors associated with transport development, development of pre-requisites for the transition to "green" growth Reducing the negative impact on the environment Compliance with ICAO standards, geographical expansion of air travel by releasing Russian technology onto the markets of developed nations Stimulating the tourism and recreation sector Protecting bioresources

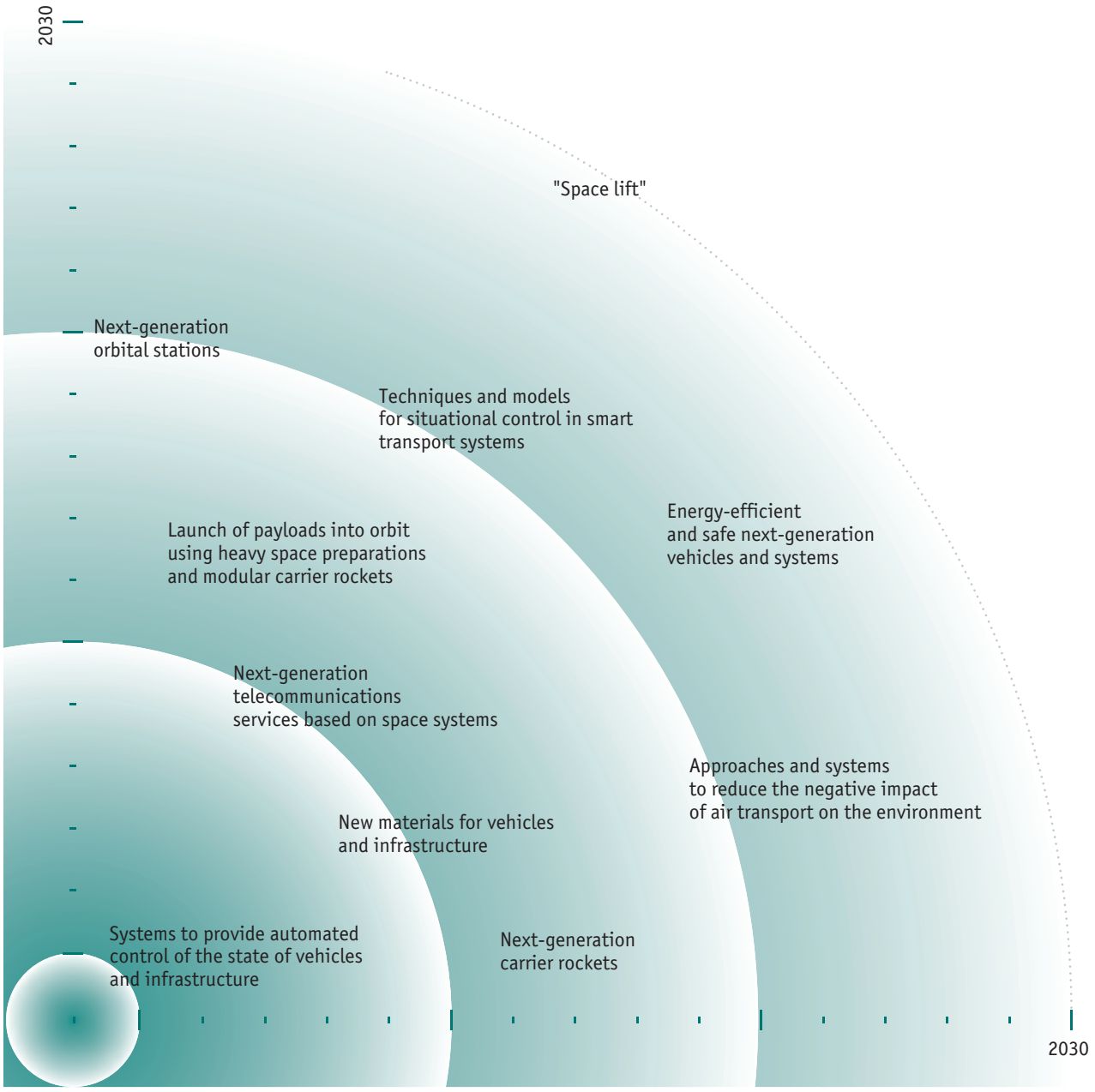
(continued)

Markets	Groups of innovative products and services	Characteristics
Transport safety systems	Systems to monitor, control and supervise safety on transport Methods and systems to increase safety on rail, air, sea, inland water, and road transport and the public road system	Growth in journey volumes, increased loading of the existing transport network and, as a result, growth in the importance of developing the legal and regulatory framework for transport security Compliance with forever tightening standards and regulations on safety
Innovative materials and technologies to create transport infrastructure and vehicles	New materials to improve efficiency, reduce weight and prolong the service life of vehicles and infrastructure New technical methods and automated systems to monitor the state of vehicles and infrastructure, monitoring maintenance and repairs New materials and technologies to develop space systems	Reducing the cost to construct and re-construct transport infrastructure Potential development of transport infrastructure in previously inaccessible locations, including in the Far North regions Reducing the operating risks of transport infrastructure and transport systems more generally Reducing operating costs by optimising repair and re-construction schedules for transport infrastructure
Rapid and high-speed travel systems	Next-generation vehicles and systems for rail, road, water and air transport	Increasing the operating speeds of traffic, broadening the cost-effective operating boundaries of vehicles Growth in population mobility, reduction in subjectively perceived distances Reduction in population density in large cities by increasing the amenity of balanced migration Stimulating tourism and recreation, broadening the scope of the population's recreational activity Potential re-distribution of transport flows on regional and federal levels Increasing the capacity of water routes
Next-generation vehicles and systems	New engine types, including electric Composite and polymer materials with improved consumer characteristics Servicing system for vehicles using alternative fuels Development of solutions to embed new types of vehicles into the existing transport and energy infrastructure	Increasing travel volumes and speeds across all types of transport Growth in energy efficiency, comfort and safety in vehicles Reducing the negative impact on the environment and transport infrastructure Reducing operating costs Potential to navigate in complex icy environments

(continued)

Markets	Groups of innovative products and services	Characteristics
		New opportunities to extract minerals from the shelf while reducing the negative impact on the environment
Space systems	Spacecraft, carrier rockets, launch complexes, orbital stations and next-generation power plants	Increasing the active existence of spacecraft Improving operational characteristics and growth in energy capacity of spacecraft while reducing servicing costs Growth in the energy efficiency and safety of rocket launches and placement in orbit Reducing the negative impact on the environment, including with extraordinary wear Growth in energy efficiency, comfort and safety when operating flying vehicles Reducing the risks of external cosmogenous effects threatening the security of life on Earth Opportunities to develop deep space Increasing production volumes for special materials and carrying out experiments in weightless conditions and space Increasing the volume of environmentally friendly energy generated without using fossil fuels or alternative fuel
Space services	Telecommunications services Global navigation and positioning Space monitoring Placement of payloads in orbit Remote probing of Earth Space tourism	Increasing the volumes, energy efficiency and safety of data transfers and multimedia content Increasing the volumes of data transfers between satellites by shifting to transmission frequencies up to 100 GHz Changing the global media market based on new formats of content provision, including personalised Growth in the energy efficiency, comfort and safety of passenger and freight transport Accuracy and speed of data collection on local and global territories Reducing the negative impact on the environment Active growth in demand for a wide range of devices with satellite interfacing

Fig. 18. Innovative Products and Services with a Radical Impact on the Dynamics of World Markets in the "Transport and Space Systems" Priority Area



stock of prospective forms of rail, road and water transport will make it possible to reduce fuel expenditure by up to 20%, increase the safety of using structures and constructions during the planned service timeframe, increase their service life, and decrease environmental pollution by almost twofold.

The creation of *effective and safe next-generation vehicles and systems* fits into the current developmental trends of this field to increase energy efficiency, comfort and safety. Vehicles entirely stripped of traditional internal combustion engines are likely to appear in the short term: electric vehicles equipped with high power electrical energy stores, including with a sub-

sidiary electricity generator, or electric vehicles based on fuel cells. It is expected that this product group will achieve leading competitive positions on the market by 2022–2025. By this time conditions will be right for the development of distributed electricity generation based on renewable energy sources and "smart" grids. Electric vehicles will be able to use distributed means to store electrical energy, cover peak electrical loads, reserve power and improve power quality. There may even be a transition to other sources of energy (for example, natural gas or hydrogen), which will bring about an increase in the competitiveness of renewable energy and will support the conservation of non-renewable fossil fuel resources. The structure of the resource base will change for the automotive industry: demand for black metal will fall and demand for polymer materials and aluminium alloys will increase.

The speed of development of *methods and systems to reduce the negative impact of air transport on the environment,* aimed primarily at reducing harmful emissions, will increase rapidly. Aside from this, new products will make it possible to reduce fuel costs for passenger transport, noise levels and increase flight safety. By 2030, it is expected that the aviation market will see the emergence of aircraft with improved key characteristics: accident rates will reduce by 8.5 times compared with 2010 levels, fuel costs and CO_2 emissions will fall by 1.6 times, NO_x emissions will drop by 1.8 times in terms of ICAO standards, and noise levels will be lower by up to 30 dB in terms of ICAO standards. In the period up to 2020, products will appear which fully satisfy future ICAO standards setting strict demands on the environmental factors of air transport.

Next-generation carrier rockets making wide use of new polymer composite materials (composite proportions 20% higher than in the Proton-M rocket) will have better characteristics compared with existing counterparts by almost twofold. A distinguishing feature of these carrier rockets will be modularity. Such a construction concept firstly helps to simplify delivery of a ready-made product to the launch site by rail transport; secondly, it makes it possible to create a whole family of carrier rockets – from light (based on a single first stage module) launching a ground payload of 1.5 tons into low-earth orbit, to very heavy (up to 50 tons). With the introduction of such systems it will be possible to place payloads of over 50 tons into an orbit of 200 km, which increases the opportunities for space tourism allows to use modular carrier rockets to launch spacecraft to the Moon or nearby planets in the Solar System, and they could even be adapted for the development of deep space. One expected production benefit is linked to economies of scale: modular systems make it possible to move from modern small-scale or even individual production of rocket modules to medium-scale output.

In terms of services *to place payloads in orbit* there will be some development in the transportation of high-mass space instruments and the volume of payloads and spacecraft will increase by using lighter materials and integrated systems alongside reductions in the negative environmental impact.

The development of *next-generation telecommunications services based on space systems* holds special importance for our country in view of its colossal territory. In this field the development of new space vehicles and infrastructure is directed at providing consumers with accessible and quality communications services by increasing the speeds of data transfer, providing higher positioning accuracy and more opportunities for the use of positioning in difficult-to-access terrain. In the future, satellite communications systems and television signal broadcasting will be in demand throughout Russian territory. The development of this field will provide an increase in data transfer volumes and multimedia content, including between satellites, by shifting to transmission frequencies up to 100 GHz.

The creation of *next-generation orbital stations* is a breakthrough innovation in this field and could make it possible to manufacture special materials, microchips and nanostructures on industrial scales in space. The development of space (orbital) groups, including by creating

new space instruments and improving existing rockets and stations and the expansion of ground-based infrastructure, including the creation of new and improved existing cosmodromes, control centres and communications, have already started to take shape. Next-generation orbital stations will have greater levels of energy efficiency, comfort and safety. Moreover, the operating principles of orbital "factories" and automated research complexes will be developed, and foundations for the construction of robotic methods to carry out orbital operations and technical servicing in automated and adaptive modes will be established to provide automated docking technologies and to bring together the modules of a multifunctional orbital complex.

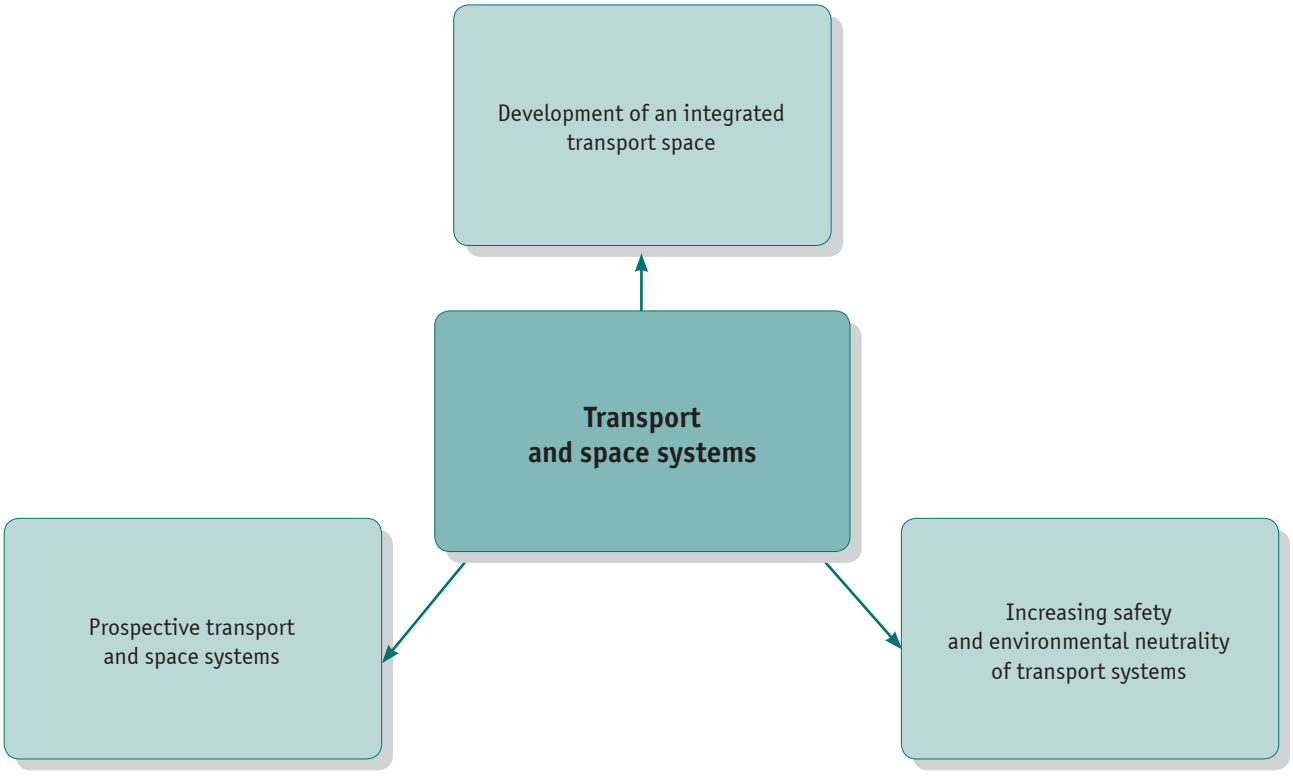
The creation of cable systems, including the development of a *"space elevator"* will make it possible to change the orbits of spacecraft, move goods between orbital stations, launch small spacecraft and deliver payloads into orbit, which for traditional rocket technologies is not realistic or would incur significant costs.

