Economics and Environment as Factors of Sustainable Development of Siberian Mineral Resources

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Introduction

Siberia is one of the major regions of the world whose energy and mineral resources will be important during the 21st century for industrial development not only of Russia but also of many other countries, particularly in Europe and the Asia-Pacific region. Siberia has some of the largest explored and potential reserves of energy raw materials in the world (gas, oil, coal, gas hydrates), as well as major concentrations of nickel, cobalt, platinum-group metals, diamonds, rare earth elements, helium, agricultural minerals, and many other types of mineral raw materials. These resources are mainly concentrated in Siberia's northern and eastern regions, commonly in very remote areas. Many of these deposits were discovered only in recent decades and have yet to be developed. It is predicted that further significant resources will be discovered in Siberia given the generally low levels of exploration that have been conducted in regions that have good geologic potential for undiscovered resources. Also, discoveries have been made of new, previously unknown genetic types of deposits with unique combinations of useful mineral commodities (figs. 1 and 2). In addition, the increasing deficiency of freshwater globally makes the large reserves in Siberian rivers and lakes of great importance for the future progress of mankind. Lake Baikal alone contains 20 percent of the world's reserves of fresh surface water (excluding water in glaciers in Antarctica and Greenland).

Although Siberia contains significant concentrations of natural resources, economic development in the region faces many challenges related to natural climatic, social-demographic, infrastructure, and industrial factors. Siberia's critical environmental, economic, social, and political problems were put on the agenda of the Earth Summit in Rio de Janeiro in 1992. The severity of natural climatic problems in Siberia is highlighted by the fact that most of the region (about 10 million square kilometers) experiences extreme climatic conditions, under which ecosystems are highly sensitive to anthropogenic loading, particularly in the areas of permafrost where most of the major extractable and promising resources are concentrated.

The economic problems of Siberia derive from the fact that, although the region has rich natural resources of great importance to the mining and petroleum industries, development is hampered by the unfavorable natural and climatic conditions of their locations and the poorly developed transportation systems and other infrastructure. In addition, the region has an imbalance between the mining and processing branches of the raw materials industry. This imbalance in general significantly decreases the resources' profitability and requires large initial capital investments to bring new deposits into production.

Social problems in Siberia are to a large extent the result of the former two factors (natural climatic and economic) and the historical social disparity between Siberia and the European parts of Russia. This disparity has been responsible for unfavorable demographic trends in the region. The social and economic problems of the northern and eastern regions of Siberia are further complicated by the fact that these regions require expensive measures for protection and preservation of natural environments and for protection of aboriginal populations, with their specific cultural adaptation to extreme natural conditions.

Politically, effective use of the strategically important natural resources of Siberia, particularly its energy resources, is one of the most important factors for addressing the current economic crisis for Russia, stabilizing its economy, and integrating with the world-market-based economic system. We place particular emphasis on the development of energy resources because of their importance to basic macroeconomic indices. As early as the beginning of the 1970s, Dennis L. Meadows and a group from the Club of Rome, while examining possible scenarios of world development at the close of the 20th and beginning of the 21st century, found through analysis of statistical data that there is a linear relation between the per capita gross domestic product (GDP) and energy consumption in industrialized countries (Meadows and others, 1972; see fig. 3 of this paper). Deviations from this linear relation can result from differences in climate, local prices of energy resources, and the level of contribution of heavy industry to the economy of countries.

Recently, in considering the development of Russia's energy strategy for the 21st century, Kontorovich and others (1999a) analyzed world economic data from the last three

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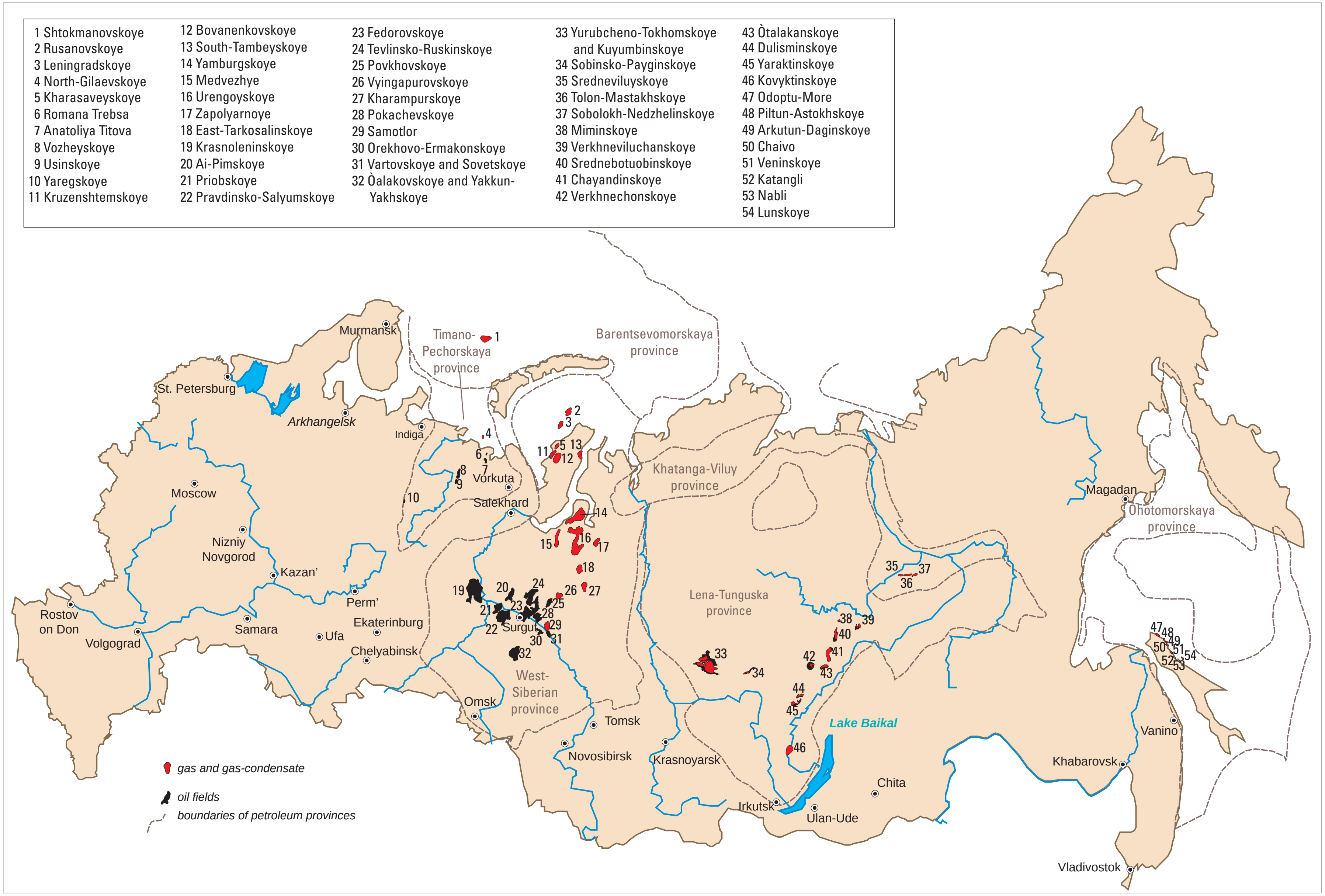

Figure 1. Map showing location of major oil and gas fields of the Russian Arctic, Siberia, and Far East.

