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PROSPECTS FOR NEW TECHNOLOGIES OF COAL GASIFICATION IN THE DEVELOPMENT OF THE COAL INDUSTRY IN RUSSIA

The article studies behavior of the Russian coal industry and its problems of the present day, and sets forth its prospects for growth. Despite an increment in coal production output until 2023, the industry faces high losses because of decrease of export and due to global re-focusing on energy-saving technologies. Moreover, there are problems connected with lack of personnel and up-to-date equipment, complex logistics and insufficient railway infrastructure in Russia, which also abridges the export potential of the industry. On the other hand, the coal industry possesses considerable prospects for growth, connected with stimulation of innovative R&D, introduction of novel coal gasification technologies and with improvement of eco-friendliness of mining operations, which can mitigate ill-effects of coal on air and make coal products environmentally safe.

The methods of research were the system analysis, statistical processing of information, comparative analysis, performance prediction, evaluation of economic efficiency, risk assessment, and other.

Keywords: *coal, mining, resources, innovations, introduction, problems, solutions, projects, efficiency*
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Introduction

Coal industry is a constitute element of the mineral mining sector of the Russian Federation; it has for many years been supplying the industrial and municipal economy with energy and heat. However, in recent decades, there is a tendency of transition to renewable, atomic and alternative energy sources in the country, which has greatly altered the coal demand and the product market. Coal power is ecologically unfriendly and, in the conditions of transition to green energy, is in slackened demand. At the same time, the coal industry has opportunities of growth. It enjoys technological development toward green production and processing of coal so that coal products are inexpensive energy source in high demand in the industry not only in Russia but also in other countries.

For another thing, Russia possesses huge coal reserves, thus, coal production is one of the strategic industries, which promotes the use of various technologies in coal mining and processing.

In the conditions of transformation of the coal market, expansion of the global competition and the increasing energy-saving trends contributing to introduction of technological innovations, there is a search for solutions aimed at enhanced safety and lower cost of coal production. Such solutions are based on innovations in engineering, management and digitalization in the mining industry.

The mineral sector of Russia is subjected to strong geopolitical impact, which conditions challenges and risks in evolvement and expansion of the country's export potential [1]. As a consequence, the Russian coal industry strives for the sustainable development, which calls for the coal mining companies to find new technologies and innovative decisions to ensure achievement of strategic objectives, optimization of production processes and introduction of novel digital systems.

Sustainable development of the coal industry in Russia implicates technological innovations toward minimization of costs, mitigation of environmental impacts, development of green and more efficient methods of mining, as well as introduction of digital management for identification and control of ecological, industrial and other types of risk [2].

These issues enjoy a vivid discussion in the present-day scientific community, which is proved by a great many publications on the topic.

For example, Yu. V. Meleshko [3], while speaking about specificity and role of technologies in coal mining and processing, highlights the value of the industry in Russia. Coal production concentrates in the regions rich in coal, such as Western Siberia, Russian Far East and the Urals. Such location enables production optimization as closeness to a resource is the critical factor of optimality in industrial engineering.

On the other hand, according to A. E. Tsivileva [4], the Russian coal industry is faced with serious challenges because of the anti-Russian sanctions. Dependence on import of equipment and technologies, restricted access to foreign innovative technologies, deficit of professional people, entanglement logistics and need to re-orient export to new markets has brought severe complications in the industry.

For this reason, the coal industry increasingly more actively uses production, logistics, information and personnel innovations to adapt business to the new trends.

V. B. Kondratiev [5] emphasizes a strong global demand for coal irrespective of its eco-unfriendliness. The low price of coal and its infrastructural availability increases demand for this resource in the countries–consumers of energy, which expand coal-fired power generation, maintain stable demand and offer prospects for the industry growth, including handling of the prevailing technological and environmental challenges. Such countries as Pakistan, Indonesia, Bangladesh and other representatives of Southeast Asia demonstrate a sustainable trend of increasing utilization of coal, and the coal industry has good prospects for success and any task solution.

At the same time, S. Yu. Alferov [6] thinks coal extraction and consumption shrinks in European countries today due to relocation of production to Asia. For this reason, although coal consumption decreases in Europe, it dynamically grows in Asia.

Yu. A. Plakitkin [7] highlights that industrialization advances to the new Industry 4.0 level, and has a considerable economic effect on the market of coal and other minerals (iron ore, ferrous and nonferrous metals, rare and noble metals, etc.) in each country as this has an influence on energy price.