Research in these fields is being carried out in a wide range of leading Russian and foreign scientific research centres whose expertise has been analysed during the forecast process. The leading organisations – as a rule, major space, air and automotive concerns – are concentrated in the USA, EU (primarily France and Germany), Canada and Japan. Russian developments in the field of space systems are on a par with foreign developments, but in other fields there is some lag behind the leaders.

6.3. Promising Research Areas

The evolution of the aforementioned innovative products and technologies requires further development of Russian scientific research in three major thematic fields (fig. 19).

Fig. 19. Thematic Fields of the "Transport and Space Systems" Priority Area



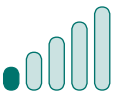
Among the most competitive areas of Russian R&D are the development of research models to study the transport situation in the Arctic and subarctic areas, the development of air- and spacecraft to launch suborbital small-size space satellites, and several other areas related to new-generation carrier rockets and spacecrafts, innovative modes of transport and systems for marine and air transport. Still, this is by no means an exhaustive list of priority science and technology development areas matching the forecast dynamics of global markets.

Development of an Integrated Transport Space

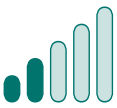
Expected results of future research:

- system to develop the transport and economic balance of the Russian Federation and forecasting its dynamics, for scientifically substantiated planning and development of efficient transport infrastructure, and the creation of a national integrated transportation space;
- system to simulate transport flows in the transport communications network, based on transport and economic balance data;
- unified integrated system for strategic management of the Russian integrated transportation space on federal, inter-regional and regional levels, based on thematic models, and transport and economic balance;
- package of efficient technologies, and their adjustment for application in transport construction, exploitation and reconstruction of national transport infrastructure.

Table 37. Promising Research Areas in "Development of an Integrated Transport Space"

Research areas	R&D Level	R&D Priorities
Research models for transport and economic balance elements, configuration of transport networks and flows, and smart management systems for them; minimum social transport standards		Building mathematical models of the transport and economic balance at various aggregation levels, to describe intraregional, interregional, foreign trade and transit transport and economic links; and mathematical models to assess the transport accessibility of various Russian territories Building efficient mathematical models to forecast directions and volumes of traffic, taking into account macroeconomic indicators making it possible to assess the dynamics of the Russian Federation's transport and economic balance Increasing the adequacy of models and accuracy of forecasting algorithms Developing new forms and procedures for statistical observation, to gather data on enterprises' freight potential and main traffic flow correlations Development of systems to maintain the transport and economic balance, calculating transport accessibility indicators for various areas, forecasting directions and volumes of traffic Development of transport flow modelling techniques based on transport and economic balance data for major tasks; development of techniques for model decomposition; using high-performance computing systems for modelling purposes

(continued)

Research areas	R&D Level	R&D Priorities
		Development of an interconnected models system, to calculate transport flows in specified directions taking into account modal break-up, multi-modal transport availability, and the location of transport nodes
		Development of techniques to integrate interconnected models into a unified transport flow model
		Decreasing computational complexity of calculation algorithms
		Development of a system of interconnected transport system models for pilot regions; model calibration techniques based on in situ measurement, to increase the accuracy of modelling
		Building a library of transport system simulations, for analysis and selection of best options for developing transport infrastructure
		Development of techniques and principles to integrate and coordinate the strategic management of the unified transportation system, on federal, interregional and regional levels
		Preparing scientifically substantiated proposals for an integral general scheme of balanced development of the transport network on regional, interregional and federal levels, taking into account increased throughput and speed parameters of transport infrastructure; development of backup transportation capacities in industrial development areas; integrated development scheme for transport corridors and nodes; and transportation and logistics scheme in coordination with customs infrastructure
Research models to study the transport situation in the Arctic and subarctic areas; promising technological solutions, materials and techniques for the construction and maintenance of transport infrastructure in these areas		Building models to estimate the effect of low temperatures on the durability and reliability of transport facilities in the northern climate zone, and in permafrost
		Development of materials and technologies to build railways and roads in the northern climate zone, and on permafrost
		Development of techniques and mathematical models to study the bearing capacity of transport facility new designs; principles and models for efficient quality control of transport infrastructure objects, using smart monitoring and evaluation systems
		Development of techniques to assess the impact of low temperatures on the durability and reliability of transport facilities
		Mathematical modelling of surface-forming on snow-covered roads
		Development and substantiation of the efficiency of transport facility new designs based on new construction materials, load-bearing elements, and construction technologies

(continued)

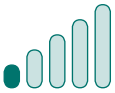
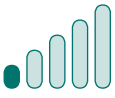
Research areas	R&D Level	R&D Priorities
		Development of production technologies for rapid-hardening, durable and high-strength materials based on nano-structured complex additives; composite and geosynthetic materials for construction and repair of automobile roads and railways
		Development of new smart road lighting equipment and systems
		Experimental development and evaluation of efficient innovative transport infrastructure building and reconstruction technologies
		Development of new technological tools and automated systems for monitoring the state of road surfaces; traffic counting; monitoring the state of railways; developing an efficient transport infrastructure monitoring and management system

Increasing Safety and Environmental Neutrality of Transport Systems

Expected results of future research:

- system to monitor the environmental, engineering and technological safety of transportation system, to provide an integrated analytical assessment of transport technological safety and its harmful impact on the environment, by transport and vehicle type and for specific areas;
- unified national multilevel system to ensure engineering and technological safety of transport, to support federal government agencies of various levels and transport companies of various forms of ownership, and to implement a set of measures to reduce transport's harmful impact on the environment.

Table 38. Promising Research Areas in "Increasing Safety and Environmental Neutrality of Transport Systems"

Research areas	R&D Level	R&D Priorities
Prospective technologies to significantly reduce transport's harmful impact on the environment		Development of techniques to measure transport's harmful impact on the environment, identification of sources and forecasting the after-effects of such impact
		Development of efficient techniques for monitoring and statistical analysis of transport's impact on the environment, including optimal positioning of environmental data collection points throughout transport infrastructure
Prospective transport safety technologies (including for vessels and aircrafts) in difficult and unfavourable conditions		Development of techniques to measure specific parameters and the overall level of technological safety, by transport and vehicle type and for specific areas, based on the reliability theory techniques

(continued)

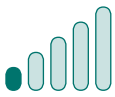
Research areas	R&D Level	R&D Priorities
		Development of efficient techniques to monitor and control compliance with technological safety parameters, by transport and vehicle type and for specific areas
		Studying transport process safety techniques; prevention of unauthorised access to transport facilities and transport infrastructure
		Development and application of safety procedures based on advanced information technologies, control and communication systems, advances in emergency medicine, human physiology and psychology
		Development of specialised training simulators and techniques for transport and space system personnel
		Development of efficient planning techniques to maintain and repair transport facilities and infrastructure, to ensure compliance

Prospective Transport and Space Systems

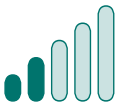
Expected results of future research:

- smart and high-speed transportation systems; space, aviation, and suborbital systems.

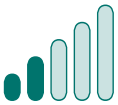
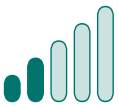
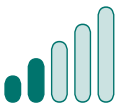
Table 39. Promising Research Areas in "Prospective Transport and Space Systems"

Research areas	R&D Level	R&D Priorities
Prospective means of transport		Development of production technologies to make combined-drive vehicles, including using integrated modelling and testing systems
		Improving engines and rolling stock of high-speed magnetic levitation transport based on superconductivity effect, using nanomaterials with high electric conductivity
		Development of self-driving technologies for high-speed levitating transport vehicles
		Development of high-speed transport vehicles based on novel physics principles (magnetic levitation, wireless energy transfer, aerodynamic screen, very large capacity energy storage systems, superconductivity, etc.)
		Development of high-precision operation technologies based on the GLONASS system for transport vehicles with speeds above 300 km/h

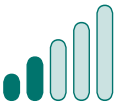
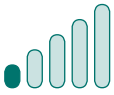
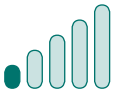
(continued)

Research areas	R&D Level	R&D Priorities
		Development of principles to monitor transport vehicle states and to operate critical objects in real-time mode, based on artificial intelligence
		Development of production technologies to make large-size pressed and stamped semi-finished products out of high-strength, corrosion-resistant aluminium alloys
		Development of systems for technological pre-processing of complex engineering products in an integrated information space
		Development of technologies for natural/hybrid laminarisation; new-generation sound-absorbing constructs; novel automated single-unit control systems; non-destructive check-up technologies for monitoring aircraft gliders and systems
		Improvement of spacecraft onboard engines, drives and energy storage systems, including to support continuous operation of a cluster of spacecrafts
		Development of technologies used to make transport vehicle and system engines: hybrid drives; linear traction electric drives; compressed natural gas drives; liquefied petroleum gas drives; cryogenic fuel drives, etc.
Clusters of small-size spacecraft (micro-, nano-, and picosatellites), for remote probing of Earth; deployment of broadband telecommunication systems; and transport vehicles' traffic control		Development of technologies for ground adjustment of small and very small spacecraft, to save time and reduce costs
		Development of specialised solar elements-based drives for small and very small spacecraft
		Development of operating schemes for very small crafts, based on "system-on-a-chip" technology
		Development of key technologies for designing and improving the design of small and very small spacecrafts (micro-, nano-, and picosatellites), based on prospective telecommunication technologies and nanoelectronic component base
		Application of composite materials to make major structural components of small-size crafts; development of methodology to design platforms for small and very small spacecraft; development of principles for their group operation (cluster launch)
Prospective launch vechicles: reusable space shuttles; space transportation systems, including with the use of nuclear energy; air- and spacecraft for launching suborbital small-size space satellites		Development of production technologies to make carrier rocket and acceleration block structural components (tanks, envelops, girders, frames, hulls, fairings, thermal shielding elements), including out of composite nanomaterials

(continued)

Research areas	R&D Level	R&D Priorities
		Development of technology for making reusable engines, high capacity electric jet engines Development of combustion chambers, flow channels, air vents, aircraft engines out of novel construction and composite materials
Wireless energy transfer systems for transportation vehicles and spacecraft		Researching techniques to transfer energy to high-speed rolling stock, including electric vehicles Researching new types of energy sources and energy storage devices based on new materials, including nanomaterials
Precision automated landing systems for aircraft and landing modules; navigation and manoeuvring systems for ground vehicles and vessels		Development of smart operation systems for transport vehicles and airspace control systems; safety systems for flying at very low and very high altitudes, for mass application at transport vehicles Controlling high-speed transport vehicles using the GLONASS system and land-based positioning systems ensuring precise positioning Development of precision positioning systems for combined and virtual reality applications Extended application of the GLONASS positioning system to new automated traffic control and online management systems Development of a system to control detached sections of carrier rockets and gliding winged aircraft to ensure their precision guidance, based on artificial intelligence elements Development of multi-purpose integrated navigation systems based on micromechanical sensor elements and satellite navigation equipment Research in aircraft streamlining and noise management; alternative fuels; full automation of flight control in the framework of air traffic control system, with four-dimensional navigation; smart materials and constructs
Very long flexible elements for making extended static and dynamic space cable systems, and space lifts		Development of key technologies for making and improving constructs out of promising non-metal composite materials Development of construction and composite materials and coatings resistant to various climatic and temperature conditions Development of new technologies and advanced automated equipment for the production of carbon fibres with improved properties, including high-strength and high-modulus ones, to enable development and mass production of carbon composite materials and products made of them

(continued)

Research areas	R&D Level	R&D Priorities
Prospective materials for the extreme conditions of space flight, high-speed movement in land-based and water environments		Research and development in novel construction and composite materials for transport vehicles based on nanotechnologies, organic and non-organic synthesis, metallurgy, and thermal treatment Development of prospective technologies for making constructions out of novel materials and coatings, and techniques for testing and application of materials and coatings Development of new path elements to ensure high-speed movement Development of technology for integrated testing of novel materials and coatings, including detection of their functionality in the course of reproducing object levels of thermal force and thermal erosion load Development of techniques for integrated application of prospective construction and composite materials to basic structural elements, to achieve improved energy and mass properties; and economic performance indicators of transport vehicles Researching potential to use new fuel types, functional units and elements made with the help of nanotechnologies
Processes typical to exploitation of prospective transport vehicles and spacecraft		Exploratory research in aerodynamics, flight dynamics, aero-acoustics, strength, alternative energy sources Development of maintenance technologies for composite materials in use Development of high-performance small-size vessel power plants, electric power and general vessel systems based on novel principles of energy generation, storage, and conversion; high-performance tools and systems for ensuring safety and durability of ships and vessels, including new-generation radioelectronic equipment based on nanotechnologies Development of highly automated smart adjustable systems for design, building, and industrial production, covering all stages of technological cycle, of ships, vessels, and other components of water transportation systems Defining optimal structure and tools of a distributed system for ongoing monitoring and online control of a group of spacecraft
Virtual design, modelling and optimisation of prospective transportation systems and their elements, using exaflop supercomputers and grid-technologies		Development of technologies for modelling spacecraft designs and units, including very small crafts Developing models of personal passenger transport vehicles with combined vertical take-off aircraft and city smart car functionality

(continued)

Research areas	R&D Level	R&D Priorities
		Development of precision modelling design techniques Development of non-destructive techniques for monitoring the state of materials and elements of engineering constructs based on combined computer modelling of thermal processes and deformed solids mechanics, taking into account non-linear and non-stationary thermal impact and structure formation kinetics, and the latest advances in the area of obtaining data on structural and stress-deformed object states, using non-destructive techniques Development of smart systems for monitoring, assessment of resources and forecasting the state of structural elements in the course of exploitation, and installing these system at new-generation transport vehicles

7 ENERGY EFFICIENCY AND ENERGY SAVING

The state of the energy industry largely determines the overall competitiveness of the economy, society's level of development and the quality of the environment. In Russia, the need to ensure the long-term sustainable and efficient development of the energy industry is defined by the country's leading export positions, and the industry's role in generating government budget revenues. The industry is highly inertial, has a long investment cycle and the development of new technologies involves high costs and a lot of time and requires interdisciplinary research. Furthermore, in practically every aspect of the industry there are several possible scientific and technological development areas to pursue, and a wrong or non-optimal choice can result in major losses and increased lag behind leading countries around the world.