Figure 2. Map showing location of major diamond, uranium (U), noble metal (Au, Pt), nonferrous metal (Pb-Zn, Al, Cu, Cu-Mo, Cu-Ni-Pt), and rare earth metal deposits of the Russian Arctic, Siberia, and Far East.

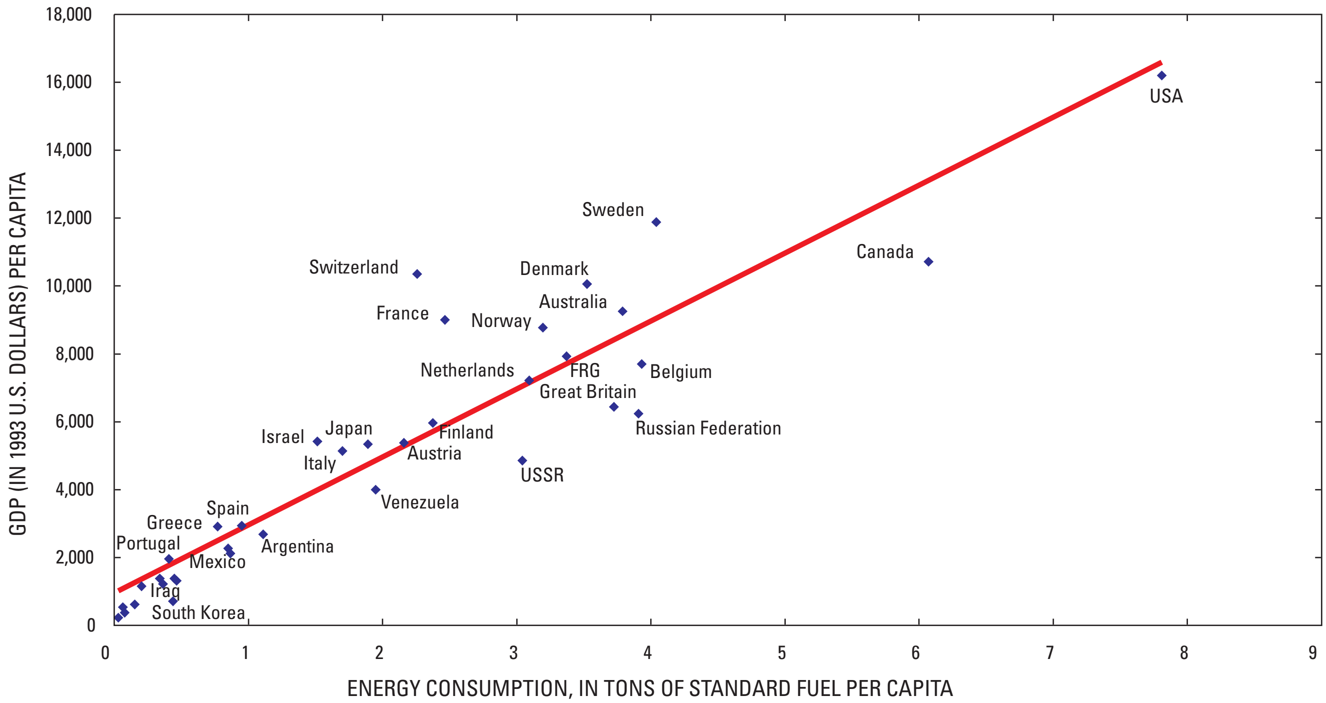

Figure 3. Graph showing the relation between gross domestic product (GDP) per capita and the consumption of energy resources by countries of the world in 1968 (modified from P.L. Kapitsa). FRG, Federal Republic of Germany.

decades and confirmed that the production and effective consumption of energy are the most important general indicators of a country's economic state. In addition, Kontorovich and others (1999a) found that an increase in the use of energy-saving technologies during recent decades accompanied a general increase in world per capita energy consumption and a growing disparity between countries in their level of energy efficiency (fig. 4).

GDP and levels of energy consumption and production were taken as basic factors in outlining a strategy for the long-term development of Russia's economy and energy industry in a global context. Factors restricting resources were also considered, including the availability of measured and indicated reserves, the profitability of present-day production and future production technologies, areal distribution of resource fields, availability of transportation, and return on investment. In addition, restrictions on the rate of GDP growth, efficiency of energy consumption, balance of energy sources (the ratio of oil, gas, coal, nuclear, and hydropower energy resources), and estimated exports of energy resources to the countries of Europe and the Asia-Pacific region were considered.

On the basis of accepted scenarios of Russia's economic development, energy consumption in the country is expected to grow from 850 million–870 million tons of standard fuel (tsf) in 2000 to 900 million–1,000 million tsf by 2010, 1,050 million–1,130 million tsf by 2020, and 1,175 million–1,450 million tsf by 2030. It is very important that the increase in energy consumption is expected to be accompanied by accelerated growth in per capita GDP of 2.4 to 2.7 times during this period, with an accompanying 3.3 to 4.2 times increase in the efficiency of energy consumption. Oil and gas are expected to remain the dominant energy sources (greater than 70 percent of all energy production) until 2030, with some decrease in the percentage of oil and, correspondingly, growth in the percentage of gas. Comparative data on production of primary energy resources for Russia and other countries of the world are given in figures 5 and 6 (based on studies conducted under the direction of academician A.E. Kontorovich at the Institute of Petroleum Geology, Siberian Branch, Russian Academy of Sciences). Estimates of production levels of the main energy sources for Russia for the period 2000 to 2020 are presented in figure 7.

Siberian Energy Resources

The distribution of oil and gas resources in different regions of Russia (figs. 8 and 9) shows that Siberian energy resources will play a determining role in any scenario of Russia's economic development in the 21st century and will markedly affect the energy supply of countries in Europe and the Asia-Pacific region, where these resources are limited. Presently, the main base of Russia's oil and gas industry is in northern West Siberia, where 90 percent of the gas and 60 percent of the oil are produced (25 percent and 10 percent of worldwide production, respectively). However, future development in this region is complicated because of a significant decline in identified reserves in the giant fields, resulting in increased well depths, decreased density of reserves, and declines in production rates. As a result of Russia's economic turmoil, exploration activities in northern West Siberia have sharply decreased, and the rate of addition of new reserves has dropped behind the rate of production.