A. Ari, P. Engler, G. Li, M. Patnam, L. Valderrama [8] define four groups of influences on the global coal market: economy, ideology, geopolitics and epidemiology. Each of these factors has many components, and they, all together, have influence on the long-term development prospects of the coal industry, which are difficult to evaluate. Nonetheless, I. Overland and J. Loginova [9] believe that the number of coal power plants will increase in China by 2030, which will keep coal production

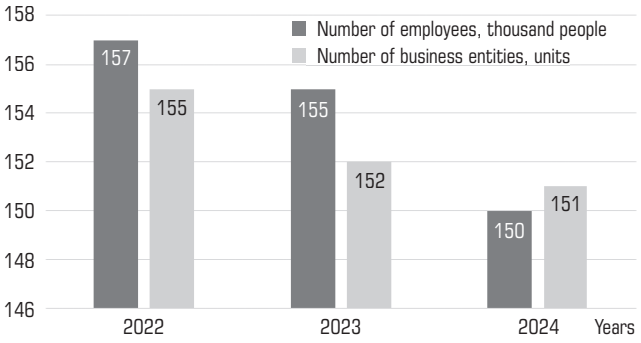

Fig. 1. Headcount and number of business entities in coal industry

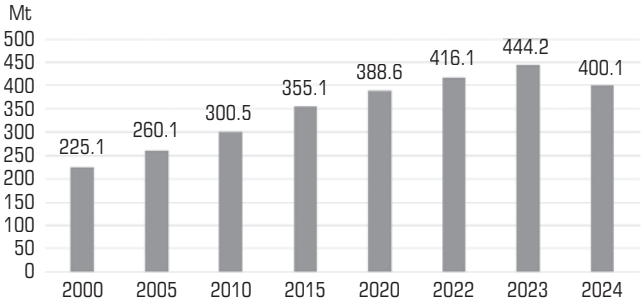

Fig. 2. Coal production history in Russia, Mt

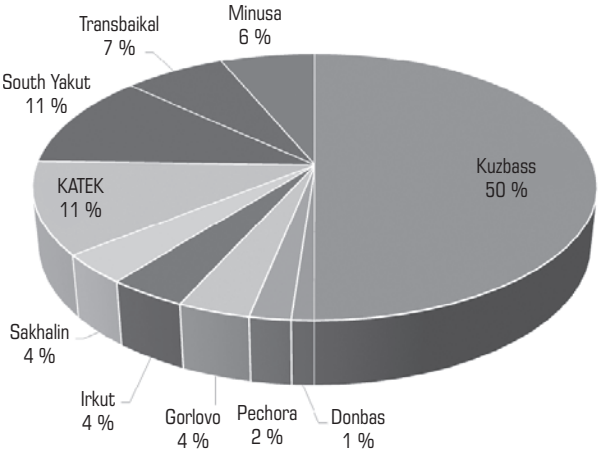

Fig. 3. Coal production output distribution per coal basins in 2024, %

going in the world. The use of green technologies in the coal industry will also promote the industry advance, which will entail other technological innovations and potentiality for coal to become a green fuel.

This study aims to review new technologies of coal gasification in terms of the coal industry development in Russia.

The study used the methods of system analysis, statistical processing, comparative analysis, industrial performance prediction, economic efficiency evaluation of projects, risk assessment, etc.

Results

The present-day situation in the mineral sector in Russia is described as a coal crisis. It is influenced by Western sanction, and by slowdown in economic growth and in logistics development, which results in an appreciable decline in profits and even in an increased negative profit of coal mining companies [10].

Nonetheless, at a scale of the country, the coal industry is rather promising since coking coal ensures power supply of important metallurgical plants in Russia, and steaming coal provides electricity and heat. It is noteworthy that the 2050 Strategy of Development of Mineral Resources in Russia (approved by the Government of Russia, Decree No. 1838-r dated 11 November 2024) reckons coking coal and iron ore among the first category minerals. This means that reserves of these minerals can satisfy the needs of the ferrous metallurgy up to 2035 in case of any scenario of economic development in the country.

At a scale of the country, coal-fired power generation is merely 13%, but it reaches 50% in some individual regions. For instance, in Siberia or in the Russian Far East, where coal provides almost 50% of electricity and heat [11]. These regions have no alternative of this fuel.

However, the coal industry in Russia has a rather developed infrastructure. **Figure 1** offers the data on the personnel strength and on the number of business entities in the coal mining industry in Russia [12].