Among the most important factors in the post-industrial energy paradigm are advancing growth in sectors and industries with low energy intensity, the use of a wider range of energy sources, localised production and bringing production nearer to consumers, and the introduction of far-reaching projects to increase energy efficiency, expand smart energy grids and energy information systems.

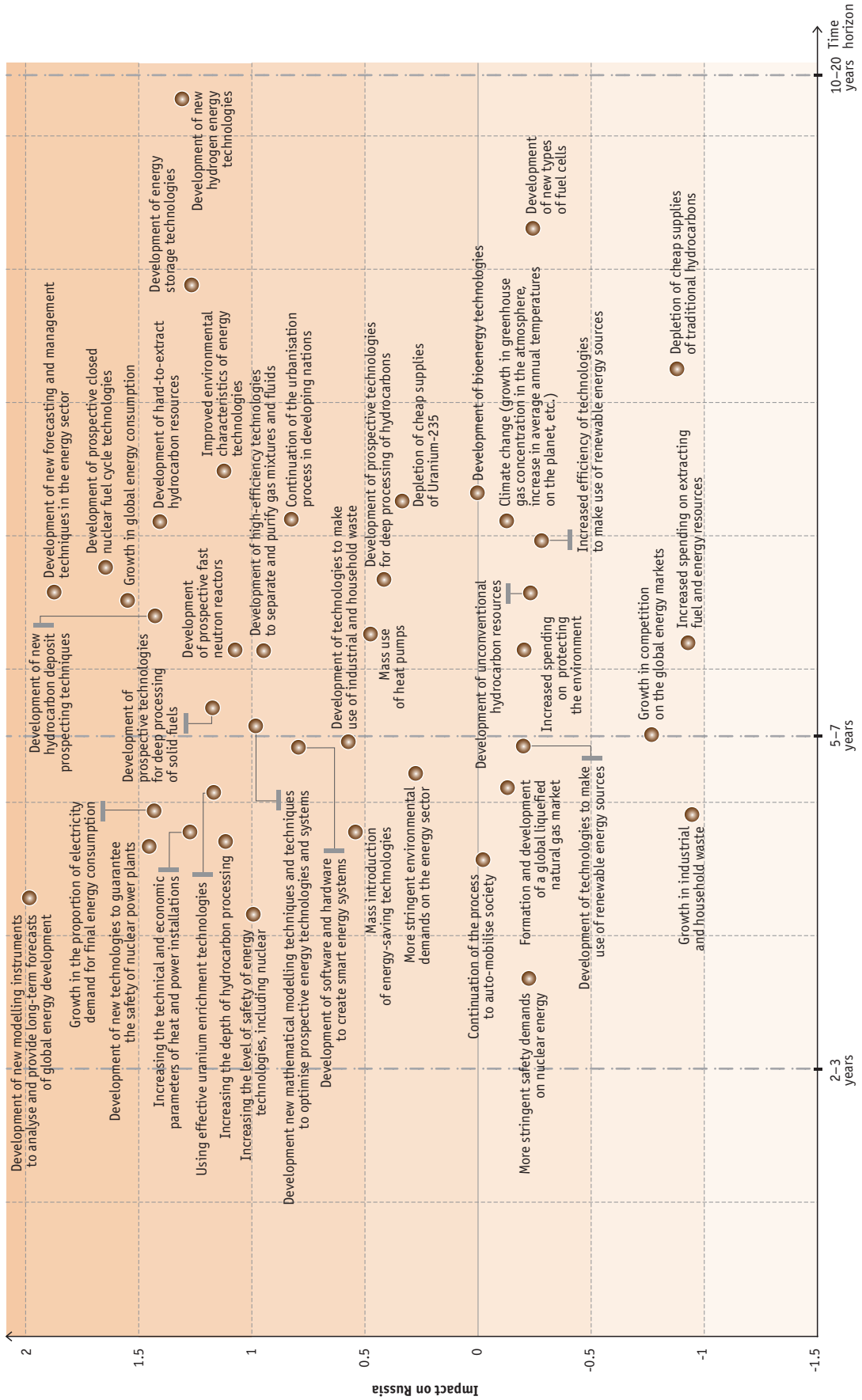
7.1. Challenges and Opportunities

Figure 20 shows the challenges and opportunities shaping the future of the "Energy Efficiency and Energy Saving" priority direction under the influence of long term global developmental trends.

The exhaustion of traditional hydrocarbons in the country is linked to the fact that a significant proportion of global oil reserves prospected over the last 20 years are in hard-to-reach locations, which means that it will require high resource and energy consumption to develop the sites and set up the corresponding infrastructure. In 40–50 years the world will come up against the *exhaustion of the world's supplies of Uranium-235* (and taking into account the low profitability of extraction at certain major deposits the possible timeframe for their exhaustion could be 20 years). In relation to this, in the medium term it is expected that the cost value of extracting fuel and energy resources will increase and unconventional energy sources will be developed. We should also expect an increase in the depth and quality of raw hydrocarbon processing, which will make it possible to reduce the extent of the negative environmental impact by producing more environmentally-friendly oil products (with a possible simultaneous increase in processing costs).

More stringent environmental demands on energy and problems linked to *climate change*, such as the increase in the average annual temperature on the planet; changes in rainfall and glaciers; and the rise in sea level and the risk of extreme weather phenomena (a further exacerbation of these problems is expected in the medium term), are forcing Russia to introduce national legislation in the energy sector in line with the new realities and international practice, as well as to put in place other economic and institutional measures directed at environmentally friendly development.

Fig. 20. Energy Efficiency and Energy Saving: Challenges and Opportunities



Source: HSE ISSEK.

Russia could take part in the formation of a *global liquefied natural gas market* and its spread to those countries to which supplying gas was previously not possible. Natural gas could be a good alternative for countries that have renounced nuclear power, and an additional fuel source for states intending to rely on renewable energy sources. The substitution of oil and coal consumption with natural gas will have a positive impact on the state of the environment: gas is the "cleanest" fossil fuel, and when burnt it releases significantly less CO_2 into the atmosphere. However, the specific geographical location of Russia's supplies is such that securing a serious (comparable with Australia or Qatar) position on this market would be extremely difficult.

The development of renewable energy technologies is a challenge for Russia geared towards use of traditional sources. The large-scale use of renewable sources brings with it the need to supplement them with energy storage systems, as well as "flexible" hydro- and gas generation capable of providing back-up reserves in the absence of suitable conditions to produce electricity from renewable sources. Moreover, renewable sources have already given rise to a multimillion dollar equipment market. There is continuing development of technologies aimed at increasing their economic and technological efficiency, which will lead to a significant increase in their use in the medium term. In this regard, we can expect large-scale development of certain technologies (for example, fuel cells based on various fuel types) only around the year 2030.

The use of industrial and domestic waste, the volume of which continues to increase around the world, is opening up opportunities for Russia to significantly reduce its harmful emissions and reduce consumption of more expensive fuels in many sectors of economy (metallurgy, cement production, etc.). Guaranteeing a high level of fuel being substituted for industrial and household waste (and in certain cases, complete substitution) requires the creation of systems to process and monitor quality of raw materials to achieve homogeneous calorific values. It should be noted that in the medium and long term there is expected to be an improvement in the environmental characteristics of all energy technologies.

The implementation of energy saving technologies will actively evolve in the short term. Their use in Russia could reduce the load on the economy by decreasing the energy intensity and cost of production, consolidating the financial stability of housing and leading to improvements in the environmental situation as a result of the reduction in greenhouse gas and other harmful substances emissions into the atmosphere. The development of technologies to store electrical and thermal energy are also important factors in increasing energy savings. With an increase in efficiency factors and service lives, a fall in production and operating costs and a lower requirements for passive power, energy storage systems will be able to significantly improve the efficiency of many centralised and decentralised generation systems, including solar, nuclear, wind, geothermal energy and others. The emergence of new electrochemical power sources characterised by high safety, high capacity and low costs has the potential to accelerate the electrification of transport systems. Special interest is being paid to chemical batteries and electrochemical capacitors.

Heat pumps are widespread in many OECD member states and have high potential to upgrade heating systems in the residential sector. Successfully solving issues relating to servicing, cutting costs and increasing the conversion coefficient, heat pumps could come to be effective sources of heat energy.

New types of fuel cells based on hydrogen could come to compete with other power sources. Their advancement requires a significant reduction in costs and the creation of infrastructure and a market for corresponding devices. There is potential to develop hybrid energy plants generating power in excess of 20 MW and with an efficiency factor above 70% based on high-temperature fuel cells. These technologies are currently in the early stages of development.

The development of promising fast neutron reactors and promising closed nuclear fuel cycle technologies will make it possible to increase the efficiency of nuclear fuels by many times and significantly reduce radioactive waste volumes.

Experts have outlined the following ***threats to Russia*** in this field:

- low levels of extraction and conversion rate of raw materials;
- incoherent electricity network structure and power generation capacity;
- low energy-saving in final consumption;
- technological backwardness and high level of wear across equipment;
- inadequate energy infrastructure for a significant proportion of the country;
- insufficient volumes and poor efficiency of geological prospecting work;
- high level of monopolisation in domestic energy markets, destroying competition and creating prohibitively high barriers to entry for any link in the value chain;
- the location of new deposits in extreme climatic and geological conditions.

7.2. Prospective Markets, Products and Services

The prospective markets, products and services in the energy industry can be viewed in relation to certain groups of energy resources: natural, recycled, converted and secondary, or by-products. These groups are traditional products in the fuel and energy sector and some other sectors of the economy.

Research and development in the energy sector are aimed at increasing the efficiency of fuel and energy extraction, processing and transfer. Besides inertial processes there are revolutionary technological changes which will bring about the emergence of radically new technologies and a drastic transformation of energy markets.

Prospective markets for the "Energy Efficiency and Energy Saving" priority area:

- oil from unconventional deposits and unconventional oil;
- natural gas from unconventional deposits;
- liquefied natural gas;
- alternative motor fuels;
- fuel cells;
- electricity and fuel long-distance transfer systems;
- storage of electricity, heat and cold;
- prospective nuclear equipment and nuclear power generation;
- biofuel;
- "smart" networks;
- equipment for renewable energy;
- heat pumps and geothermal power stations;
- high-efficiency thermal power stations;
- energy-saving equipment.

Innovative products and services for the "Energy Efficiency and Energy Saving" priority direction are shown in table 40.

Among the innovative groups of products and services listed below, we have identified those which will have a radical impact on the global markets in the long term (fig. 21). In the energy efficiency and energy saving sector these primarily relate to:

- fuels with significantly improved characteristics and consumer properties;
- energy resources produced with the use of innovative technologies or which have high consumer qualities and market potential (electric power from wind turbines, liquefied natural gas, etc.).