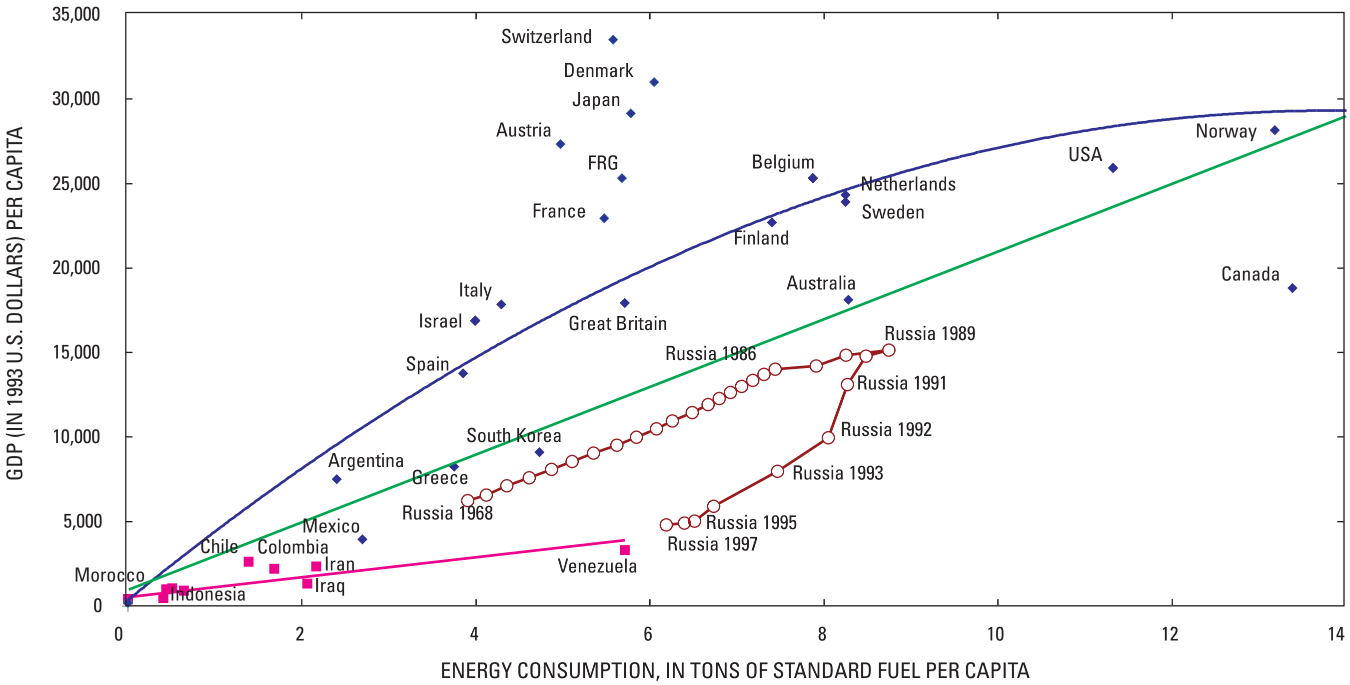

Figure 4. Graph showing the evolution of gross domestic product (GDP) per capita versus the consumption of energy resources in Russia during the period 1968–97 (hysteresis loop (red) for the Russian economy) relative to worldwide trends. Green line, average global energy consumption vs. GDP trend; blue line, fit to relatively developed countries, most of which have a GDP above the global average; pink line, fit to developing countries, most of which have a GDP below the global average. FRG, Federal Republic of Germany. From Kontorovich and others (1999a).

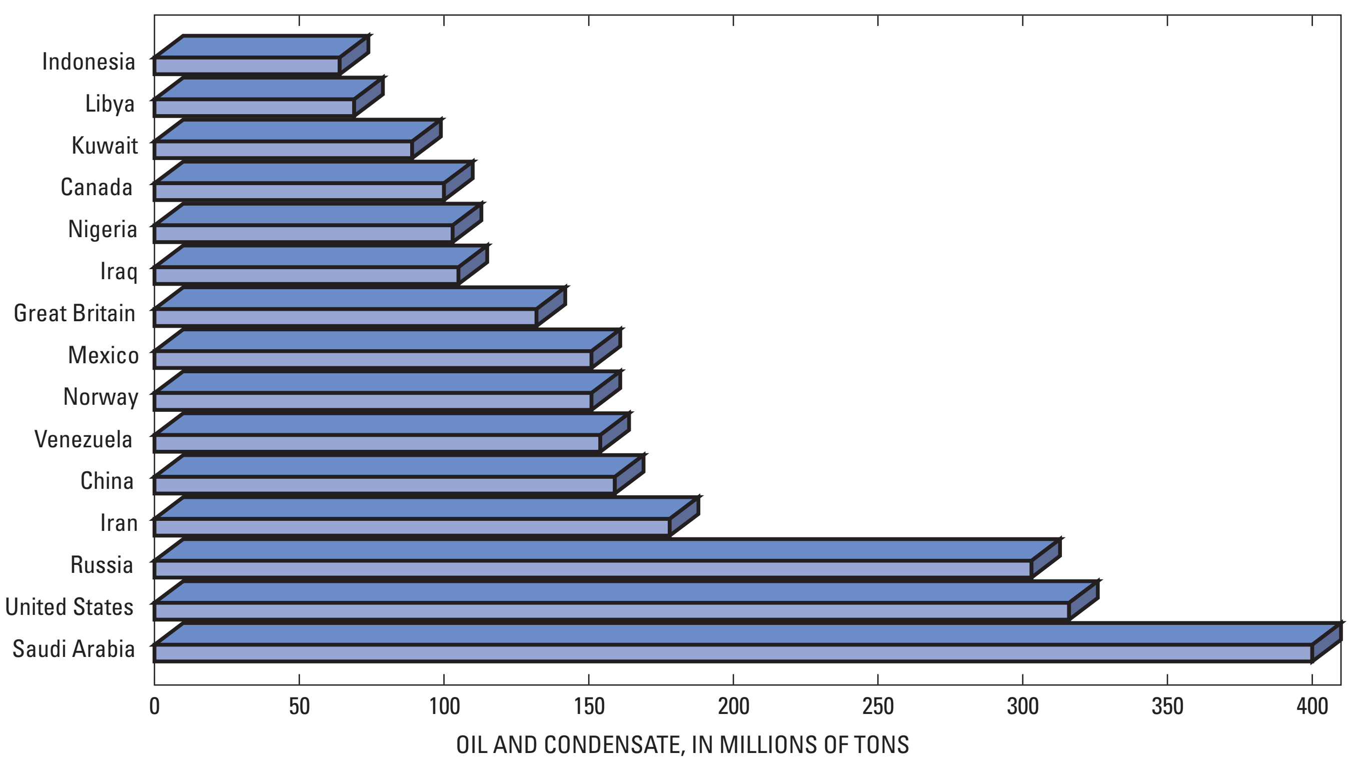

Figure 5. Graph showing oil and condensate production in 2000 by the major world producers.

