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Energy Development: Choice and Implementation of Strategic Decisions

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Abstract—The problems that have accumulated in the Russian energy sector are systemic in nature and require serious scientific analysis. The transition of this country to a market economy was accompanied by a sharp drop in electricity consumption and the commissioning of new electricity generating capacities and, as a result, led to the degradation of domestic power engineering and the collapse of the innovative system in the energy sector. Launched in 2010, the mechanism for attracting investment in the industry on the basis of capacity supply agreements allowed by 2019 to commission about 30 GW of new electricity generating capacities—two times more than in the previous 20 years. However, miscalculations in assessing the prospects for the country's economic development and, consequently, future electricity demand have led to a large excess of capacities, mainly those that are old with low efficiency. Their maintenance requires serious costs that are transferred to the price of electricity. The causes of and remedies for the current situation are analyzed. It is argued that the currently discussed expensive program of modernization of the domestic electric power industry will not be able to overcome the accumulated problems. It is necessary to change approaches to the implementation of the program. Attention is drawn to the need to strengthen the role of the state in the preparation for and implementation of optimal strategic decisions on the scientific and technological development of the Russian electric power industry and the reconstruction of an innovative system in it. It is necessary to improve the mechanisms of state support for the creation and organization of production, to introduce new domestic equipment, and to include the active involvement of business circles in this process.

Keywords: energy strategy, innovation system, scientific and technological development, modernization, electric power industry, combined cycle units, gas turbines.

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In recent years, we have published several articles on the problems of developing and implementing the new Energy Strategy of Russia [1–3]. They analyze the situation in the country's electric power industry and outline, in our opinion, the principal tasks without which the implementation of the strategy is unlikely to be successful. Among these tasks, the priority ones are the following:

• ensuring the necessary level of investment for updating the fixed assets of the industry, which are worn out by more than 60%, and its further development;

• restoration of the innovation process in the energy sector (research—experimental development—construction and development of head plants—production of serial equipment), which would ensure the creation of competitive domestic energy equipment and, as a result, the country's scientific and technological independence;

• improving the quality of preparation of strategic decisions on the development of energy, which primarily requires the improvement of the state forecasting system in the energy sector in conjunction with the development of the country's economy, global scientific and technological trends, and the emerging geopolitical situation.

The choice of these tasks is due to the combination of problems that have accumulated in this industry, as well as its fundamental features: significant inertia of technological development and close interconnections with world markets of fuel and equipment, which

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are characterized by extremely strong competition. The inertia of the energy sector is due to the high cost and long time needed to create new energy technologies, the high cost of modern power plants with a unit capacity of 1–1.5 GW, and their long service lives exceeding 30–40 years for thermal, 50–60 years for nuclear, and 80–100 years for hydraulic power plants. The key problems of the country's electric power industry are systemic and require serious scientific analysis.

The opening of the domestic market for imported energy equipment in the early 1990s led to a sharp reduction in demand for domestic equipment and the subsequent degradation of power engineering in the country. It was not ready to work in market conditions—to compete with leading world corporations with huge financial and intellectual resources. In the economic downturn, domestic enterprises did not have such resources and therefore could not quickly reequip their technological base and begin to develop new competitive equipment. The collapse of the innovation process in the industry and the alienation of the state from it only aggravated the situation. Production declined, and this led to an increase in the cost of production, implying an additional decrease in its competitiveness. According to the Russian Federal Statistics Service (Rosstat), the present domestic capacities are loaded 21% for the production of steam and gas turbines and only 13% for the production of steam boilers.

The economic downturn in Russia after the start of market reforms in 1991 led to a sharp reduction in the demand for electricity. By 1998, it amounted to only 76% of the level in 1990. This caused a long stagnation in the development of the domestic electric power industry. Over 20 years—from 1991 to 2010—the increase in electricity generating capacities in the country amounted to only 17 GW. The main production assets of the industry were rapidly aging, and the cost of electricity was growing just as fast.