Table 40. Prospective Markets and Product Groups for the "Energy Efficiency and Energy Saving" Priority Area

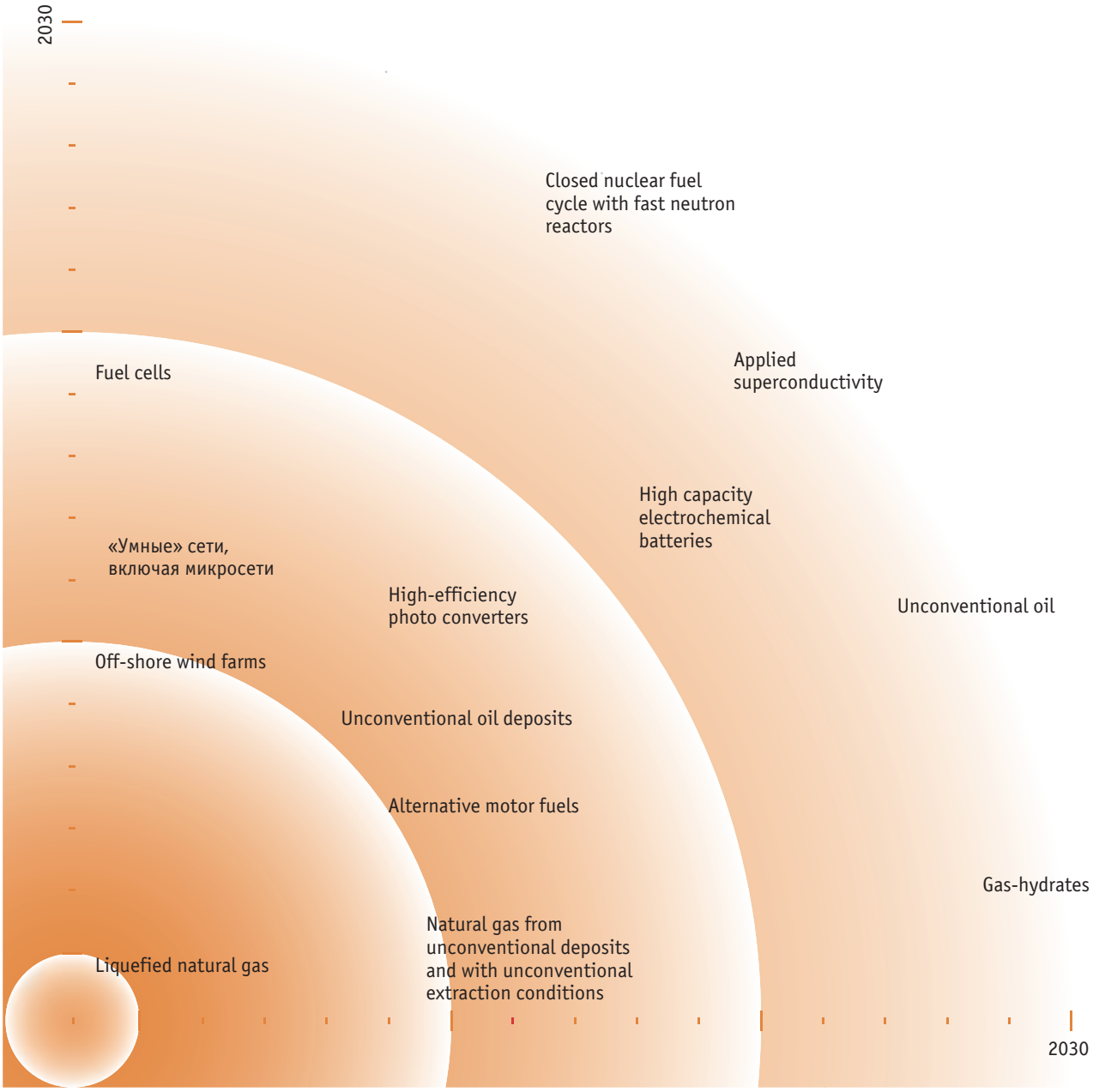
Markets	Groups of innovative products and services	Characteristics
Oil from unconventional deposits and unconventional oil	Heavy (less than 20є API) and super-heavy (less than 10є API) oil Oil sands and bitumen (less than 10є API, high viscosity) Oil extracted from rocks with low permeability (including shale), and liquid hydrocarbons related to the extraction of shale gas Bazhenov formation oil (including kerogen)	Higher production cost value compared with traditional oil cost value More «dirty» extraction technologies compared with those used when extracting traditional oil Expanding extraction volumes and geography Unsuitability of existing pipelines for transportation Processing technologies are in the very early stages
Natural gas from unconventional deposits	Coal methane Shale gas Gas from low permeability rocks Gas from deep bedrock Gas-hydrates Water-dissolved methane	Higher development costs compared with traditional gas deposits Expanding extraction volumes and geography Need to use new methods for transportation, mainly by sea, which increases transportation costs and restricts specific volumes
Liquefied natural gas*	Floating storage regasification units (FRSU) Plants to liquefy gas on-shore, dispatcher terminals, including ports, capacity to store liquefied natural gas, units to load ships (methane tankers) Methane tanker fleet Floating liquefied natural gas plants (FLNG)	Need to create an entire transport infrastructure «from scratch» Appearance of new sources of man-made risks Mobility of shelf gas extraction Mobility of natural gas acceptance and dilution
Alternative motor fuels	Synthetic motor fuel made from natural gas, coal or biomass Hydrogen for power generation in fuel cells used in vehicle engines Electrical energy taken from the grid, in electric cars	Increase in man-made and environmental safety of storage and operation Reduction in production cost value Growth in delivery reliability
Fuel cells	Fuel cells with proton-exchange membranes / with polymer electrolytes Phosphate acid fuel cells Fuel cells with carbon fusion Solid oxide fuel cells	Increased efficiency in converting the chemical energy of a fuel into electricity Small size

(continued)

Markets	Groups of innovative products and services	Characteristics
	Direct methanol fuel cells Other types of fuel cells are at various stages of development, in particular: – those with direct coal oxidation; – microbiological; – reversible, etc.	Increased capacity High cost of platinum used as the catalyst
Long-distance transfer systems for electricity and fuel	Technology for applied superconductivity (high-temperature superconductors) Gas-insulated lines to transmit high power electricity	Low transmission loss Increased transport volumes per time unit Broadened consumption geography
Storage of electricity, heat and cold	Pumped-storage hydroelectric power stations Air-storage units Superconductive magnetic energy storage units Electrochemical batteries	Increased working time and battery power Increased efficiency of energy conversion Increased electricity supply reliability
Prospective nuclear equipment and nuclear power generation	High-power fourth-generation thermal neutron nuclear power reactors Fast neutron nuclear reactors High-temperature nuclear reactors Low power reactors Innovative pressurised water reactor (European Pressurised Water Reactor, EPR) Optimal generating unit control systems for nuclear power plants Nuclear district heating	Improvements in technological and environmental safety Increased volumes of zero carbon energy production
Biofuels	Bioethanol Biodiesel	Reduction in production cost value Improved operating characteristics Increased energy intensity
«Smart» networks	Smart networks as part of a Unified Electricity System of the country Smart mini- and micronetworks based on distributed generation	More effective operations, optimisation and load distribution across the network Reduced need for large-scale capital expenditure on new substations and power lines

* An important factor in the selection of transport method for natural gas is the haul distance. According to assessments by the International Energy Agency, based on modern production capacities, the delivery of liquefied natural gas over distances exceeding 2500–3000 km is more efficient than by pipeline.

Fig. 21. Innovative Products and Services with a Radical Impact on the Dynamics of World Markets in the "Energy Efficiency and Energy Saving" Priority Area



Oil from unconventional deposits includes problematic reserves of hydrocarbon raw materials, in particular traditional (or mobile) oil resources with difficult extraction conditions and immobile (or slow-moving) oil, caused by low porosity of collectors or high molecularity of the hydrocarbons themselves – dense and high-viscosity oils. However, on account of the lower consumer qualities and high costs of extraction, oil supplies from unconventional deposits with unconventional extraction conditions are evaluated only provisionally. The extraction of heavy oils is currently carried out in Canada, Venezuela, the USA and a number of other countries, including Russia, but according to the majority of forecasts, in the next two decades these products will not make a significant contribution to the global oil recovery.

The cost-effective development of *unconventional oil* (heavy oils and bitumen) will make it possible to significantly (by several times) increase the hydrocarbon resource base. At the same time, the extraction of heavy oils is much more polluting from an environmental perspective and is characterized by significant increases in CO_2 emissions as compared with traditional oil extraction. The extraction costs will only be paid back under the conditions of high global oil prices. Thus, heavy oils are coming to be a strategic reserve of liquid fuel to provide energy for developed nations in the event of a crisis.

Natural gas from unconventional deposits with unconventional extraction conditions (shale, water-dissolved, gas from other low-permeability formations and deep beds, coal methane, gas hydrates) is unique for its lower mineral content per unit area and higher development costs compared with traditional reservoirs. Unconventional gas resources are estimated at about 950–1200 trillion m^3 (excluding gas-hydrates and water-dissolved gas, which increase this value considerably) and are more than double the volume of traditional resources.

In recent years the global energy market has seen a significant increase in the role of *liquefied natural gas*. Its main advantage lies in its potential for transcontinental transportation using high-capacity cryogenic tankers. The development of liquefied natural gas has had a serious impact on the globalisation of world gas markets: opportunities have arisen to extract gas in regions where the routing of pipeline systems is not seen to be appropriate. Additionally a number of countries without their own supplies of natural gas and in geographical disadvantageous regions obtain a possibility to bring gas fuels and raw materials into their economies. Increasing share of natural gas in the global energy balance due to substituting oil and coal gives an impetus to the development of these technologies which also lead to reduced CO_2 emissions into the atmosphere.

In Russia there are favourable conditions for the formation and conservation of significant *gas-hydrate* reserves. It should be noted that this build-up of natural methane hydrates has the greatest possible commercial prospects for industrial development, which is currently limited by the high cost of extraction and high technological risks. The development of industrial technology to extract gas-hydrates would contribute to unprecedented increases in gas reserves, capable of satisfying global demand for several centuries into the future. The extraction of methane from new major gas-hydrate deposits could radically change the configuration of the global gas market and the composition of its major players – both producers and buyers. This is due to the fact that large methane hydrate resources are held by countries which import natural gas (for example, Japan). In Russia, the continental resources of gas-hydrates which are the most promising for industrial development are estimated at approximately 400 trillion m^3 and are concentrated in areas along permafrost formations in Eastern Siberia, the Timan-Pechora and Western Siberian oil and gas basins.

Global growth in electrical capacity at wind farms in the period up to 2035 is expected to be approximately 860 GW, 20% of which should come from high-tech sea-based wind farms. These will be built fastest of all; their total power, according to experts, should grow by more than 40 times, which grounds the interest to *off-shore wind farms*. At present wind farms' share of total electricity generation is no more than 1.7%, with the majority only serving as pilot projects. The spread of this type of power plant will make it possible to significantly expand the use of wind's resources and avoid a number of problems related to the development of land-based wind power, such as the inability to use the land for other economic activities, noise pollution, and the influence of strobing, etc. Off-shore wind is more of a "quality" resource for wind energy, as it is characterised by greater average annual speeds and continuity.

Alternative motor fuels are intended to satisfy future demands for liquid fuel and are characterised by acceptable costs, minimal environmental and health impact, and increased reliability of supply to domestic markets. In relation to the expected growth in demand for motor fuel, which in Russia now accounts for at least 80-85% of petroleum product output, this alternative

product could replace an increasing share of fuels derived from crude oil. According to experts, the likelihood of such fuels competing with traditional fuels after 2020 is high.

Fuel cells are also potential avenues for development in environmentally-friendly energy. The development of devices offering direct conversion of a fuel's chemical energy into electricity has for several decades laid claim to the role of a breakthrough technology capable of completely revolutionising the energy sector. The achievements of recent years have brought this technology close to the stage of mass commercial adoption and have regained interest from energy companies. Three main types of fuel cells use are being considered: stationary energy (electricity generation, cogeneration, uninterruptible power supply units); transport energy (power sources in electric vehicles, trucks, military equipment, spacecraft, etc.); portable energy (power sources in mobile devices, battery chargers, etc.). The key strengths of fuel cells are considered to be their high efficiency factor (60–80%) and small size. Shortfalls include the lack of infrastructure for charging and the high cost of platinum which is used as a catalyst.

In the near future, solar energy will be based primarily on the use of various types of *highly-effective photoconverters*. One of its key advantages is the ability for end users to generate electricity directly, which makes it possible to save on the development of the electricity networks. Currently new promising photoconverters are being actively developed. The technology previews using the full spectrum of solar radiation, characterized by high efficiency factor and long life. Photovoltaic power sources are used to supply power to consumers across a broad power spectrum: from several watts (mini-generators for watches and calculators) to several megawatts (power stations). One key use of photovoltaic converters is in various types of solar arrays; transport and aviation applications for solar arrays are currently under development.

Electrochemical batteries to store electricity (accumulators) have seen widespread use in many sectors, primarily for mobile devices and on transport, as well as in stationary units – to provide an uninterrupted supply to important devices (communications, computer equipment, etc.). *High capacity electrochemical batteries*, used in the energy sector for relatively long-term storage of electricity, could play an important role in distributed generation systems to provide an operational reserve and stabilise the electrophysical parameters of local power systems, including regulating the frequency and voltage. The use of next-generation electrochemical batteries will make it possible to increase the competitiveness of renewable energy sources and to practically implement the distributed generation concept – increasing the load and efficiency of traditional electricity generation units through the opportunity to store energy, increasing the quality of the electricity supply to end consumers, reducing electricity loss in the power grids, cutting development and operating costs for trunk power lines, storing electricity and creating an operational power reserve directly at consumers' location.

The development of *"smart" networks, including micro-networks*, is aimed at reducing the cost of electricity and creating power reserves directly at end consumers' location. The result of further improvements to this technology should be an increase in the reliability and security of power supplies, higher levels of technological processes' computerization, the introduction of digital technologies and microprocessor equipment into monitoring and control systems, and reductions in operating costs. Demand for these technologies and equipment in Russia is relatively high, due to the need for large-scale renovation of Russia's electrical energy sector. The growth in global demand for electrical equipment also creates high export potential.