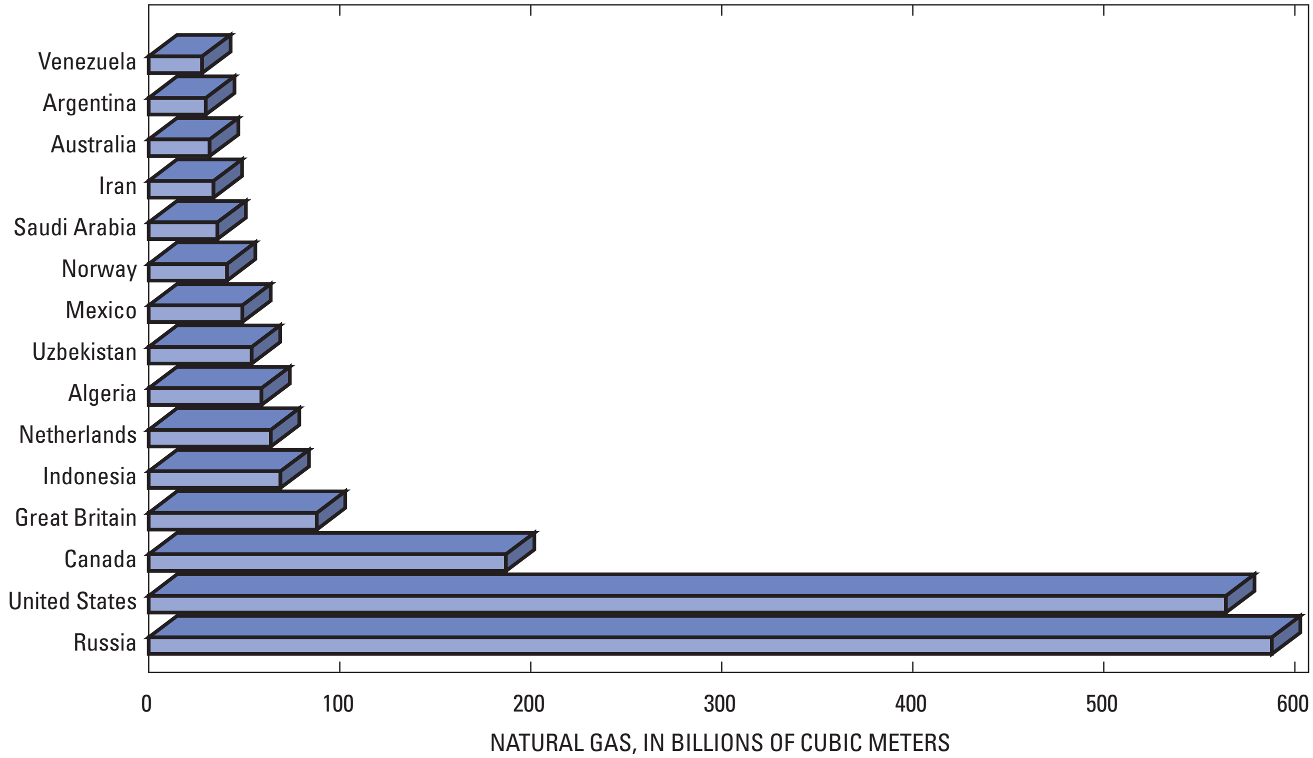

Figure 6. Graph showing production of natural gas in 2000 by the major world producers.

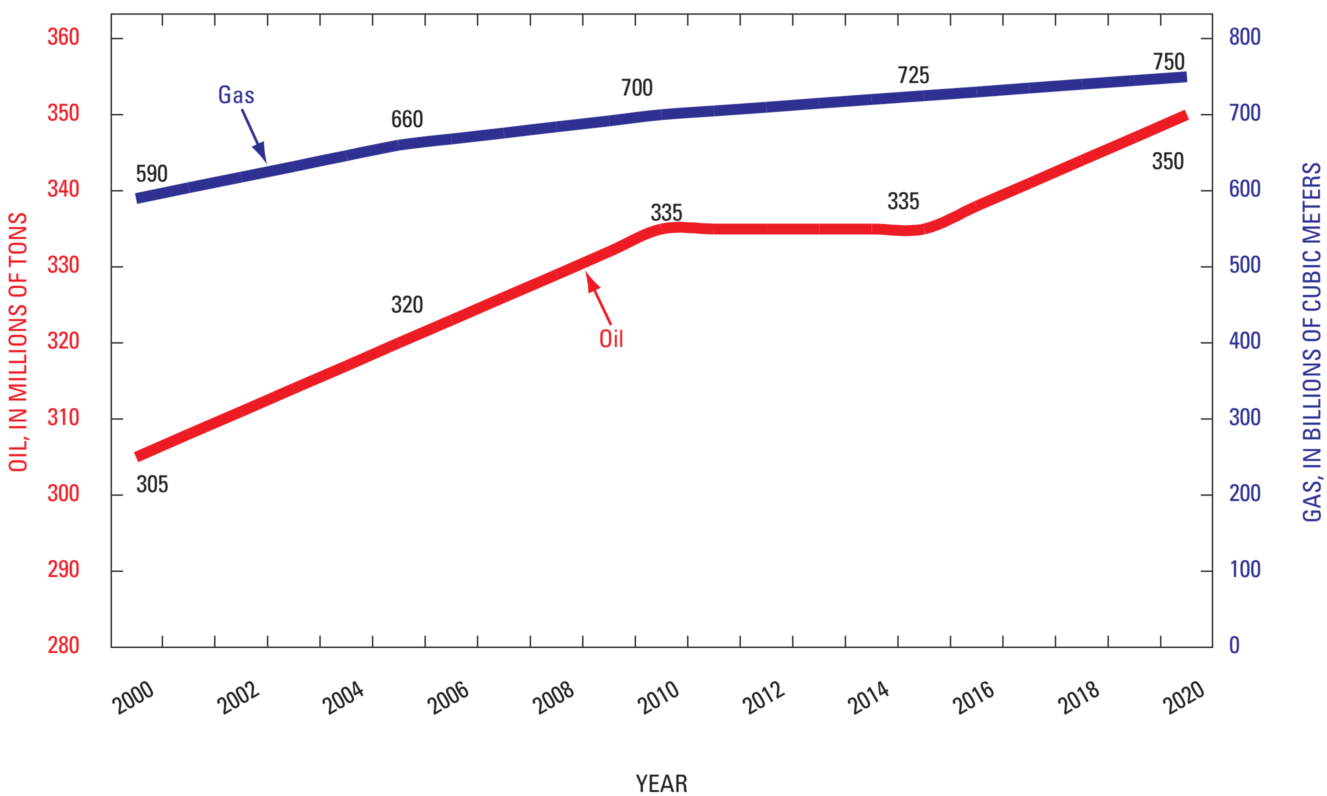

Figure 7. Graph showing forecast of oil and gas production in Russia from 2000 to 2020 (data from The Project of Energy Strategy in Russia until 2020).