Capacity supply agreements. The economic recovery that began after 1998 led to an increase in demand for electricity, and by 2010 it reached 95% compared to 1990. There was a need to find new ways to stimulate the development of the country's electricity industry already in market conditions. The resolution of the Russian Government of April 13, 2010, No. 238, launched a mechanism to attract investment in the industry on the basis of capacity supply agreements (CSAs) [4]. The state guaranteed the investor a return of capital within 10 years with a yield of 14% due to increased tariffs. In turn, the energy companies undertook to comply strictly with the conditions, first of all, the established deadlines for commissioning new capacities. The penalties for violation of the deadlines were quite strict.

The order of the Russian Government of August 11, 2010, No. 1334-r, approved the list of generating facilities introduced under the CSA. [5]. According to this document and subsequent amendments to it, the total volume of new capacities in the period 2010–2018 amounted to 29.8 GW, of which 19.1 GW (66.2%) accounted for combined-cycle gas turbine (CCGT) units; 2.3 GW (8%), for gas turbine units (GTUs), 7.1 GW (25%), for steam turbine units (STUs); and 0.2 GW (0.8%), for hydraulic power plants (HPPs). The CSA program cost electricity consumers about ₽4 trillion.

The CSA mechanism concerned only public power plants operating as part of the Unified Energy System (UES) of Russia. In 2018, the share of the UES of Russia in the country's electricity industry with a total installed capacity of about 279 GW and electricity generation of 1105 TWh reached 87.2% in capacity (243.2 GW) and 97.6% in electricity generation (1078.9 TWh). For the period 2010–2018, about 42.1 GW of new capacities were commissioned in the UES of Russia—2.5 times more than in the previous 20 years. Of these, 70.7% accounted for the CSA program. The UES of Russia decommissioned 16.3 GW of obsolete capacities during this period.

Thanks to the implementation of the CSA program, approximately 15.5% of the capacity of the country's thermal power plants was updated. Unfortunately, imported equipment was largely used for these purposes, mainly due to the lack of powerful domestic gas turbines. Currently, more than 64% of GTUs operating in the country (by capacity) are imported, including all gas turbines with a capacity of more than 170 MW [6]. For the sake of cost savings, companies often did not purchase the most advanced equipment available on the market. Most of the CCGT units put into operation had an efficiency of about 50–52%, while CCGT units with an efficiency of 57–63% were available on the market. In fairness, it should be noted that the higher figures relate to gas turbine units with a capacity of 300–500 MW, the need for which was not always the case.

Updating the equipment of the country's thermal power plants (TPPs), including through implementation of the CSA program, allowed us to reduce the specific fuel consumption for electricity production by about 7.6%. Thanks to this, electricity generating companies save about 16 mln tons of standard fuel or ₽80 bln annually with an average fuel cost of ₽5000 for a ton of equivalent fuel. At the same time, according to Rosstat, for the period 2010–2018, the price of electricity for consumers increased 1.7 times, which is almost equal to the total consumer price index for goods and services. Consequently, the main benefit from the implementation of the CSA program so far has been received by energy companies.

Do we need so many power plants? The miscalculations in assessing the prospects for Russia's economic development resulted in expectations regarding the growth of electricity demand that were too high. While in the period 1998–2010, the average annual growth rate of electricity consumption in the country amounted to about 1.8%, in the period 2010–2018, it fell to 0.8%. As a result, the commissioned capacities turned out to be redundant. This led to a decrease in the load of power plants and, consequently, to an increase in the cost of electricity production. At TPPs, the installed capacity utilization factor by 2018 dropped to 0.41 against 0.50 in 2010, while in 1990 it was 0.61.

Currently, the demand for electric power is practically not growing in the country. According to the UES System Operator, the maximum load of power plants of the UES of Russia per hour of the annual maximum power consumption in the period 2010–2018 changed slightly: in 2010, it amounted to 151.3 GW, and in 2018, to 153.6 GW. At the same time, the installed capacity of the UES of Russia power plants per hour of maximum load increased during this period from 211.9 to 243.9 GW, i.e., by 32 GW.

If we take the value of the required power reserve in the UES of Russia, including the repair reserve, as equal to 20% of the maximum load, then it should have reached 30.3 GW in 2010 and 30.7 GW in 2018. As is clear, the changes are completely minor. The actual power reserve per hour of maximum load in the UES of Russia for this period increased from 60.5 GW in 2010 to 90.3 GW in 2018, i.e., by 29.8 GW. This increase is practically in line with the increase in the capacity of power plants of the UES of Russia under the CSA program. Thus, the available power reserve is currently three times higher than necessary. The content of excess capacity is paid by consumers through a fee for capacity included in the electricity tariff.