One of the limitations for modern nuclear energy with an open nuclear fuel cycle and thermal neutron reactors is the significant and ever growing amount of stored irradiated nuclear fuel. Moreover, these technologies do not make it fully possible to use the energy stored in nuclear energy resources, as more than 90% of extracted uranium remains in enrichment plant heaps, and the effectiveness of the fuel's use in hot water reactors is low. An integrated solution to existing problems is possible by concentrating efforts and resources to develop next-generation nuclear energy based on *fast neutron reactors with a closed nuclear fuel cycle*. This is

a set of connected technological solutions, capable of guaranteeing extended reproduction of fissile nuclear material together with generating electricity while minimizing radioactive load on the environment across all technological conversion stages and, thus, having a revolutionary impact on the global nuclear energy market. A further benefit of the closed nuclear fuel cycle is the ability to use fast neutron reactors to solve the historically inherited problem of accumulating nuclear waste. This innovative technology is fundamentally different from existing ones due to the lack of the two key expensive technological conversion processes – uranium extraction and enrichment – and the existence of a technologically new conversion process – the multifold refabrication of the nuclear fuel which is combined with the immobilisation and final isolation of the high-level radioactive waste.

One of the most promising innovative directions to increase energy efficiency is *applied superconductivity* technology, namely the integrated development and establishment of production of a wide range of electro-technical equipment based on the latest technologies with the use of unique materials – high-temperature superconductors. In the commercial energy sector, the use of superconductors is particularly attractive in terms of creating cables and power engineering and electricity storage (inductive capacitors). Superconductive cables, on account of their extremely low energy loss, are able to display a higher level of energy-efficiency in networks, creating fundamentally new conditions to manage generation facilities and to export electricity. Superconductive energy storage technologies will smooth out peak loads and align voltage and current, offsetting electricity supply in the event of network incidents, which will make it possible to negate the varying nature of alternative generation. Electro-technical equipment and power units based on superconductivity are designed to increase efficiency on rail and sea transport, in the energy sector, in the oil and gas industry, in the manufacturing sector, and others. Maximum results can be obtained by combining these with smart grid technologies. Russian developments in high-temperature superconductors are at various stages, from basic research to operational testing of prototypes of various forms of superconductor equipment. Forecasts of the Russian superconductor electrical equipment market are very optimistic and reflect its high potential and opportunities for long term growth. It is expected that the production volumes of various types of equipment (storage (5–20 MJ), current limiters (3–35 kW), generators (5–35 MW), electric motors (5–35 MW), synchronous compensators (5–35 MW), cables (1 km, 20 kW, 2 kA), transformers, etc.) will account for 36.5 billion roubles by 2020.

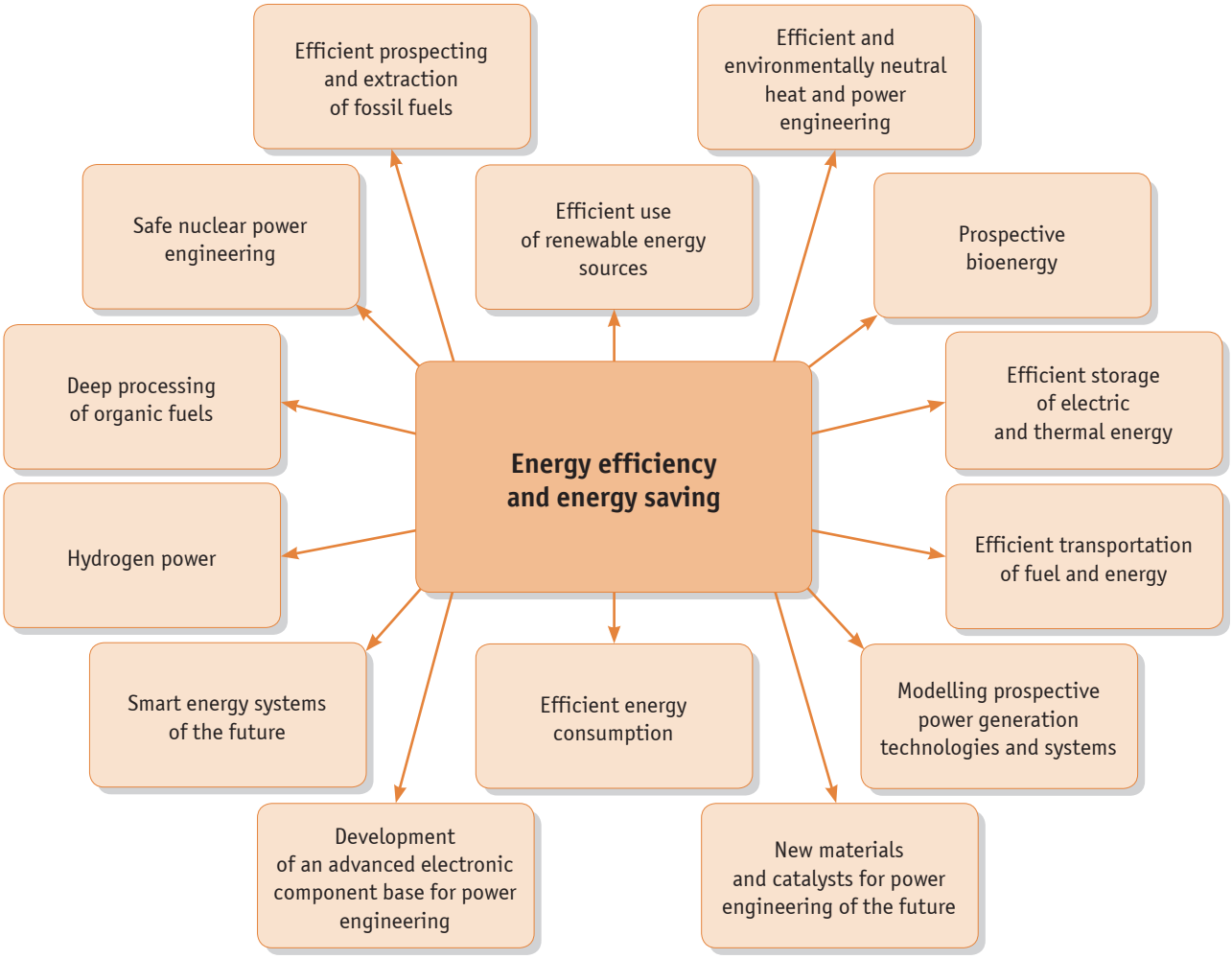
These areas will contribute to the radical transformation of traditional markets and will create considerable opportunities for the emergence of new ones. Experts have noted the following prospective and attractive segments for Russia: storage of electricity, heat and cold; unconventional oil markets; sale of equipment for renewable energy, fuel cells and bioenergy technologies.

For those products which may have a radical impact on the global markets in the long term, key Russian and foreign centres undertaking research and development in these directions have been identified. Among the leaders in this field are organisations from the USA, the EU (primarily, France, Germany, United Kingdom and Norway), China and Japan.

7.3. Promising Research Areas

Having reviewed the key prospective markets for the priority direction “Energy Efficiency and Energy Saving”, as well as the most innovative products and services singled out from each of these markets which are likely to appear in the period up to 2030, we will proceed to analyse the existing Russian scientific and technological groundwork in these fields. Fourteen thematic areas of applied research with the greatest potential have been identified for Russia (fig. 22).

Fig. 22. Thematic Fields of the "Energy Efficiency and Energy Saving" Priority Area



Regarding fossil fuel production, among the most important research and development areas there are robotic installations for submarine and subterranean hydrocarbon production, remotely controlled and with prolonged automated operation periods; and the development of technologies for efficient hydrocarbon production at unconventional sites (including gas hydrates, oil sands, extra-heavy crude oil, shale gas, coal strata gas) and under anomalous conditions (dense formations, abnormally high pressure, ultra-deep horizons, large depths, low volume density of resources, etc.). Technologies for deep processing of off-grade natural gas and low-grade coal resources to produce competitive motor fuels and chemical products are also being actively developed.

Thermal power engineering will develop along the line of materials and technologies used to create highly-mobile high power gas turbine units with maximum efficiency ratings and minimum harmful substance emissions which in the long term will serve as a key high-power energy base. Intensive research into safe fast neutron and closed cycle nuclear reactors – an important element of centralised energy supplies – is continuing. The development of low power energy is linked to the creation of low-temperature fuel cells with maximum efficiency and long operational life, which do not have special requirements for quality fuel and which have low acquisition and ownership costs.

Regarding renewable energy, the range of research topics being pursued is quite wide: designing inexpensive photoelectric converters with maximum efficiency factor and long opera-

tional life, utilising the full solar radiation spectrum; development of technologies for high-capacity marine wind power, to ensure reliable operation of deep-water far-from-shore units; and development of high-performance hydrogen production technologies based on photochemical and electrolytic water decomposition. As regards distributed energy generation from renewable sources, high-capacity and high-power low cost energy storage technologies are coming to be of critical importance. Bioenergy plays an important role as it is becoming a new segment of the industry which has been developing taking into account the need to protect the environment and to prevent climate change.

The development of energy saving technologies and equipment remains among the major trends of power engineering. A new impetus to the energy-saving problem should come from research aimed to create smart local electrical energy systems with automated real-time management of energy consumption based on integrating electrical and information networks.

Expert assessments of the level of research in Russia in the field of energy efficiency and energy saving vary considerably: from "blank spots" in fields such as gasification of next-generation solid fuels and technologies of energy equipment remote control to recognition of significant groundwork comparable to global developments (in particular, in safe fast neutron reactors and technologies to extract certain types of untraditional hydrocarbon resources).

Efficient Prospecting and Extraction of Fossil Fuels

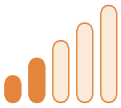
Expected results of future research:

- Promising environmentally safe fossil fuel prospecting and production technologies offering high recovery rates.

Table 41. Promising Research Areas in "Efficient Prospecting and Extraction of Fossil Fuels"

Research areas	R&D Level	R&D priorities
Promising seismic prospecting technologies		Development of 4D hydrocarbons prospecting technologies offering high-resolution visualisation of results Development of 3D/4D technologies for prospecting of marine hydrocarbon sites, based on submarine autonomous self-targeting devices and GPS/GLONASS navigation, including for polar environments Creation of sensors and multichannel receivers for submarine hydrocarbon prospecting Development of software to collect and analyse large geological exploration data arrays, based on supercomputers
Prospective oil and gas production technologies		Development of smart hydrocarbon site concept, and tools required for its implementation Building submarine robotic extraction units with long service lives, for automatic operation and remote control Development of equipment and tools for ongoing monitoring of oil and gas field collectors, with high-resolution computer processing of the collected data and 4D visualisation of results Development of technologies to make ice-resistant anti-seismic platforms for hydrocarbon production in the Arctic

(continued)

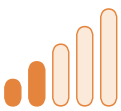
Research areas	R&D Level	R&D priorities
		Development of technologies for drilling, casing perforation, including low permeability formations, and new types of drilling fluids, including polymer-based ones
		Development of new secondary and tertiary techniques to stimulate production of hydrocarbons, including high viscosity ones
		Development of technologies to produce hydrocarbons from unconventional sites (gas hydrates, oil sands, high viscosity oil, shale gas, coal strata gas) and under anomalous conditions (dense formations, abnormally high pressure, ultra-deep horizons, large depths, low volume density of resources, etc.)
Prospective coal mining technologies		Development of new technologies for geological exploration of coal sites, new software and techniques for mathematical modelling of mines' geophysical states
		Development of robotic technologies for highly selective subterranean coal mining
		Development of borehole coal recovery technologies, including subterranean gasification and hydraulic mining
		Development of efficient technologies for degassing of coal formations, with production of coal methane
		Development of instruments to support efficient and safe mining, including mining georadars, equipment for ongoing chemical monitoring of mine atmospheres, etc.

Efficient and Environmentally Neutral Heat and Power Engineering

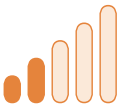
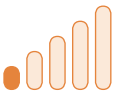
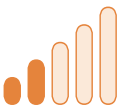
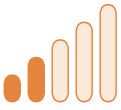
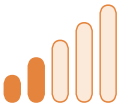
Expected results of future research:

- Next-generation organic fuel, environment and climate friendly heat and power units, with close to maximum efficiency factors and high performance figures.