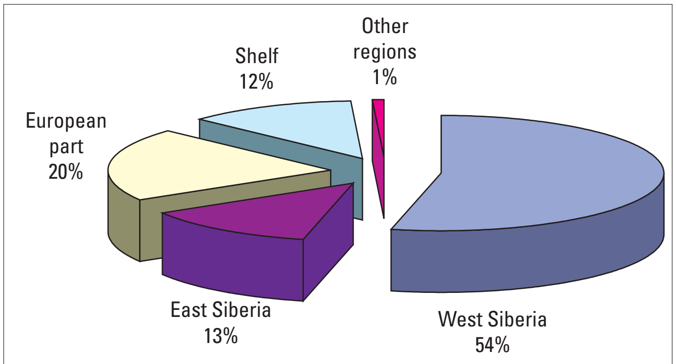

Figure 8. Pie diagram showing the distribution of in-place oil resources in Russia.

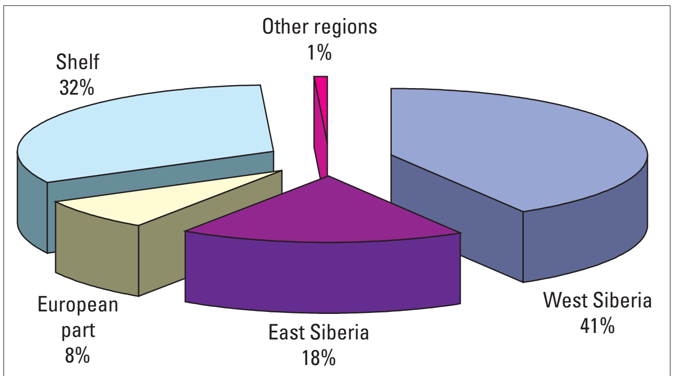

Figure 9. Pie diagram showing the distribution of in-place gas resources in Russia.

Oil and Gas Resources

In the near term, stable development and export of Russia's energy resources require continued exploration for additional reserves and improvements in development technology, particularly in the mature fields in northern West Siberia. In the middle term, the gas fields in the Yamal Peninsula (northern West Siberia), with identified reserves exceeding 10 trillion cubic meters, will need to be brought into production, and new centers of oil and gas production established in East Siberia (area of the Siberian Platform). Resource estimates made at the Institute of Petroleum Geology of the Siberian Branch of the Russian Academy of Sciences (Kontorovich and others, 1999b,c) suggest that, if the proposed scenarios of development of the oil, gas, and coal resources are realized, cumulative production in Russia will be 8.1 billion–10.9 billion tons of oil, 20 trillion–21.5 trillion cubic meters of gas, and 9.8 billion–11 billion tons of coal for 2001 to 2030. During this period, major additions to Russia's reserve base from Siberia should be at least 400 million tons per year of oil, 900 billion cubic meters per year of gas, and 350 million tons per year of coal.

For growth of Russia's energy reserve base to occur, it is necessary that exploration activity be significantly increased over current levels and that state-of-the-art drilling methods and new geophysical and research techniques be applied. In addition, increased exploration should be supported by national economic incentives for major investments in resource development. We believe these objectives will be addressed given the significance of the predicted hydrocarbon resources in Siberia.

Scientists of the Siberian Branch of the Russian Academy of Sciences have prepared proposals on the development of some Siberian petroleum provinces and area-administrative units for the Government of Russia within the context of the new energy strategy of Russia (figs. 10 and 11). In the near term, because of current regional, national, and geopolitical conditions, emphasis should be placed on development of an oil and gas industry in East Siberia, including the Sakha Republic (Yakutia). This region has very large hydrocarbon reserves, but they remain largely undeveloped. Only the Sakha Republic (Yakutia) is a current producer of oil and gas, with a production of more than 1 billion cubic meters per year. In the remainder of East Siberia and the Russian Far East, coal, mainly in low-rank deposits, accounts for more than 70 percent of the energy base. In this region, high-energy-consuming and environmentally harmful industries also are widely

Subjects of Federation	Years			
	2000	2010	2020	2030
Khanty-Mansy autonomous okrug	154,250	210,139	329,562	330,000
Yamal-Nenets autonomous okrug	26,364	43,755	69,992	70,000
Tomsk region	6,300	7,000	3,600	2,600
South of Tyumen region	190	2,040	3,000	3,000
Novosibirsk region	52	1,206	1,280	1,280
Sakha Republic (Yakutia)	390	3,000	5,150	6,624
Irkutsk region		5,379	6,743	7,341
Krasnoyarsk kray	80	2,500	34,990	36,035
Total	**187,626**	**275,019**	**454,317**	**456,880**

Figure 10. Chart showing forecast of maximum oil production of oil fields of the West Siberian Plate and Siberian Platform under current technologies and resource base in 2000 to 2030 (values in thousands of tons).

Subjects of Federation	Years			
	2000	2010	2020	2030
Khanty-Mansy autonomous okrug	12,989	14,000	11,621	5,606
Yamal-Nenets autonomous okrug	527,030	603,160	610,000	615,570
Tomsk region		8,151	10,200	10,200
Sakha Republic (Yakutia)	1,868	11,610	44,530	77,649
Irkutsk region		25,677	26,764	18,520
Krasnoyarsk kray		9,771	27,753	15,841
Total	**541,887**	**672,369**	**730,868**	**743,386**

Figure 11. Chart showing forecast of maximum gas production of gas fields of the West Siberian Plate and Siberian Platform under current technologies and resource base in 2000 to 2030 (values in millions of cubic meters).

developed. In comparison to the European part of Russia, Western Europe, and North America, consumption of cleaner fuels such as natural gas is very low in East Siberia and the Russian Far East, as well as in countries of the Asia-Pacific region geographically close to Siberia. Only Japan, which does not possess significant resources of natural gas, consumes gas in significant quantities. In Japan, environmental protection legislation prohibits the use of coal in electric power stations (with the exception of Hokkaido).

Current estimates suggest that the actual demand for natural gas in southern East Siberia and the Russian Far East by 2010 is expected to be about 30 billion–40 billion cubic meters per year. In addition, demand for natural gas in China, Japan, and Korea is estimated to be more than 50 billion cubic meters per year.

In the 1970s through the 1980s, before the current economic crisis in Russia, significant geologic exploration was conducted in East Siberia and the Sakha Republic (Yakutia). In this region, annual deep wildcat and exploratory drilling was up to 300,000–350,000 meters, and up to 20,000 kilometers of seismic profiles were laid out by the common-depth-point (CDP) method. This work resulted in the discovery of more than 35 oil and gas fields during a short period, many of which are very large. Development of the petroleum fields in the region (for example, Lena-Vilyuy, Nepa-Botuoba, Katanga, Baikit, and Angara-Lena) will be important for creating a successful oil and gas industry in the region.