At the same time, the quality of this huge reserve remains low. In 2018, 32.5 GW of reserve were unavailable for use during peak hours when it was most in demand. Of these, 20.5 GW constituted restrictions on the output of power by power plants, and another 12 GW accounted for the so-called unreleased reserves, due to limitations in the capacity of electric grids. Unfortunately, there is a further deterioration in the quality of the existing reserve: since 2010, the amount of inaccessible reserve has increased by 10.4 GW, including 6.6 GW due to problems at power plants, and by 3.8 GW due to restrictions in electric grids.

Despite the implementation of the CSA program, there are still a lot of old low-efficient capacities in the electric power industry of Russia. Large costs for their repair and maintenance negatively affect the cost of electricity produced and, therefore, its price for consumers. A deplorable situation is developing at combined heat and power plants (CHPPs). Meanwhile, in about half of the country's installed TPP s, the electric capacities fall on CHPPs. Due to the drop in demand for thermal energy, the heat and power capacity of the CHPPs was very overstated. For this reason, about half of the electricity at the CHPPs is currently produced in the uneconomical condensation mode. [7]. The introduction of high-efficiency combined cycle gas turbines (CCGTs) in the electric power industry and highly efficient boiler houses in heat supply systems has led many CHPPs to lose in competition with separate electricity and heat production.

Modernization & overhaul. The General Scheme for Placing Electricity Facilities, adopted in 2017, envisages the decommissioning of 38 GW of old TPP capacities by 2035 and the commissioning of 40 GW of new capacities in return, as well as the modernization of 55 GW of generating equipment in operation by 2030. In 2019, the modernization program was amended. In the next 4–5 years, it is planned to commission the first stations with a total capacity of 8–10 GW. Next, projects will be selected for 3–4 GW per year. The necessary investments under this program are estimated at ₽1.5–1.9 trillion.

Success in attracting investment in the implementation of the CSA program has led to the fact that, after lengthy discussions, its principles were extended to the modernization program for the existing TPPs, which was called CSA-2. Investment contracts are expected to be concluded for 15–16 years. The main criterion at issue is the limitation of the level of specific capital costs; in addition, a requirement has been formulated to use domestic equipment or equipment of foreign companies with the full localization of its production in Russia for the purpose of modernization.

However, in our opinion, when developing the CSA-2 program, the fundamental differences between the modernization of the existing TPP equipment and the creation of new capacities based on the CSA principles were not taken into account. A major difference is that there was no alternative to CCGT when creating new gas thermal power plants. In the case of modernization, it is necessary to take into account the features of the power units under reconstruction, which determines the possibility and necessity of using various technologies. Modernization, where it is technically and economically justified, should be carried out on the basis of new technologies and should aim at a significant increase in the energy and economic efficiency of the reconstructed plants at reasonable capital costs.

An analysis of the results of the preliminary selection of modernization projects [8], carried out without taking these factors into account, has shown, in our opinion, absolutely unsatisfactory results. At facilities with an installed capacity of approximately 8.5 GW, only eight steam turbines and not a single boiler unit will be replaced. No innovative circuit solutions using the latest equipment are provided (it can hardly be considered an innovative solution to replace six power generators). Efficiency improvement is not mentioned, but the basic requirement—limiting the level of specific capital costs—has been met.

This is not modernization. Recall that modernization "provides for the improvement, enhancement, and updating of the facility, bringing it in line with new requirements and standards, specifications, and quality indicators" [9]. We are observing "a complex of significant work to improve the condition of machinery and equipment, restore the working capacity and resource of the facility, not related to changes in the main technical and economic indicators." This is a major overhaul [9]. As a result of its implementation, we get the same blocks with an extended resource (10 years at best) and, possibly, but not necessarily, with slightly increased efficiency. To agree with the plans of such a "modernization" means to doom the country's electric power industry to lag for many years behind the world level. As a result, power engineering will not receive the necessary volume of innovative orders; prototypes of equipment based on new energy technologies will not be created; and educational institutions will have to meet the need for training only operational personnel. The industry is no longer even facing stagnation but scientific and technological degradation. The consumer will pay for all this, and in full.