It is seen that despite the reduction in the number of mines, the number of employees remains high in the coal industry. By now, more than 150 thousand people work in the industry, which demonstrates a high social value of the latter as it ensures stable income for more than 500 thousand people on a per-family basis.

In Russia there are 17 monotowns dependent on the coal industry. Over 1.5 billion people live in such towns [13].

All this proves that the coal industry is highly important for many people in the country, and, that, if it is totally abandoned, the majority of people will become unemployed and minimum 17 monotowns will become ghost towns as people will move to other places.

The coal production history in Russia over the period of 2000–2024 is described in **Fig. 2** [14].

Irrespective of all problems, production output in the industry dynamically grew until 2023. However, production output dropped by 10% in 2024, due various industry issues and because of sales challenges. The main sources of coal are Kuzbass and some other coal basins. The distribution of coal production output per coal basins in 2024 is shown in **Fig. 3** [14].

It is seen in Fig. 3 that the major percent, namely, 50%, of total coal production belongs to Kuzbass, while KATEK and South Yakut basins take 11% each. The rest of the participants produce less than 10% of total coal produced in the country. At the same time, all mines face the issues connected with marketing, cost escalation, unavailability of import equipment and many other.

The main consumers of the coal industry are:

—power stations;

—by-product coke plants;

—population of Russia;

—foreign markets (export).

Figure 4 demonstrates coal distribution per groups of consumers [15]. As seen, most of coal is exported, but the export decreased in 2024 owing to sanctions pressure and due decrease in demand for coal products in different countries.

In 2024 coal export dropped by 10%. Earlier the share of export in the total volume of shipment of the Russian coal was 50%, but in 2024 domestic consumption increased the share of export.

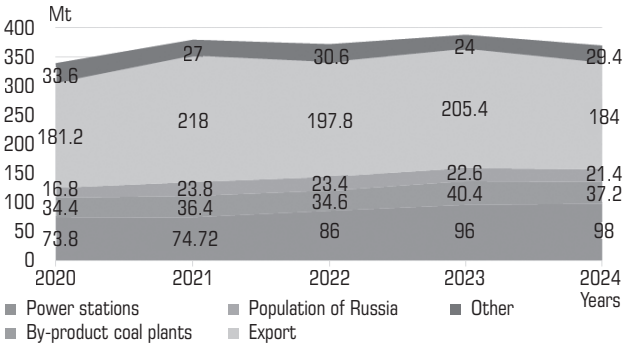

Fig. 4. Distribution of coal consumption per groups of consumers, Mt

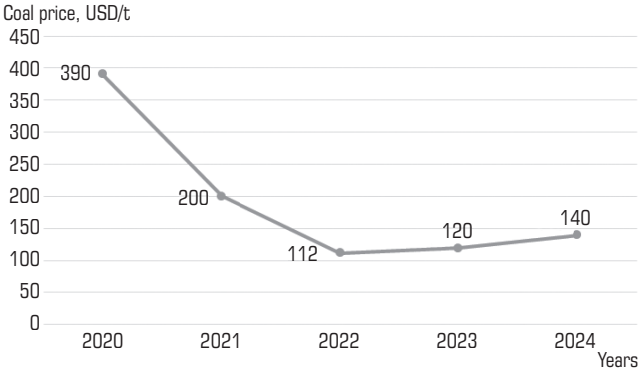

Fig. 5. Price of coking coal on the world market, USD/t

The coal price behavior also affected development of the coal industry (**Fig. 5**) [14].

The price behavior is unstable; at the end of the test period of time, the price elevates somewhat, but there are sags, especially concerning the last positions. Aside from that, Russia exports coal at large discount, which makes the coal industry even more vulnerable.

On the whole, the coal industry is in crisis, which cuts down regional and federal tax revenue, as well as reduces investment in education, health, municipal housing economy and other socially valuable sectors of the national economy.

Results and discussion

Coal mining industries have a bad time in the whole world. The situation is aggravated in Russia because of sanctions as many foreign countries stopped coal import from Kuzbass. Although coal export was re-oriented to the East in 2022, the sales markets were only partly modified. For instance, Japan and South Korea declined coal from Russia, and the volume of export shrank as a consequence [10].

For another thing, an alternative solution of the problems in logistics for many mineral producers at the moment is railroad transport, but not every railroad section is capable of transporting the required volumes of coal. All in all, the volume of railroad transportation of coal is 54 Mt per year, which is definitely insufficient.

At the same time, new rivals from Australia and Indonesia entered the market and covered the sales outlets in China and in some other countries. Generally, the price of coal dropped almost three times in 2023, from 370 to 130 USD/t. In 2024 the price stabilized somehow but remained at the level of 120–140 USD/t [16].