Among the most prospective targets in East Siberia are the Yurubcheno-Tokhomskoye oil-gas field (Krasnoyarsk Territory) and the Kovyktinskoye gas field (Irkutsk region). In the Yurubcheno-Tokhomskoye field, which is the world's oldest recognized giant oil-gas deposit hosted in a sedimentary cover sequence (1 billion–1.4 billion years old), the predicted reserves are estimated at about 1 billion tons of oil and about 1 trillion cubic meters of gas. In the Kovyktinskoye field, gas reserves are estimated at about 1 trillion cubic meters. The identified and predicted resources in these fields would allow the creation of one of the world's largest oil and gas producers, which could provide energy supplies not only to Siberia and the Russian Far East but also to countries in the neighboring Asia-Pacific region.

In light of the energy resources already identified in East Siberia and those predicted to occur, annual gas production in the region could be brought to 125 billion–175 billion cubic meters. Thus, development of these large natural gas resources, along with production of associated oil, could provide a stable source of environmentally clean energy to a region having a significant portion of the world's population for a period of at least 50 to 60 years. If the last quarter of the 20th century is considered as a period of growth and development of an oil and gas industry in European Russia and West Siberia, then the first decades of the 21st century should be the period of growth and development of a similar industry in the East Siberia and Asia-Pacific region. The realization of this level of development of a new energy-producing industry in East Siberia and the Asia-Pacific region should be among the highest priorities for Russia in the first quarter of the 21st century.

Achieving this level of development will require a rapid increase in geologic exploration in the region and the planning and construction of a large system of gas pipelines and related processing and manufacturing operations. This, in turn, will require large financial investments, particularly with regard to providing necessary environmental protection. The rate of financial return from such a program of natural gas development can be significantly increased by the simultaneous development of oil fields and creation of a large-scale petrochemical industry. Additional support could come from construction of a major helium industry based on the unique association of helium reserves with many of the oil fields. In the 1970s through 1980s, the Soviet Union succeeded in developing such an energy program in West Siberia and Europe with support of some West European countries. It is necessary now that Russia and its eastern neighbors concentrate their efforts to fulfill a similar development program in East Siberia and the Russian Far East.

For the more distant future, the undeveloped resources of Russia's continental shelf in the Arctic and Far East seas may represent the world's largest remaining reserve of hydrocarbons (Gramberg and Laverov, 2000). Although the very low level of past exploration in these areas precludes a reliable estimate of their actual hydrocarbon resources, very high potential can be inferred from exploration criteria such as the total area and thickness of the sedimentary cover; presence of local structures; optimum combination of oil source, reservoir, and sealing rocks; paleogeographic and structural-geodynamic prerequisites; high success ratio of exploratory drilling; and other factors (fig. 12).

Three giant gas fields, Shtokmanovskoye, Rusanovskoye, and Leningradskoye, have been discovered on the shelves of the Barents and Kara Seas. These discoveries were made as a result of minimum drilling (with a success ratio of 31.2 percent in the Barents Sea and 66.6 percent in the Kara Sea). No wildcat drilling has been conducted in the eastern sector of the Arctic and Far East seas; however, geologic criteria indicate that the discovery of large new fields can be expected there.

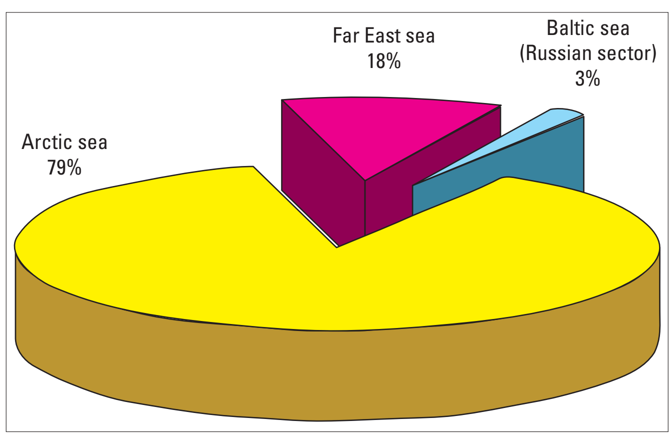

Figure 12. Pie diagram showing the distribution of initial extracted resources of hydrocarbons in the seas of Russia.

In total, the hydrocarbon resources of the Arctic shelf are estimated at a minimum of 83 billion–110 billion tons (as converted to oil), and those of the Far East region (shelf with adjacent continental areas) at 0.4 billion tons of oil and 1.6 trillion cubic meters of gas. Although estimates of Arctic and Far East hydrocarbon resources made by different groups of specialists sometimes differ, all estimates suggest a high hydrocarbon potential in these regions. However, development of these resources will require large investments, particularly for the development of marine resources. In the future, energy also may be derived from gas hydrate reserves of the Arctic regions. The development and use of gas hydrate resources are, nonetheless, still at an early stage of scientific and technological investigations. In any scenario for the future development of world energy supplies, the resources of Siberia and its adjacent shelves will be of great significance not only for Russia but also for other countries of the world.

Coal Resources

The coal industry of Siberia is also of great importance to Russia's economy. With the change to a free-market economy, the coal industry is in drastic need of restructuring. Recently, the problems of the coal-mining industry were considered by academician K.N. Trubetskoi (2000) and those of the coal-producing industry were considered by Y.N. Malyshev (2000). The resource, economic, and environmental problems of Siberia's operating coal mines also have been analyzed by G.I. Gritsko (1999). Analysis of the situation has shown that most coal mines in the European part, Far East, and north of the country appear to be uneconomic under new economic conditions and should be shut down. Restructuring of the coal industry will necessitate reestimation of coal reserves throughout Russia. All the identified coal reserves (201.7 billion tons) have been divided into favorable and unfavorable, taking into account economic, environmental, and mining factors. This analysis suggests that about 40 percent of Russia's current coal reserves are subeconomic to uneconomic.

A great majority of the most favorable, well-explored, and especially commercial coal reserves in Russia are concentrated in the two largest coal-producing regions of West Siberia—the Kuznetsk coal basin and the Kansk-Achinsk brown-coal basin. Lesser reserves also are located in deposits in East Siberia and the Russian Far East. The development potential of high-quality, economic coal deposits in Western (European) Russia and the Urals appears to be very limited. Thus, the main areas of future coal production in Russia will be concentrated in Siberia. Development of these coal resources, however, may result in increased environmental impacts.

Along with restructuring of Russia's coal industry and the economic production of coal for traditional applications (energy, coke chemistry, export), new technologies and uses for coal should be developed; for example, thermochemical processing to produce valuable fuel and nonfuel products, such as synthetic liquid fuel, adsorbents, mineral wax, and humates.

In addition, new technologies should be applied for the recovery and utilization of coal-bed methane from underground developments. Recovery of the methane would provide an important additional energy source and help address the dangerous problem resulting from gas concentrations in underground coal mines. Current estimates suggest that the major coal basins of Russia contain at least 60 trillion cubic meters of methane (Methane Emissions Mitigation, 2000). This amount is equal to almost 30 percent of the resources in conventional gas fields and represents about half of the world reserves of coal-bed methane (133 trillion cubic meters).