It is necessary to understand the reason for adopting such decisions and propose measures to correct the current situation. The reasons can be conditionally divided into organizational, economic, and scientific–technical, which, of course, are closely intertwined.

Industry modernization strategy, or what is to be done? The first group of reasons is diverse. First of all, it is necessary to point out the miscalculations in assessing the necessary volume of electricity production in the country, which leads either to the formation of an excess of generating capacities, or to their deficit. The consequences will be negative in any case. In conditions of excess capacities, as now, the most reasonable solution is to decommission the least efficient of them. The modernization of the remaining equipment must be approached extremely scrupulously and have in each case a good feasibility study. TPP modernization can often save capital costs and reduce specific fuel consumption.

Without decommissioning obsolete and worn-out equipment, the CSA-2 program will be a list of capital repairs and cannot claim the status of a modernization program for the country's electric power industry. It should also include the creation and commissioning of new highly efficient power units to replace the ones that are being decommissioned. In this case, it is necessary to take into account the forecast demand for electricity, which will be determined to a decisive degree by the new technological revolution and the transformation of the economy and social sphere caused by it [10]. We can expect a significant change in the territorial structure of demand and its key characteristics, in particular, the density of electrical loads and power consumption modes. As a result, there will inevitably be new requirements for the introduced power generating equipment.

The cost of investments attracted to the electricity industry under the CSA scheme using state guarantees is very high. This is acceptable when creating new power units to eliminate a possible shortage of electricity. In the case of attracting investments for TPP modernization and even in conditions of excess installed capacity, other financing schemes should be considered.

Severe sanctions against energy companies for delaying the commissioning of new units force them to use already proven solutions, for example, imported GTUs instead of new domestic ones. As a result, advanced Russian developments turn out to be unclaimed.

The successful implementation of the CSA-2 program requires improvement of the existing scheme for selecting assets for modernization and decommissioning. It is necessary to determine correctly the necessary volumes of work and the composition of the technologies used. Today, structures such as the UES System Operator, the Administrator of the trading system, and the Market Council are involved in this procedure. The documents regulating the activities of these organizations determine their responsibility for managing technological regimes, forecasting the current production and consumption of electricity, ensuring the stability and reliability of electricity supply, and balancing the interests of producers and consumers of energy and capacity. All these requirements are reliably met in the presence of excess capacity in the system. The greater the excess, the easier it is for these organizations to carry out their functions. However, the CSA mechanism is not purely market-based, and the relationship of its participants is far from market specifics. In these conditions, it would be right to increase the role of the state in the formation of the modernization program and in the development of mechanisms for its implementation and control.

So far, the nationwide problems of increasing the industry's efficiency, primarily related to a decrease in specific fuel consumption, heat supply development, and reliable supply of energy to consumers at affordable prices, remain beyond the scope of CSA-2. To regulate this sphere effectively, it is advisable to have an appropriate scientific and technical entity under the Ministry of Energy of Russia provided with the necessary budget funding. It should fulfill the functions of the general designer of the country's electric power system, attracting competent scientific organizations, higher educational institutions, and production companies to solve the salient scientific, methodological, technical, and forecasting problems. This, of course, will contribute to a significant increase in the level of strategic management of the country's electric power industry, including its technological support.

In particular, the need has long been ripe for optimizing the technological and territorial structure of generating capacities in the UES of Russia and solving the problem of the lack of peak installations. Removing restrictions on the capacity of electric grids would make it possible, without building new power plants, to attract an additional 12 GW of capacity during hours of maximum electrical loads. The transition to low-carbon energy imposed on the country, which is fraught with many uncertainties and potential dangers, requires careful analysis. The planned rapid development of renewable energy without taking into account the negative system effects caused by it can have significant negative technical and economic consequences. It was shown in [11] that a share of more than 15–20% of solar and wind power plants, characterized by stochastic energy transfer, in the power system displaces thermal power plants from the base part of the schedule of electric loads to the half-peak and even peak zone. This dramatically worsens their operating modes, leading to excessive fuel consumption, accelerated depletion of technical resources, and an increase in the cost of electricity generated. Then comes the turn of nuclear power plants, the transition of which to the half-peak zone is unacceptable not only for economic reasons but also for nuclear safety requirements.