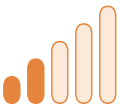
Table 42. Promising Research Areas in "Efficient and Environmentally Neutral Heat and Power Engineering"

Research areas	R&D Level	R&D priorities
Prospective high-performance natural gas heat and power units		Selecting optimal heat schemes and parameters for natural gas heat and power units with complex thermodynamic cycles and high initial working substance parameters
		Development of highly flexible high-power gas-turbine units with maximum efficiency factor and minimum pollutant emissions

(continued)

Research areas	R&D Level	R&D priorities
		Development of medium- and low-power gas turbine solutions, including high-speed ones, for application as part of cogeneration units Development of efficient systems for automatic processes and power management of complex natural-gas heat and power units
High-performance environmentally- and climate-safe solid-fuel heat and power installations		Development of prospective solid-fuel steam-turbine installations with ultra-high steam parameters (720–750 °C, 35 MPa) Development of steam-gas installations with intra-cycle solid fuel gasification Development of new high-performance reliable technologies for solid fuel gasification Development of hybrid gas and steam cycle power plants integrating fuel cells based on solid fuel gas and vapour cycle gasification products Development of efficient systems for automatic operation of complex solid-fuel heat and power installations, including algorithms and techniques for diagnosing equipment states and robustness, water-chemical regime, engineering and operating data
Prospective low-temperature cycle heat and power installations		Development of new types of low-temperature cycle heat and power installations, optimisation of their technological modes and parameters Selecting prospective working substances for low-temperature Rankine cycle heat and power installations; substantiating optimal technological solutions for mainline equipment
New types of piston technology electric power plants		Development of new types of external combustion engines to produce energy from low-quality fuels Development of new types of internal combustion engines for stationary cogeneration plants, including working on solid fuel gasification products Development of new types of steam engines for cogeneration plants
New technologies for direct conversion of organic fuel's chemical energy into electricity, with high efficiency factor and long service life		Development of new types of low-temperature high-performance fuel cells with minimum fuel quality requirements Development of new types of high-temperature maximum efficiency fuel cells Development of new types of fuel cells with direct oxidation of organic fuel
New technologies for environmentally neutral burning of organic fuels and combustible waste		Development of new organic fuel burning technologies, with minimum emissions of harmful substances Development of environmentally safe technologies for burning combustible waste, including domestic waste, and including using a multi-stage scheme with prior gasification, e.g. plasma gasification

(continued)

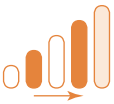
Research areas	R&D Level	R&D priorities
		Studying catalytic oxidation processes of organic fuels in various aggregate states Preparing science and technology proposals on the development of organic fuel oxidation technologies in chemical cycles
High-performance technologies to separate and purify gaseous mixtures and liquids, for prospective power generation and energy technology plants		Development of high-performance technologies to purify combustion gases from sulphur and nitrogen oxides, and solid particles Development of efficient technologies to separate CO_2 from combustion gases and producer gas Development of technologies for integrated purification of combustion gases generated by combustible waste burning plants from harmful substances, including heavy metals, polyaromatic hydrocarbons, etc Development of efficient air separation technologies for application in prospective power plants Development of new water and liquid waste treatment technologies for application in prospective power plants

Safe Nuclear Power Engineering

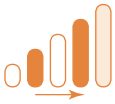
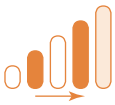
Expected results of future research:

- Safe nuclear power plants and efficient fuel cycle.

Table 43. Promising Research Areas in "Safe Nuclear Power Engineering"

Research areas	R&D Level	R&D Priorities
High-power fourth-generation water-cooled power reactor		Development of technology and equipment for fourth-generation water-cooled power reactors with increased safety and performance, capable of operating in a manoeuvrable regime Research to increase the efficiency factor of nuclear power plants by increasing average cycle temperature, optimising the plant's thermal scheme, and improving mainline and secondary equipment Research to increase nuclear plant efficiency, by increasing equipment reliability, extending use of fuel, reducing investments in nuclear power plant construction, and reducing running costs
Increased-safety fast reactors		Development of technology and equipment for various types of increased-safety fast reactors Development of mathematical models for fast reactors and power plants based on them

(continued)

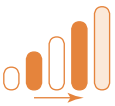
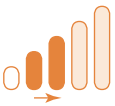
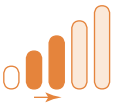
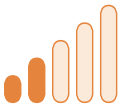
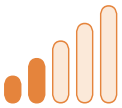
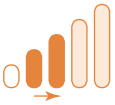
Research areas	R&D Level	R&D Priorities
		Assessing long-term prospects, scale, and economic efficiency of fast nuclear reactors Development of optimal structure for fuel supply of nuclear power plants based on fast reactors Research aimed at minimising the threat of fissionable material proliferation
High-temperature nuclear reactors and relevant infrastructure for them		Development of technology and equipment for increased-safety high-temperature nuclear reactors of various types Development of large-scale energy technology complexes of various functionality, based on high-temperature nuclear reactors Assessment of the economic efficiency of high-temperature nuclear reactors, and identification of more efficient application areas for them
Safe and efficient low- and medium-power nuclear reactors		Development of technology and equipment for safe and efficient low- and medium-power nuclear reactors and nuclear power plants based on them, including transportable and floating nuclear power plants Discovering best application areas for low- and medium-power nuclear reactors, assessing their economic efficiency, and research into optimising logistical shemes for their production and use
New technologies to close the nuclear fuel cycle		Development of new nuclear fuel production technologies (MOX fuel, dense fuel, cermet fuel, microfuel, etc.) Development of new technologies for recycling nuclear waste ("dry" recycling, fractionating, etc.), improving "wet" processing technologies, and creation of a safe system to treat irradiated waste Optimising the technological structure of closed nuclear fuel cycle of increased safety and efficiency
Optimising the structure of the nuclear power industry		Defining the optimal structure for the national nuclear power industry, to ensure nuclear and radiation safety and guarantee non-proliferation across all elements of the civilian nuclear complex, and at all stages of the nuclear plant life cycle – from uranium mining to disposal of nuclear waste Development of optimisation models for the country's nuclear power industry and relevant mathematical models
Basic technologies of controlled nuclear fusion for power generation purposes		Development of reliable technology for controlled nuclear fusion in industrial-scale reactors Development of equipment for industrial fusion reactors Optimising the technological scheme and parameters for industrial fusion power plants

Efficient Use of Renewable Energy Sources

Expected results of future research:

- prospective technologies for the application of sustainable energy, and development of a new power generation industry in the country.

Table 44. Promising Research Areas in "Efficient Use of Renewable Energy Sources"

Research areas	R&D Level	R&D Priorities
Prospective converters of solar energy into electricity		Development of solar converters with high efficiency factors and long service lives; utilisation of full solar radiation spectrum Development of direct solar radiation heat and power generation plants; selection of promising working substances; optimisation of solar power plant thermal schemes and parameters Development of solar energy concentration systems
Prospective solar collectors		Development of liquid heat carrier solar collectors; selection of promising heat carriers Development of gaseous heat carrier solar collectors, and heat supplying systems based on them
Prospective converters of wind energy into electricity		Development of wind-powered engines Development of technologies for marine wind-power engineering, to ensure long and reliable operation of power installations at great depths and long distances from shore Development of optimal automated operation systems for wind power plants Research to improve techniques to measure wind potential and forecast wind parameters
New hydroelectricity technologies		Development of efficient technologies to convert water flow mechanical energy into electricity Development of new technologies to monitor power plant equipment and hydraulic facilities
New technologies to convert the mechanical energy of the marine environment into electricity		Development of technologies to convert tidal energy into electricity, with minimum environmental impact Development of technologies to convert wave energy into electricity
Prospective technologies to use the low-potential heat of the natural environment		Development of binary technologies to use geothermal energy; discovering highly efficient working substances; optimising thermal schemes and parameters of binary installations; minimising negative environmental impact Development of efficient technologies to extract heat from large-depth dry rock, and deliver it to the surface with minimum losses and low hydraulic resistance

(continued)

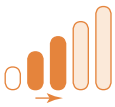
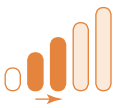
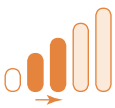
Research areas	R&D Level	R&D Priorities
		Development of new economically efficient deep-hole rock drilling technologies; increasing their heat carrier permeability Creation of heat pumps of different varieties with the use of new working mediums, thermodynamic cycles, and technical principles and schema

Prospective Bioenergy

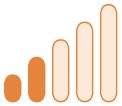
Expected results of future research:

- prospective technologies for the production and efficient use of energy biomasses, direct motor fuel production from CO_2 and the development of a new power generation industry in the country.

Table 45. Promising Research Areas in "Prospective Bioenergy"

Research areas	R&D Level	R&D Priorities
Prospective technologies for energy biomass production		Development of technologies to grow cultures with high biomass yield and low resource requirements (e.g. soil quality, water and fertiliser consumption) Development of new technologies to grow aquacultures with high biomass yield; production of highly efficient micro-organisms Development of technologies to use CO_2 power plants with biomass production Development of biomass production technologies based on artificial photosynthesis
Prospective energy biomass processing technologies		Development of efficient biochemical production from various vegetable raw materials, based on bioengineering advances and including production of highly efficient microorganisms Development of new liquid motor fuel production technologies, including aircraft kerosene and components, from vegetable raw materials Development of new biomass processing technologies to make high value added chemical products (plastics etc.) Development of new biomass processing technologies to produce high-quality solid fuels
Prospective technologies for biomass application for energy-related purposes		Development of biomass burning technologies, and power plants based on them Development of environmentally safe biomass gasification technologies, and electric power installations based on them

(continued)

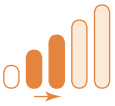
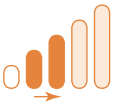
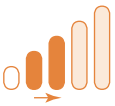
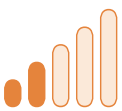
Research areas	R&D Level	R&D Priorities
New biotechnologies to produce motor fuels from CO_2 without using photosynthesis		Development of novel biochemical techniques to produce high-quality motor fuels from CO_2, which do not involve application of photosynthetic processes Creation of new types of environmentally safe genetically modified micro-organisms efficiently producing motor fuel components by fixing CO_2 from gaseous mixtures, with external power supply

Deep Processing of Organic Fuels

Expected results of future research:

- discovering optimal ways to increase the efficiency of using organic fossil fuels produced in the country;
- corresponding scientific and technological research necessary to develop advanced technologies, which would allow a significant increase in added value created by fuel production industries, and the country's export potential.

Table 46. Promising Research Areas in "Deep Processing of Organic Fuels"

Research areas	R&D Level	R&D Priorities
New technologies for deep processing of oil and gas condensate		Development of new technologies to maximise the depth of processing hydrocarbon raw materials, achieving high quality end products Optimising the technological schemes and parameters of oil refineries to maximise energy efficiency and minimise negative environmental impact
Efficient technologies to use associated petroleum gas		Development of prospective equipment to process associated petroleum gas, reliable, compact, and highly automated, for application in remote areas with harsh climates
New technologies for deep processing of natural gas, to produce liquid motor fuels and a wide range of chemical products		Research to achieve more integrated utilisation and deeper processing of natural gas and associated resources Development of new production technologies for high-quality motor fuels from natural gas Development of new production technologies for chemical products (polymers etc.) from natural gas
Prospective technologies for deep processing of solid fuels, with integrated use of mineral components		Development of new solid fuel gasification technologies to produce synthetic gas; selecting optimal parameters and designs for mainline equipment Development of new solid fuel hydrogenation and pyrolysis technologies; selecting optimal parameters and designs for mainline equipment

(continued)

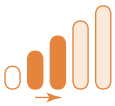
Research areas	R&D Level	R&D Priorities
		Development of production technologies to make a wide range of products from synthetic gas; selecting optimal parameters and designs for mainline equipment
		Development of optimal technological schemes for energy technology installations based on deep processing of solid fuels, to produce high-quality fuels, electricity and chemical products
		Research to achieve more integrated utilisation and deeper processing of solid fuels, by extracting valuable elements from the mineral component, and disposing of the ashes
		Development of mathematical models to optimise technological schemes and parameters of prospective solid fuel processing technologies
		Studying the long-term prospects of large-scale processing of solid organic fuels, and assessing their effects over energy markets

Efficient Storage of Electric and Thermal Energy

Expected results of future research:

- prospective electric and thermal energy storage technologies for application in electric power and heating supply systems (for "grid" consumption) and for individual consumers.

Table 47. Promising Research Areas in "Efficient Storage of Electric and Thermal Energy"

Research areas	R&D Level	R&D Priorities
Prospective high-capacity electricity storage systems, including seasonal and daily accumulation		Development of high-capacity high-power electrochemical batteries, extra-safe, supporting a large number of charge-discharge cycles, and with low energy losses during storage
		Development of high-performance super-condensers
		Development of mechanical (kinetic) electricity storage systems
		Development of efficient electricity storage technologies based on compressed air energy storage installations, including ones using adiabatic compressors
		Development of superconductive inductive electricity storage systems
		Development of effective ways to accumulate electrical energy using the basis of cryogenic technologies

(continued)

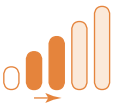
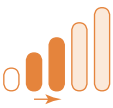
Research areas	R&D Level	R&D Priorities
Thermal energy storage technology, including seasonal and daily storage		Development of liquid-based thermal energy storage systems Development of solid-state thermal energy storage systems Development of thermal energy storage systems based on phase transition

Hydrogen Power

Expected results of future research:

- prospective technologies for the production, storage and use of hydrogen to support the large-scale shift to hydrogen-based power engineering.

Table 48. Promising Research Areas in "Hydrogen Power"

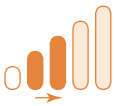
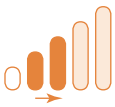
Research areas	R&D Level	R&D Priorities
Prospective technologies for large-scale hydrogen production		Development of new water electrolysis technologies Development of new thermochemical water decomposition technologies, including based on high-temperature nuclear reactor heat Development of new high-performance technologies for large-scale hydrogen production based on organic fuels Development of new technologies for efficient conversion of organic fuels into hydrogen, at fuel cells-based power plants Development of hydrogen production technologies based on photochemical water decomposition
New technologies for safe hydrogen storage		Development of new technologies for safe high-pressure storage of gaseous hydrogen Development of new cryogenic technologies for liquid hydrogen storage Development of new technologies for bound hydrogen storage
Prospective technologies for efficient hydrogen use		Development of new types of safe, high-performance stationary hydrogen power plants Development of new hydrogen-based technologies to meet peak electricity grid loads Development of new safe high-performance technologies for use of hydrogen in mobile device power supply units

Efficient Transportation of Fuel and Energy

Expected results of future research:

- prospective technologies for long-distance fuel and energy transportation.