The main source for coal-bed methane in Russia is the Kuzbass basin, the interior of which contains up to 13 trillion cubic meters of gas to a depth of 1.8 kilometers. Most of the methane is concentrated in giant deposits, with the density of methane resources reaching 600 million–1,200 million cubic meters per square kilometer (Methane Emissions Mitigation, 2000). This density is 4 to 5 times as great as that in the developed San Juan field in the United States.

Presently, new technologies are being devised for the enrichment and thermochemical processing of coals, as well as for producing, transporting, and burning water-coal suspensions. Combustion of water-coal suspensions results in significantly lower emissions of ash, sulfur oxides, and nitrogen into the atmosphere. Currently, an experimental system is being built to transport a water-coal suspension 264 kilometers from Kuzbass to Novosibirsk. When completed, its annual production capacity is expected to be 3 million tons.

The identified coal resource base of Siberia is sufficient to meet Russia's coal needs for many more decades. In the future, the fields in the northern regions of Siberia, particularly the giant Tunguska coal basin in the Siberian Platform, will provide additional coal resources that can be brought into production.

Siberian Mineral Resources

The regions of Russia's Arctic, Siberia, and Far East also possess significant concentrations of other strategic mineral resources, such as gold, diamonds, and base and noble metals (fig. 2). Presently, the value of mineral exports from these areas accounts for about 60 percent of all Russian exports, with the base metals nickel and cobalt representing more than 20 percent of world sales and platinum-group metals about 50 percent. In total, Russia exports 93 percent of its produced aluminum, 94 percent of its nickel, 77 percent of its copper, 67 percent of its zinc, 62 percent of its uranium, 60 percent of its oil and oil products, 31 percent of its tin, and 32 percent of its gas resources, all mainly from Siberia.

Major gold deposits are concentrated in Siberia. The highest priority deposits for commercial development and significant gold production are the Sukhoy Log deposit in the Irkutsk region, containing about 1,000 tons of gold and at least 500 tons of platinum-group metals; the Olimpiadinskoye deposit in the Yenisey Range, Krasnoyarsk Territory, with more than 600 tons of gold; the Kholbinskoye deposit in Eastern Sayan (not shown in fig. 2), with more than 500 tons of gold; the Nezhdaninskoye deposit in Yakutia, with about 500 tons of gold; and a number of deposits in the Magadan region. In the Sukhoy Log deposit, large-scale production totaling 20–30 tons of gold is feasible. In total, by 2005 gold production could be increased by 50–60 tons per year in the regions of East Siberia and the Far East. Along with development of the Sukhoy Log gold deposit, development should begin of the large deposits in the Udokan (copper), Katuginskoye (rare earth elements), and Northern Baikal (lead, zinc) regions along the main Baikal-Amur railroad.

The Noril'sk mining complex is the major producer of nickel, copper, and platinum-group metals in Russia. Stable development of the Noril'sk mining complex can be achieved, in spite of exhaustion of reserves of rich sulfide ores, by bringing large reserves of lower grade platinum-bearing disseminated ores into production and by improving recovery of associated mineral commodities.

Siberia may also offer a solution to the problem of providing Russia with sufficient alumina raw material. It is known that Russia does not possess significant bauxite resources. However, the predicted resources of nepheline and syenite resources that could serve as a raw material for producing aluminium are significant in southern Siberia (Kemerovsk region, Krasnoyarsk Territory, Tyva Republic, Buryat Republic). The positive results of the Achinsk alumina plant, which is using nepheline to produce aluminum without a decline in production levels, shows the feasibility of using domestic feldspar-rich materials to replace imported bauxite.

Russia also has very good prospects to increase production of high-quality diamonds. Achieving increased diamond production, however, requires the active support and participation of the Government. A serious problem for the diamond-producing industry of Yakutia is the increase in depth of rich deposits, which makes inevitable the transition to underground mining. Increased diamond production also requires that development begin of the new high-grade kimberlite pipes found in recent decades in the Yakutsk and Arkhangelsk regions.

Economic and Environmental Factors Affecting Development

One of the most important economic and environmental issues related to the use of Siberian mineral resources is the application of environmentally and economically efficient technologies to deal with the materials in waste (tailings) dumps from mining operations. Many past attempts to process waste materials have had a low efficiency, with only selective recovery of a limited number of useful components from these complex deposits. This problem has led to the accumulation of large waste dumps, some of which contain dangerous environmental pollutants. At the same time, many of the waste dumps can be considered as secondary resources (manmade deposits) for many types of commodities, particularly noble (platinoids, gold, silver) and base metals, rare earth elements, and diamonds. Consideration of this problem in detail is beyond the scope of this paper, and we discuss it only conceptually here.

At the present time, mining science in Russia emphasizes the development of new methods for effectively processing complex raw materials (including waste dumps), new technologies fostering the most effective reduction or removal of various waste materials, and new methods to help prevent irreversible changes in the environment. Saving water and land areas is an important function of these technologies. Technologies that reduce the amount of waste allow for more effective use of natural resources and greater efficiency in mining operations. This effort includes obtaining additional production from and rehabilitation of quarries and mines; reducing dangerous dust and gas emissions into the atmosphere; reducing the release of quarry and mine waters into local and remote water basins; and decreasing the removal of valuable lands for locating dumps and other waste storage facilities. Because land areas and water resources have been damaged or destroyed by the wastes from mining and mineral processing operations, choosing technologies that reduce the amount and toxicity of waste materials should be a determining factor in decisions regarding future development and processing of mineral resources.

The mineral raw material base of the 21st century will be affected by the depletion of many large near-surface deposits having relatively high concentrations of mineral commodities. This depletion will necessitate the application of new mining and processing methods to allow development of previously uneconomic mineral deposits, as well as exploration for and development of deposits of varying sizes and grades at greater depths and in remote areas. In addition, it will be necessary to develop the mineral raw materials of the continental shelves and reprocess waste materials (for example, tailings) from past mining operations.

The development and use of Siberian mineral resources will depend on the solution of a number of critical economic and environmental problems. These include the following:

1. The development and use of new economically efficient and environmentally safe technologies for the mining and processing of mineral resources and reprocessing of materials in existing waste dumps, many of which contain environmentally harmful pollutants.
2. Monitoring and scientific study of predicted environmental changes, particularly in the northern regions of Siberia, where the danger of catastrophic degradation of permafrost due to worldwide climatic warming is particularly acute and has serious consequences for the oil, gas, and mineral industries and associated social infrastructure.
3. Reduction of methane emissions into the atmosphere during the development and transport of gas, oil, and coal. Presently, methane content in the atmosphere increases by 1–2 percent annually. This problem and others were considered at the 2d International Conference "Methane

Emissions Mitigation" held in Novosibirsk, in June 2000. At the conference, particular emphasis was placed on the necessity of mitigating methane emissions from the petroleum and coal industries in Siberia; these emissions total about 30 percent of the natural methane balance.