The Ministry of Energy should concentrate on creating favorable conditions for implementing the modernization program for the electric power industry and developing the necessary regulatory framework for this. We need laws to ensure compliance with the interests of the state during the CSA-2 implementation and at the same time unlimited activities of electric power market entities. It is necessary to create incentives for the active involvement of domestic electricity generating companies in innovation. They should be interested in investing in the development of new technologies and, more importantly, in their speedy implementation, including testing of prototypes. The use of the principles of the liberal market in combination with planning for the development of the electric power industry with the decisive role of the state today is typical for most leading countries of the world.

An increase in the role of the state can be manifested, in particular, by introducing requirements for energy companies to provide all consumers of electricity without any restrictions and without charging fees for connecting to grids, eliminating the existing cross-subsidization and monitoring of electricity tariffs. An analysis of the structure of the cost of electricity production at TPPs would make it possible to assess more reasonably the necessary volumes of additional funds for overhaul in addition to depreciation. Toughening the requirements for financial openness of energy companies, primarily those with state participation, and expanding consumer control over their activities would help curb the growth of electricity tariffs. In this case, our point of view directly contradicts the oft-touted proposals to increase energy tariffs, without which it is supposedly impossible to implement the industry modernization program successfully.

There is another serious problem, the solution of which requires government intervention. In the preselected projects of the CSA-2 program, preference is given to large condensing stations to the detriment of CHPPs. This would be justified in the face of a capacity shortage (and in our country capacity is, we recall, redundant), but now this approach is hardly justified. Failure to include CHPPs in the modernization program seems to be a clear mistake. The maximum efficiency of CHPPs is achieved when generating electricity for heat consumption, but the rules of the federal wholesale market for energy and power (FOREM) often force the System Operator to require CHPPs to work without a heat load, which drastically reduces their efficiency.

One of the possible solutions to this problem could be the creation of regional retail heat and electricity markets that interact with FOREM [12]. CHPPs would be the main suppliers of electricity to them. Distributed generation facilities, including those operating on renewable energy sources, could also enter these markets. An important requirement for such units to include them in the CSA program is the ability to control their load by the System Operator. Within the retail market, such conditions can be implemented with greater efficiency. It would also be easier to solve the urgent task of containing the growth of tariffs for electric and thermal energy in the regions.

The issue of the level of tariffs for electric and thermal energy in the country is starting to acquire a political color and requires a separate consideration. We only note the nonobviousness of allegations of low electricity tariffs in Russia, for example, compared with the United States. Indeed, if estimates are based on the dollar exchange rate, electricity in Russia is cheaper than in the United States. If we compare by the purchasing power parity (at the dollar exchange rate half as much), which is more correct, the picture will be reversed. By the way, the same situation holds with regard to the cost of power equipment. When calculating PPP, the cost of building power plants in Russia is greater than abroad.

The second group of reasons for making incorrect decisions in the field of development of the Russian energy sector is due to the collapse of the industry's innovative environment. The ties between science, power engineering, and energy companies have been broken. Science does not have the resources to carry out the expensive research needed to develop new energy technologies. In the absence of orders, mechanical engineering does not have the means to modernize the production base and create leading models of new equipment. Power generating companies are not interested in testing and implementing them, since this requires increased operating costs. It is easier and cheaper for them to purchase well-tested imported equipment, albeit not the most advanced. This explains the noncompetitiveness of the products of many domestic energy machine-building enterprises.

The implementation of the organizational and economic proposals put forward at the beginning of this article will make it possible to link and coordinate within the country issues of fuel supply and the development of power engineering, power generation, and the electric grid complex. The foundation will be laid for the restoration of the innovation process in the energy sector, implemented in a market environment. In this case, the development of new technologies can be carried out on the terms of a public–private partnership—one of the most effective forms of attracting additional investments to the innovation process and controlling their spending, as well as reducing risks for the state.