Table 49. Promising Research Areas in "Efficient Transportation of Fuel and Energy"

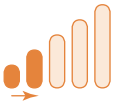
Research areas	R&D Level	R&D Priorities
Prospective long-distance electric energy transfer technologies		Research to increase the efficiency of long-distance alternating current electric energy transfer technologies Development of technologies and equipment for high-performance long-distance direct current electric energy transfer Development of technologies and equipment for electric energy transfer based on high-temperature superconductivity Development of radically new long-distance electric energy transfer technologies
New high-performance natural gas transportation technologies		Development of new high-performance long distance natural gas transportation technologies; new techniques for reducing hydraulic resistance of pipelines, and for increasing efficiency of compressing technologies Development of new technologies for production and safe transportation of liquefied natural gas by ground and marine transport
New technologies for safe and efficient transportation of hydrogen		Development of new technologies for safe and efficient long distance transportation of gaseous hydrogen Development of new technologies for safe and efficient long distance transportation of liquid hydrogen

Smart Energy Systems of the Future

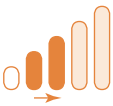
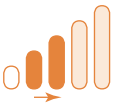
Expected results of future research:

- radical improvement of control systems, the reliability and performance of major power generation systems: electricity generation, gas transportation, and centralised heating supply.

Table 50. Promising Research Areas in "Smart Energy Systems of the Future"

Research areas	R&D Level	R&D Priorities
Smart power, heating and gas supply systems; integration of various distributed energy generation resources and tools		Development of smart power, heating, and gas supply systems with complex functionality and modes, for active consumers Development of new schematic, technological and management solutions for integration of various kinds of energy resources, technologies and energy storage systems

(continued)

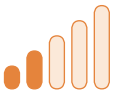
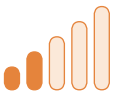
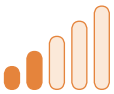
Research areas	R&D Level	R&D Priorities
		Development of scientific and technological proposals for efficient integration of distributed electricity generation systems, including electric vehicles, to reduce power requirements (peak time and regular demand), ensure adequate reliability and quality of power supply; development of district virtual power plant concept
Physical demonstration of smart technologies, monitoring and diagnostic tools for real-time remote control of complex power generation system equipment and operating modes		Development of new smart technologies, monitoring and diagnostic tools for power generation system equipment Development of new technologies, techniques and automated control tools for equipment and operating modes of complex power generation systems, smart systems, and technical dispatching tools Development of mathematical methods for optimisation of standard and emergency operating modes of complex power systems Development of new tools for optimised control of complex centralised heating supply systems with distributed heating sources and regulating devices, including mathematical methods and computer systems to optimise hydraulic and thermal modes of complex heating networks Development and demonstration of principles, techniques and technologies for real-time automatic control of end-user electricity consumption according to economic criteria, based on integration of electric and information networks; development of EnerNet concept
New techniques and tools to ensure optimum reliability and safety of smart energy systems, including in emergencies		Development of concept and modelling tools to ensure the reliability and safety of smart energy systems and installations in critical and emergency situations Development of concept and modelling tools for risk management at critical and potentially dangerous elements of energy infrastructure, to prevent crises and emergencies, or to mitigate their after-effects Development of mathematical models for possible accidents at various energy installations, and relevant software Development of methodology and computational tools for assessment of crisis and emergency after-effects in energy infrastructure

Efficient Energy Consumption

Expected results of future research:

- new technologies, tools and control techniques to significantly reduce end user energy loss, primarily in power-hungry industries (metallurgy, chemical industry, mechanical engineering, transport, etc.) and in housing, communal services and social sectors.

Table 51. Promising Research Areas in "Efficient Energy Consumption"

Research areas	R&D Level	R&D Priorities
Increasing the energy efficiency of power-hungry industries		Development of new energy-efficient technologies for mainline operations in power-hungry industries Development of new technologies designed to minimise production waste and maximise its recovery Development of scientific and technological proposals to extend the application of prospective electro-physical and electro-chemical technologies in the economy Development of scientific and technological proposals to increase the economy's energy efficiency by using more durable materials, objects, devices and equipment
Low energy consumption buildings		Development of novel architectural solutions, design and construction technologies to build minimum energy consumption buildings Development of new types of barriers, including transparent ones, with maximum heat insulation properties; application of vacuum technologies for heat insulation Development of new high-performance energy-efficient ventilation emission heat recovery technologies Development of new high-performance heating and ventilation systems for housing, public and industrial buildings Development of new techniques to reduce building pipeline hydraulic resistance, corrosion and scaling, and cleaning techniques for them
High-performance electrical equipment and control systems for it		Development of new types of electric motors, including based on superconductive materials Development of new electric drive control technologies and systems Development of high-performance transformers and electric switchgear
Novel light sources and smart lighting systems		Development of novel light sources with high luminous efficacy New lighting systems and lighting mode control tools, including based on luminance and motion sensors
Smart energy consumption control systems for technological processes and buildings		Development of smart energy consumption control systems for technological processes Development of smart integrated energy consumption control systems for buildings, taking into account actual climatic conditions

(continued)

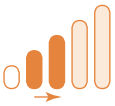
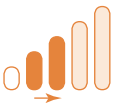
Research areas	R&D Level	R&D Priorities
		Development of new technologies and hardware/software solutions for remote control of production processes and equipment, consumer appliances and in-house systems, based on mobile communication and information networks, for energy saving and security purposes («smart house»)
Intensification of heat- and mass exchange processes		Development of new techniques to intensify heat- and mass exchange processes in energy generating and consuming installations, for energy saving purposes

Modelling Prospective Power Generation Technologies and Systems

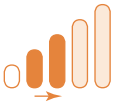
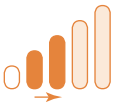
Expected results of future research:

- new techniques, mathematical models, and computational tools for system analysis of prospective energy-generating technologies, optimal management of development and operation of large-scale power engineering systems, achieving adequate reliability and safety of their operation; analysis and forecasting of global energy system and energy market development trends;
- timely detection of emerging major technological trends in global power engineering; forecasting development and application of major innovative energy-related technologies;
- preparing reliable forecasts of external demand for Russian primary and secondary energy resources, for development and timely adjustment of optimal long-term strategy for Russia's behaviour on external energy markets.

Table 52. Promising Research Areas in "Modelling Prospective Power Generation Technologies and Systems"

Research areas	R&D Level	R&D Priorities
Modelling physical and chemical processes in power plants		Development of novel techniques and technologies for thermodynamic modelling of matter and energy conversion processes in multicomponent systems, including with external effects and under extreme conditions Development of novel kinetic modelling techniques for chemical processes taking place in power plants, including fast ones Development of novel techniques for modelling heat- and mass exchange processes, to develop prospective power generating installations
Modelling and optimising prospective power generation installation schemes and parameters		Development of novel mathematical modelling techniques for emergency processes in power plants Development of new mathematical modelling methods of emergency processes in power stations

(continued)

Research areas	R&D Level	R&D Priorities
New techniques and tools for system analysis of prospective energy technologies		Development of new techniques and tools for system analysis of prospective energy technologies, taking into account their life cycle Development of new techniques and multiplicative effect measurement tools for assessing long-term prospects of energy technology development Development of new techniques and ambiguity and risk measurement tools for system analysis of energy technologies Development of scientific and technological proposals to create national system for forecasting scientific and technological progress in the energy industry
Modelling the development and operation of energy systems		Development of novel mathematical techniques for modelling the operation and development of national and regional fuel and energy complex Development of novel mathematical techniques for modelling the operation and development of electric energy systems, based on simulation, optimisation, and multi-agent modelling Development of novel mathematical techniques for modelling the operation and development of pipeline systems (gas-, oil-, and heating supply)
Modelling the global energy industry and energy markets		Development of new-generation optimisation, multi-regional and dynamic models for global energy system Development of models for world energy markets (oil and oil products, natural gas, coal), with a regional breakdown

Development of an Advanced Electronic Component Base for Power Engineering

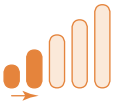
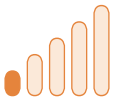
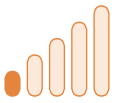
Expected results of future research:

- advanced Russian element base for power and low-current electronics for use in smart energy systems, prospective energy generation and energy saving technologies.

Table 53. Promising Research Areas in "Development of an Advanced Electronic Component Base for Power Engineering"

Research areas	R&D Level	R&D Priorities
New-generation power electronics		Development of new-generation smart high-power semiconductor devices for application in power engineering

(continued)

Research areas	R&D Level	R&D Priorities
New-generation instrumentation devices and automatic control tools		Development of highly sensitive instrumentation devices including temperature, pressure and flow sensors Development of prospective automatic control systems for energy-saving technologies Development of novel technological solutions for safe exploitation of prospective energy equipment Development of new instrumentation devices to monitor generating equipment at power plants, and hydraulic facilities
New-generation microprocessor devices for use in power engineering		Development of microprocessor devices for application in smart energy systems and installations, automatic electricity, heating and gas consumption control systems
Technologies and tools for remote control of energy equipment		Development of new technologies and hardware/software solutions for remote control of production processes and consumer appliances, based on mobile communication and the Internet Development of wireless interfaces and element base for them, for application in power engineering

New Materials and Catalysts for Power Engineering of the Future

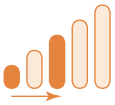
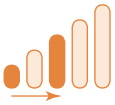
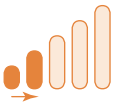
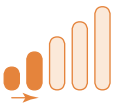
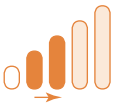
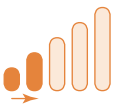
Expected results of future research:

- new materials for new-generation prospective energy production, consumption, and transport technologies and systems.

Table 54. Promising Research Areas in "New Materials and Catalysts for Power Engineering of the Future"

Research areas	R&D Level	R&D Priorities
New construction materials and coatings		Development of new construction materials and coatings (thermal barrier, anti-erosion, anti-corrosion), retaining their functionality in extremely high temperatures and high dynamic load, for making powerful gas turbines with long service life under variable load, with large and rapidly changing amplitudes Development of new materials and coatings for windmill blades, and technologies for their processing and application Development of new materials and coatings with high absorbing capacity and long service life, for making solar collectors Development of new coatings with high reflective capacity and long service life, for making solar concentrators

(continued)

Research areas	R&D Level	R&D Priorities
New heat-resistant materials		Development of new heat-resistant materials for application under high pressure in dusty high-temperature gaseous environments, to make solid-fuel heat-and-power installations with ultra-high steam parameters
New radiation-resistant materials		Development of new highly radiation-resistant materials capable of retaining their functionality for a long time in reactor cores, to enable reliable and safe operation of nuclear power plants for at least 60 years Development of new materials capable of retaining their functionality for a long time in gas-cooled nuclear reactor cores Development of new materials for fusion reactors
New electrically conductive and electrically insulating materials		Development of new high-performance electrically conductive and electrically insulating materials, for prospective power engineering systems and electrical equipment Development of superconductive materials suitable for industrial power engineering application Development of new materials for photo-converters
Heat-shielding and heat-insulating materials		Development of new heat-shielding and heat-insulating materials with high thermal resistance and improved properties, for application in prospective power generating installations, and for energy saving
New functional pipeline coatings		Development of new functional coatings with low hardness-salts adhesion, low roughness, and high anti-corrosion properties, to increase service life of heating networks and reduce their hydraulic resistance
New membrane materials with specified pore size		Development of new membrane materials with adjustable pore size, for prospective gas and liquid separation technologies Development of new membrane materials and conductive structures for electrochemical generators and batteries
New catalyst types		Discovering new catalysts, with high selectivity, long service life and acceptable production costs, to increase the depth of hydrocarbon raw material processing and improve quality of produced motor fuels Development of new catalyst types to make motor fuels and a wide range of synthetic gas-based chemical products

RECOMMENDATIONS ON USE OF THE RESULTS

Russia 2030: Science and Technology Foresight (RSTF) is one of the most important documents in the government strategic planning system, aimed at providing methodological, data, expert and analytical support for corresponding administrative decision-making in the field of science, technology and innovation policies. The basis for this task is the setting national priorities of science and technology development.

The results of the Foresight study are multifaceted – the most promising science and technology areas for Russia have been identified alongside prospective markets and product groups in which the results of the research and development could find application.

Accordingly, the conclusions and recommendations of the RSTF can be used by various interested parties for different purposes:

- federal executive bodies – when developing, implementing and adjusting sector-specific strategic planning documents and state programmes of the Russian Federation, including special federal programmes relating to science and technology;
- large public-owned companies implementing innovative development programmes; technology platforms; innovative regional clusters – when implementing and adjusting relevant programme documents;
- higher education institutions and research organisations – when defining priority areas for their work and when developing, implementing and adjusting strategic development documents;
- the private sector – when developing and implementing research and production programmes and projects and searching for new technology partners.

The use of the Foresight results should envisage provision of step-by-step activities.

Communication of the Foresight Results

RSTF was organised as a participatory exercise with involvement of both research and professional communities. A number of efforts were made to reinforce and develop the communication network by creating, on the basis of the leading universities, an infrastructure of S&T Foresight centres in particular S&T areas. This network united leading experts from business, academia and government and contributed to monitoring trends and anticipating the prospects of particular S&T areas and emerging markets as well as providing for wide dissemination of results. Since the Foresight study covered a broad range of economic and societal issues, it is not just a tool for supporting decision-making in science and technology. Wide communication of the Foresight results via mass-media, special web-sites, conferences and workshops contributed to building a better understanding of the future of science, technology and innovation among citizens and a wider research community. It also helped to involve new players, including representatives of NGOs and civil society, into existing networks thus making discussions of the future more focused on the emerging demand for S&T from the society.

Suggestions to organise a series of events to inform stakeholders and a broader society about the results of the Foresight study were approved by the Interdepartmental Committee on Technology Foresight under the Presidium of the Presidential Council for Modernisation of the Economy and the Innovative Development of Russia at its 2013–2014 meetings[1]. According to

[1] Minutes of 4 October, 2013 № 77-NG/12 and 23 January, 2014 № AP-26/02.

the committee's decisions, several workshops and round table discussions have been held with participation of a wide range of stakeholders including representatives of federal executive agencies, the Russian Academy of Sciences, development institutes, companies, research organisations, universities, technology platforms, and innovative territorial clusters.