4. Preservation of fragile ecosystems during the development of mineral resources, including in the Lake Baikal and Gornyi Alatai regions that have received special World Heritage Site status from the United Nations Educational, Scientific and Cultural Organization (UNESCO).

Lake Baikal, with its unique ecosystem (80 percent of the biological species are endemic) and the largest freshwater reserves in the world, can be considered a prime example of the need for appropriately planned and regulated development of natural resources in a unique and fragile environment. Since the 1950s to 1960s, the scientists of the Siberian Branch of the Russian Academy of Sciences, first, under the guidance of academician A.A. Trofimuk, and then academician V.A. Koptyug, have been playing a leading role in the struggle for conservation of Lake Baikal and its adjacent landscapes.

It has taken the focused long-term efforts of scientists, as well as the heightened concern of the public and involvement of the international scientific community, to change government and industry policies in the Lake Baikal region from ones focused only on the development of natural resources to ones that include protection of the environment. This change in policies has led to stopping the development of environmentally harmful industrial plants, new environmental regulations for operating industries like pulp and paper mills, and efforts for a Federal law granting special protective status to the Baikal region. Such protective status would help assure that future development of the region's natural resources also preserves the integral ecosystems and biodiversity of the entire Baikal region (water basin and adjacent areas), as well as conserves the functional and aesthetic aspects of the natural environment. For these reasons, strict environmental regulations have been developed for licensing geologic exploration and development technologies for the unique base-metal deposits (Udokan and Kholodninskoye, fig. 2) located in the conservation zone of the Lake Baikal region.

Recognition of the unique character of the Lake Baikal region both nationally and internationally has led to its becoming the focus for the design and testing of new strategies for environmental and resource management in Russia. Further, this recognition has led to establishment of several cooperative international scientific investigations in the Baikal region, whose results have helped shape regional and global environmental policies. According to incomplete data, more than 20 international governmental and nongovernmental organizations are offering significant funding for environmental studies in the Lake Baikal region. With the support of the international community, the Lake Baikal region was designated a World Heritage Site by UNESCO. On the initiative of academician V.A. Koptyug, the Baikal region has been recommended to the consulting board on sustainable development, under the General Secretary of the United Nations, to serve as a global model for sustainable development.

An international conference on the general problems of Russian and international foundation cooperation for investigations in the Lake Baikal region was held in Ulan-Ude, September 9–12, 1998. Considered in some detail at the conference were interdisciplinary projects supported by the International Association for Promotion of Cooperation, with scientists from the independent states of the former Soviet Union and other international foundations, as well as the projects and programs of technical assistance performed within the framework of Technical Assistance for the Commonwealth of Independent States, World Bank programs, and others. Also discussed at the conference were the prospects of further international cooperation and recommendations for regulations for economic development and environmental protection and monitoring on the local, national, and international level. Results of the conference are published in Dobretsov (1999).

Many of the conclusions and recommendations made at the Ulan-Ude conference on Lake Baikal can be applied to problems of sustainable resource management in other regions of Siberia. Many of the problems are particularly characteristic of the northern and eastern regions of Siberia that contain the major mineral resources. Along with international and state regulations, of special importance for the efficient management of natural resources (including mineral resources) in these regions is the direct involvement of local jurisdictions to incorporate the interests of native populations to preserve their cultural heritage.

Conclusions

Because of the difficult social and economic conditions currently in Russia, many of the policies required for sustainable national and regional development programs have yet to be established. Russia's transition to a free-market economy presents specific difficulties, particularly with regard to laws regulating financial return on resource production (especially mineral resources) and criteria and methods for monitoring natural resource development at the Federal, regional-administrative, and local levels. However, the general trends in current strategic development of Russia follow the principles of sustainable development stated at the world conference in Rio de Janeiro in 1992. The examples highlighting the success of addressing the most critical economic and environmental problems in Siberia convincingly illustrate the benefits of an increased role of science and international scientific cooperation in the modern world.

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References Cited

Dobretsov, N.L., ed., 1999, Baikal as an area of the World Heritage List—Results and prospects of international cooperation—Transactions of the International Conference, Ulan-Ude, Russia, September 9–12, 1998: Novosibirsk, Siberian Branch, Russian Academy of Sciences, 312 p.

Gramberg, I.S., and Laverov, N.P., eds., 2000, The Arctic on the threshold of the third millennium (resources potential and ecological problems): St. Petersburg, Nauka Press, 247 p. (In Russian with English summary and table of contents.)

Gritsko, G.I., 1999, The role of coal in Russia's fuel-energy complex and ecological problems of a coal-producing region in transition to sustainable development, *in* International scientific conference on the 275th Anniversary of the Russian Academy of Sciences, Ecological problems of the coal industry in a region during transition to sustainable development: Kemerovo, Kuzbassvuzizdat, v. 1, p. 23–27.

Kontorovich, A.E., Dobretsov, N.L., Laverov, N.P., Korzhubaev, A.G., and Livshits, V.R., 1999a, Energy strategy of Russia in the 21st century: Vestnik RAN, no. 9, p. 771–789. (In Russian.)

Kontorovich, A.E., Korzhubaev, A.G., and Livshits, V.R., 1999b, Oil- and gas-producing complex and the future of Russia, *in* Science of Tyumen at the turn of the century: Novosibirsk, Science Press, p. 20–42. (In Russian.)

Kontorovich, A.E., Korzhubaev, A.G., and Livshits, V.R., 1999c, The prospects of development of Russia's economy and fuel-energy complex in the first decades of the XXIst century, *in* Collection of reports at the conference "Petroleum Geology at the Boundary of Centuries—Forecast, Prospecting, Exploration and Development of Fields," v. 3, The raw material base of Russia's oil industry, its structure and prospects of development: St. Petersburg, VNIGRI, p. 232–250. (In Russian.)

Malyshev, Y.N., 2000, Technology of development of coal deposits at the boundary of centuries, *in* Evolution of new scientific trends and technologies of development of the Earth's underground resources: Moscow, p. 132–144. (In Russian.)

Meadows, D.H., Meadows, D.L., Randers, Jorgen, and Behrens, W.W., III, 1972, The limits to growth—A report for the Club of Rome's project on the predicament of mankind: New York, Universe Books, 205 p.

Methane Emissions Mitigation, 2000, Reports of the 2nd International Conference, Novosibirsk, June 18–23, 2000: Novosibirsk, Institute of Coal and Coal Chemistry of the Siberian Branch of the Russian Academy of Sciences, 711 p.

Trubetskoi, K.N., 2000, The problems of mining sciences in relation to scientific-technological evolution in development of the Earth's underground resources, *in* Evolution of new scientific trends and technologies of development of the Earth's underground resources: Moscow, p. 4–22. (In Russian.)