Great hopes for the restoration of the innovation process in the energy sector are associated with the implementation of the main provisions of the Strategy for Scientific and Technological Development of the Russian Federation, approved by the Decree of the President of Russia dated December 1, 2016, No. 642 [13]. This document provides for the creation of an innovation system in the country, the key elements of which should be comprehensive scientific and technical programs and projects of the full innovation cycle, developed on the basis of the principles of public–private partnership. The same document defines the priority areas of scientific and technological development of Russia, one of which is energy.

The functions of substantiating industry priorities, expert and analytical support for their implementation, and the formation of relevant scientific and technical programs and projects are entrusted to the Priority Councils. In energy, it is the Council for Transition to Environmentally Friendly and Resource-Saving Energy, Increasing the Efficiency of Production and Deep Processing of Hydrocarbons, the Formation of New Sources, Methods of Transportation, and Storage of Energy, headed by Academician V.E. Fortov. The activities of the councils and their powers are regulated by a special resolution of the Government of the Russian Federation [14].

The councils are formed on an equal footing from representatives of science, government, and business. This should contribute to a balance of decisions and provide a more thorough selection of programs and projects, the implementation of which will create science-intensive high-tech products that are in demand in the country's economy and have great export potential.

Complex programs and projects can be funded from budgets of various levels (federal, regional, local), as well as from the funds of interested businesses. An important condition is the mandatory participation in the formation of programs and projects of the Russian Ministry of Education and Science, which is designed to provide budgetary support for the scientific component of programs and projects aimed at creating truly innovative technologies and products. The presented mechanism for financing new domestic developments for the energy sector is a worthy alternative to the proposal to create a special investment fund for these purposes [1, 2]. It was proposed to form such a fund at the expense of the investment premium to electricity tariffs. It was expected to be less burdensome for consumers than financing the developments with bank loans. In the case of a programmatic approach, development costs are not associated with tariffs. Nevertheless, the proposal to create a specialized fund for the modernization of the energy sector may be relevant under certain conditions.

It should be noted that the country has a lot of unclaimed technical proposals. In particular, the Joint Institute for High Temperatures (JIHT), RAS, has developed technologies of interest for use in the TPP modernization program. They allow you to include gas turbines in the existing steam turbine power plants without a fundamental restructuring of their technological schemes. First of all, we are talking about a gas-turbine superstructure with partial oxidation of natural gas, patented [15] and recognized by the ASME International Congress [16] as one of the five promising areas in the energy sector.

In the scheme proposed, a standard medium-capacity gas turbine serves as a kind of generator of combustion products with a temperature of about 1100°C, containing up to 17% oxygen. The combustion products are sent to the conversion chamber, where natural gas, which undergoes partial oxidation to hydrogen and carbon monoxide, enters in excess with respect to stoichiometry. The resulting combustible products expand in the power turbine and are discharged into the upper tiers of the operating boiler. At the same time, the lower tiers of the boiler operate as before. Burning a mixture of hydrogen and CO in the upper tiers of the boiler allows virtually eliminating the formation of nitrogen oxides and thereby dramatically increases the environmental attractiveness of the modernized power unit.

Such a scheme allows the use of standard gas turbines of small and medium capacity (primarily aircraft derivatives), mass-produced by domestic industry. In particular, they have already found wide application for driving compressors in gas mains. According to the calculations, when the K-315-240 steam turbine unit is superstructured with one AL-31 serial gas turbine engine, manufactured by Saturn, an additional useful unit power of about 40–50 MW and fuel economy of 4.7–5% can be obtained. Higher numbers refer to the regime with energy injection of steam into the GTU combustion chamber.

The Westinghouse company once showed interest in implementing the proposed scheme, offering to participate in financing the creation of a prototype at one of Mosenergo's CHPPs. However, the position of Mosenergo at that time was reduced to the fact that all existing steam turbine units would be converted to CCGTs and their partial modernization was not practical. New CCGTs have indeed been built, but GTUs continue to operate, and their modernization is still relevant. From this point of view, an in-depth analysis of the possibilities of the proposed technology should be carried out taking into account the use of other types of GTUs, as well as other circuit and layout solutions. This work could be done by specialized design organizations on the instructions of Mosenergo in order to prepare standard solutions for their subsequent replication, which would significantly reduce the cost of the implementation of TPP modernization projects.