S&T Foresight results are applied by relevant federal executive agencies and organisations, including for developing, adjusting, and implementing the RF state programmes and specifically federal targeted S&T development programmes, and the action plan on development (adjustment) of a system of industry-specific critical technologies based on the S&T Foresight results. Plans and detailed implementation schedules for the state S&T development programmes for the planning period include specific measures to ensure systematic application of the S&T Foresight results.

Proposals on developing a system of roadmaps for prospective projects to be implemented in the scope of state S&T development programmes will also be prepared, including federal targeted programmes based on the S&T Foresight results.

Implementation of the Foresight Results in State Programmes

In accordance with the Decree of the President of the Russian Federation dated 7 May 2012, № 596 "On long-term state economic policy", measures to develop the national innovation system in line with the Strategy of Innovative Development of the Russian Federation for the period up to 2020, approved by order of the Government of the Russian Federation dated 08 December 2011, № 2227 (hereinafter, the Strategy), as well as with developing a Technology Foresight System to satisfy the prospective demands of the manufacturing sector of the economy (hereinafter, Technology Foresight System). The key state programmes of the Russian Federation having impact on the development of the national innovation system have been approved.

The implementation of technology Foresight measures has been envisaged, among others, as part of the following state programmes:

- sub-programme 2 "Applied Problem-oriented Research and Development of Science and Technology Groundwork in Prospective Technologies" as part of the State Programme "Development of Science and Technology" for 2013–2020, approved by order of the Government of the Russian Federation dated 15 April 2014, № 301-r.;
- sub-programme 7 "Aviation Science and Technology" as part of the State Programme "Development of the Aviation Industry for 2013–2025", approved by order of the Government of the Russian Federation dated 15 April 2014, № 303-r;
- Federal Programme "Development of Civil Marine Facilities" for 2009–2016, approved by order of the Government of the Russian Federation dated 21 February 2008, № 103 (rev. dated 24 October 2013);
- sub-programme "Ensuring the Innovative Development of the Civilian Nuclear Industry Sector and the Expanded Use of Nuclear Technologies" as part of the State Programme "Development of the Nuclear Power Industry", approved by order of the Government of the Russian Federation dated 02 June 2014, № 506-12;
- Federal Space Programme for 2006–2015, approved by order of the Government of the Russian Federation dated 15 December 2012, № 1306;
- State Programme of the Russian Federation "Space Activities of Russia" for 2013–2020 approved by order of the Government of the Russian Federation dated 15 April 2014, № 306.

Measures to guarantee the functioning of the Technology Foresight System are also included in the plans and detailed schedules for implementation of programmes for the next financial year and planning period developed in accordance with the instructions of the Government of the Russian Federation dated 28 June 2012, № DM-P13-3699 and dated 30 March 2013, № DM-P13-2008 (hereinafter, plans and detailed schedules).

The results of RSTF as a key element of the Technology Foresight System can be used by federal executive bodies when implementing state programmes of the Russian Federation, as well as when adjusting them:

1) with a view to determining the priority areas of public support for science, research, experimental and design work and technological production modernisation which should correspond to the most promising areas of science and technology development, as identified based on the results of the Foresight. Such a practice has been applied, among others, when developing the Federal Programme "Research and Development in the Priority Areas for Development of Russia's Science and Technology Complex for 2014–2020", the structure of which, in terms of thematic units, was consistent with the priority science and technology areas and critical technologies in the Russian Federation;

2) when forming themes and drawing together funds to finance research and development work and projects supported by state programmes of the Russian Federation, including federal programmes (compliance with results is one of the theme selection criteria). The theme of any research and development project supported by the state should correspond the most promising science and technology areas as defined in the RSTF. If the research and development theme is defined based on proposals by interested parties (higher education institutions, research organisations, business communities), an assessment of the level of compliance of the submitted proposals with the prospective areas determined on the basis of the Foresight results can be carried out. In this case, a decision to approve the theme can be linked to the results of the assessment. If a theme is established from the top-down, it can be set on the basis of the Foresight results by identifying a research and development theme which is consistent with prospective science and technology areas identified in the Foresight with follow-up support for the work in the theme as part of a state programme of the Russian Federation or a federal programme;

3) for competitive selection of those carrying out research supported by a state programme of the Russian Federation, including federal programmes (compliance with results is one of the application selection criteria). In this case, the applicant's proposal to carry out the research and development could be assessed in terms of the compliance of the proposed approaches to solving the scientific and technological problems, the constructive and other principles of the samples under development, and the specified scientific, technical and technological solutions with the most promising science and technology areas, as defined in the Foresight;

4) when preparing proposals to formulate federal budget provisions in terms of federal programmes and allocation from the federal budget in capital construction not included in federal programmes, as well as when providing the budgets of Russian Federation subjects with subsidies to co-finance the capital construction of public property of subjects of the Russian Federation (municipal property). In this case, the results of the Foresight could be used to assess the appropriateness of the support from the federal budget for capital construction of public or municipal property relating to science and innovation infrastructure, and in particular those with a technological slant.

Implementation of the Foresight Results in Strategic Planning Documents

Currently, a state strategic planning system is being established to plan the socio-economic development of the Russian Federation, provided for by the federal law № 172-FZ "On Strategic Planning in the Russian Federation", signed by the President of the Russian Federation on 28.06.2014, which makes provisions for the coordination of strategic management and budgetary policy measures (hereinafter, the Law).

According to the Law, the state strategic planning documents to be developed on a federal level include:

1) strategic planning documents at the federal level, including following:

– annual Presidential Address to the Federal Assembly of the Russian Federation;
– strategy of the socio-economic development of the Russian Federation;
– national security strategy of the Russian Federation, as well as basics of state policies, doctrines and other documents in the sphere of national security of the Russian Federation;

2) documents developed as part of a special programme for sectoral and territorial planning, including:
– industry-specific state strategic planning documents;
– strategy of the spatial development of the Russian Federation;
– strategies for socio-economic development for macroregions;

3) Documents developed in the framework of forecasting:
– science and technology Foresight of the Russian Federation;
– strategic forecast of the Russian Federation;
– long-term forecast of socio-economic development of the Russian Federation;
– long-term budget forecast of the Russian Federation;
– mid-term forecast of socio-economic development of the Russian Federation;

4) planning and programming documents including:
– main directions of activities of the Russian Government;
– state programmes of the Russian Federation;
– state armament programme;
– schemes of territorial planning of the Russian Federation;
– plans of activities of the federal agencies.

According to the Law, science and technology Foresight is considered as one of the key documents of the system of state strategic planning.

The results of the Foresight should be used when developing, implementing and updating the above mentioned state strategic planning documents (a part of which is already in effect, whereas others are due to be developed in the near future).

Moreover, the results of the Foresight should be used when drawing up a forecast of the long-term socio-economic development of the Russian Federation.

Regulations to ensure the effective use of the Foresight results in the development of strategic planning documents for the socio-economic development of the Russian Federation are set out in the Law.

They are being developed further in by-laws. Also due to be adopted are the resolution of the Government of the Russian Federation "On the Procedure for Drawing up a Long-term Science and Technology Development Foresight for the Russian Federation" and the resolution of the Government of the Russian Federation "On the Procedure for Drawing up State Strategic Planning Documents", which are due to cover questions of the use of results from the Technology Foresight System when drawing up strategic planning documents for the socio-economic development of the Russian Federation.

During the drafting of the RSTF, requirements should be set out, with regard to the following:

1. Structure and content of the RSTF:

1.1. The Foresight should cover as wide a range of science and technology development as possible. Based on the results of the Foresight study, extracts from the report should be prepared containing the most important conclusions and recommendations for each of the key state strategic planning documents separately, including those relating to science and technology. If advisable at the end of the Foresight study, proposals should be prepared to draw up new state strategic planning documents (for example, roadmaps to develop the most promising technological directions).

1.2. As regards the structure and content, the Foresight should meet the requirements of the federal executive bodies responsible for drawing up and implementing state strategic planning documents, including those relating to science and technology.

2. Development and approval of materials on methodological, organisational and other questions relating to the drawing up of the RSTF.

2.1. All basic materials making it possible to carry out the Foresight study (Foresight design, etc.) must undergo prior discussion with members of the research, education and business communities, interested federal executive bodies, and non-governmental associations. The core documents, including the Foresight design, must be coordinated between departments.

3. Organisation of work and procedure for drawing up the RSTF.

3.1. All core interested parties must have the opportunity to participate in the development of the Foresight. Before launching the Foresight study, a list of federal executive bodies and organisations taking part in its drafting must be drawn up. Members of federal executive bodies and organisations taking part in the drafting of the Foresight must be included in coordinating, expert and working bodies, including temporary bodies, forming the basis for the drafting of the Foresight study.

3.2. Prior to the Foresight study, a relevant design and interdepartmental coordination plan to harmonise the activities of federal executive bodies must be drawn up. This plan must be agreed upon with a schedule for preparation of state strategic planning documents and with a schedule for preparation of other technology Foresight studies. This design and plan may be submitted for discussion at a session of the Interdepartmental Commission on Technology Foresight under the Presidium of the Presidential Council of the Russian Federation for Modernisation of the Economy and the Innovative Development of Russia.

4. Results of the RSTF.

4.1. The Foresight results should meet the requirements of the federal executive bodies responsible for drawing up and implementing the state strategic planning documents, including those relating to science and technology. Based on the results of the Foresight, a set of information and analytical material must be prepared which meets the requirements of the various federal executive bodies, as well as core organisations.

4.2. The results of the Foresight must contain:

- a problem-oriented science and technology Foresight, the main result of which should be a list of prospective research areas and technology packages to solve some of the most important socio-economic problems facing Russia and road maps for these key problems;
- a list of prospective technology packages making it possible to increase the competitiveness of the relevant sectors of the economy, and draft roadmaps for Russia's prospective manufacturing sectors;
- a Foresight of the demand for human resources and skills needed for developing relevant research areas and technology packages;
- draft lists of priority areas and critical technologies on national and sector-specific levels (for all fields of the sciences);
- proposals to use the results of the RSTF when developing, implementing and adjusting state strategic planning documents;
- proposals for public measures to support the development of some of the most promising technologies.

5. Informing federal and regional executive bodies of the Russian Federation and other interested parties of the main provisions (results) of the RSTF.

During the drafting of state strategic planning documents, the following requirements, among other things, should be set out:

5.1. In methodological recommendations (materials) on the drafting of state strategic planning documents (primarily, state programmes of the Russian Federation with regard to science and technology, including relevant special federal programmes, strategies to develop economic industries and sectors, Russia's long-term socio-economic development), the following should be set out:

- the need to take into account the results of the Technology Foresight System;
- the presence, in the state strategic planning documents, of sections containing a description of the prospects for the science and technology development of the corresponding the-

matic fields (long-term trends, challenges, the most promising directions, etc.) and technological priorities and goals, etc. developed on the basis of the results of the Technology Foresight System. The corresponding supporting materials may be included as supplements or accompanying materials in state strategic planning documents.

5.2. In this regard, a schedule for drawing up state strategic planning documents and a schedule for federal executive bodies, state development institutes and other interested organisations to carry out the technology Foresight studies must be agreed upon.

5.3. Draft state strategic planning documents relating to science and technology must be approved by the corresponding federal executive bodies (primarily, the Russian Ministry of Education and Science and the Russian Ministry of Industry and Trade).

5.4. The coordinating, expert and working groups (for example, temporary working groups) formed with a view to drafting departmental S&T Foresight studies must include members of other federal executive bodies drawing up state strategic planning documents on the corresponding technological theme.

5.5. A list of documents must be defined which should take into account the results of the Technology Foresight System and the main methods to estimate its results (for example, when developing themes and estimating the necessary funding for work and projects as part of special federal programmes relating to science and technology during their drafting, implementation and adjustment).

Recommendations to Ensure the Ouality of S&T Foresight Studies

Fast growth of Foresight activities in Russia within the last years makes it necessary to establish at least minimal quality standards of methodologies to be used and results to be achieved in such type of studies. The analysis of best international practices allows identifying key characteristics of a high-quality Foresight study including the following:

- engagement of all categories of stakeholders (research community, companies, key experts, government agencies, development institutes, etc.);
- use of a solid evidence base (e.g. with involvement of international experts);
- validation of the results achieved;
- orientation towards the integration into the system of decision-making and practical application of the results.

One of the factors ensuring success of a Foresight study is skills of the practitioners involved in its implementation. They ideally should be confirmed by certificates of leading international Foresight centres, publications in peer-reviewed journals, references by previous clients etc.

The methodology used should include a wide variety of methods (quantitative and qualitative, expert and evidence-based). The evidence-based background of the study should include analysis of best available practices of Foresight studies (performed in Russia and worldwide, e.g. by international organisations) as well as key national strategic documents (strategies, programmes etc.) in relevant areas. Another prerequisite of high quality assurance is linking the logical framework of the study with global challenges, threats and risks as well as with socio-economic trends. The methodology should be discussed and verified with key international experts that should be selected based on the following criteria: not less than 5 publications on Foresight in peer-reviewed journals in the last five years; the citation index (Web of Science or Scopus) not less than the global average for the field of Foresight.

The Foresight results should be presented in a form applicable for further use for policy design and policy-making (as a rule – in the form of policy recommendations). The results should be widely disseminated via publications in mass media, presentations and other channels for open public discussions.

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Russia 2030:
Science and Technology Foresight

Edited by *A. Maksutova*
Design *P. Shelegeda*
Desk-top publishing *V. Parshina*

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