Gas-turbine superstructures with the discharge of combustion products into the boiler can be extremely promising in the modernization of many existing and newly created large gas boiler plants. In the simplest and cheapest option, they can be used to provide a load of hot water. During the transition to the heating season, the boiler's heat output is increased by burning additional natural gas in it. Gas combustion occurs in the GTU combustion products containing enough oxygen for this. The advantages of this method are obvious; it has been discussed many times but has not received practical implementation. Meanwhile, this is one of the low-cost technologies of distributed generation, which provides significant fuel savings. Its widespread implementation should be of interest to municipal and regional authorities and energy supply companies. However, technology needs government support.

Technologies can be created on the GTU basis with characteristics that are superior to traditional CCGT units. An example is a steam-gas cycle with steam injection into the CCGT combustion chamber and using the resulting gas–vapor mixture as the working fluid of the gas turbine [17]. In this case, partial steam condensation at a temperature above 100°C and the subsequent deep expansion of the working fluid in the turboexpander allow the heat of condensation of the water vapor generated during the combustion of natural gas to be used in the cycle, that is, to use its higher calorific value. In this case, the efficiency of a power unit can exceed 100% when calculated by the traditional method—based on the lower calorific value of the fuel.

There are other promising proposals for a wider GTU use in the energy sector, which have also not yet been implemented. Here we should indicate the unit scheme with the release of CO_2 in liquid form directly in the GTU cycle [18]. This technology should be in demand when greenhouse gas restrictions are introduced for power plants, which is highly likely after the implementation of the Paris Climate Agreement.

This country has not yet developed and adopted a program for the creation and production of domestic high-capacity gas turbines. Meanwhile, this is a critical technology for the development of the domestic electric power industry for the entire strategic perspective. The lack of domestic competitive gas turbine equipment will negatively affect the implementation of the modernization program. The reasons for delays in the development and introduction of new domestic technologies have been repeatedly discussed, in particular, in our works [1–3].

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In conclusion, we emphasize once again the need to increase government attention to the development and implementation of optimal strategic decisions on the scientific and technological development of the electric power industry and the reconstruction of an innovative system in it. The priority need is to improve the mechanisms of state support—organizational, scientific, financial—to create, manufacture, and introduce new domestic equipment and actively involve Russian business circles in this process.

The main role in the technological renewal of the country's electric power industry should be played by CHPPs, which can provide the greatest economic and social effect. The CHPP modernization should and can be carried out using domestic equipment: small- and medium-capacity gas turbines and steam turbines. In the longer term, the development of heat supply systems will require new cogeneration technologies based on fuel cells. Their development is becoming an increasingly relevant scientific and technical task.

In order to modernize large TPPs, it is necessary to develop domestic gas turbines with a unit capacity of up to 500 MW and maximum-efficiency combined-cycle plants based on them (with an efficiency of more than 66–67%) and with good maneuverability. To do this, it is necessary to bring the temperature and pressure in the cycle to the limit values and complicate the thermal circuit of the unit. This is a very difficult scientific and technical task, the solution of which will require significant resources and time. Breakthroughs are needed in the development of new heat-resistant materials with good mechanical properties, new approaches to cooling highly loaded units, and new program codes for optimizing the design of turbines with the correct description of unsteady thermomechanical and physicochemical processes taking place in them. Such CCGTs would be competitive in the world market. There is every reason to believe that powerful CCGT plants will be among the key technologies in the energy sector of the 21st century. We are waiting for a long "era of gas"—the dominance of natural gas in the energy sector of the country and the world, despite the projected high growth rates of the use of renewable energy sources. Gas turbines are science-intensive and high-tech products, without exaggeration, the pinnacle of scientific and engineering thought in the energy sector. Only a few countries, including Russia, have the relevant competencies. We have a powerful scientific and technical reserve in aircraft engine manufacturing, which can and should be converted into energy gas turbine construction. This will allow us to become world leaders in this field.

I would like to hope that the state will consistently and persistently implement the main provisions of the Strategy for Scientific and Technological Development of the Russian Federation in close cooperation with the scientific community, in particular, with the Russian Academy of Sciences. It is science that can help the state in choosing the optimal strategic decisions and in their implementation. It must be understood that fundamentally new energy technologies can only be created on the basis of basic research.

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