All these problems are systematized in **Table 1**.

At the end of 2024, the coal industry had a total negative profit of 126 billion Rubles. The consolidated loss of coal mining companies in Russia in 2025 totaled 350 billion Rubles, which proved the crisis and possible bankruptcy of the business. In 2024 in the Kemerovo Region, 9 business entities, including two mines and 7 open pits, stopped operation. By the end of 2025, 23 coal mines were closed, and 53 mines appeared at the verge of closure. The warehouses of the mines hold an ample quantity of coal, some of which is loaded on train cars, but the shipment is problematic in view of a low potential of the Russian Railways. Moreover, the coal transportation privileges were abolished and the Russian Railways raised the rates of running empty cars, and all that added up to the problems in the coal industry.

At the present time, a discussion is held not to close mines but to postpone their activity as the industry yet has a potential of recovery. This issue has many time been talked over at strategic governmental sessions on development of the coal industry, as well as on panels of various economic forums. A breakthrough in the coal industry is the use of advanced technologies connected with coal decarbonization with regard to environmental problems and transition to low-carbon economy [19].

Table 1. Problems and their solutions in coal industry

Problem	Description	Possible solutions
Price drop on the world market	The drop is conditioned by a high level of loading of storage facilities in China, by an increase in the use of renewable energy sources and by a decrease in the industrial demand in Asia	1. Diversification of export markets. 2. Increase of investment in marketing and promotion of coal as a reliable source of energy. 3. Development of new technologies to raise competitive capacity of coal
Costs exceed profits	In the conditions of negative or minimal netback, it is unprofitable for mining companies to ship coal and they just stop production	1. Optimization of production processes toward cost reduction. 2. Finding new sales markets and prices higher than cost. 3. Development of financial support programs for mining companies.
Diminution in demand for coal in the context of reduction of greenhouse gas emissions and development of low-carbon economy [17]	Heightened attention of the industry to environmental problems and transition to low-carbon economy lead to reduction in demand for coal as a traditional energy source	1. Participation of the coal industry in development and introduction of decarbonization technologies. 2. Investment in R&D on alternative energy sources and coal gasification. 3. Cooperation with government in stimulation of transition to low-carbon technologies [18]
Recession in demand for long-flame coal	Internal market demonstrates a drop in demand and prices of long-flame coal, which makes domestic shipments scarcely profitable	1. Finding new domestic consumers, for instance, construction and other industries. 2. Development of programs aimed at enhancement of coal quality. 3. Supporting governmental initiatives on the use of coal in new industries

Table 2. Coal gasification technologies

Description	Fixed-bed	Fluidized-bed
Operating principle	Heat return; coal and air are fed in reactor, where the process of loading, unloading and cooling runs cyclically	Modernized boiler BKZ-75; coal is continuously fed in fluidized bed, which ensures continuity of the process
Products	Coke and combustible gas	Semicoke and combustible gas
Ecology	Air emissions are high because of the process circularity	Air emission is reduced; semicoke is a clean fuel and sorbent
Capital cost	High cost; new equipment and new production process are required	Low cost; modification of the existing equipment allows substantial cost reduction
Productivity	Process circularity reduces productivity	Continuous process ensures high productivity
Flexibility	Creation of a new production cycle is required	Existing boilers are adaptable to new technologies

The domestic alternative is technological innovation of partial coal gasification which improves eco-friendliness of coal and enables simultaneous generation of heat energy. In this technology, instead of ash, we obtain a solid carbon residue, or semicoke [19]. As a result, the atmospheric emissions are reduced, and an ecologically clean fuel is produced, which is also a sorbent with a large specific surface area. Herewith, coal undergoes incomplete combustion and partial gasification.

In this regard, there are two technologies: fixed-bed gasification and fluidized-bed gasification; they are described in **Table 2**.

Each technology is used in specific conditions. Both technologies have advantages and disadvantages. For instance, in fixed-bed gasification, it is required to load, unload and cool the reactor. Intrinsically, the process circularity reduces productivity. The fluidized-bed technology uses a modernized boiler which makes the process continuous, coal is fed continuously and the product in the form of semicoke is produced also continuously. Thus, the second technology is less cost-intensive and allows higher productivity.

In case of fixed-bed gasification, a new production operation should be launched, while in the second case, the existing boiler plant ensures production of semicoke. This technology is applied at a boiler plant at the Berezovsky open pit [20]. The plant has two boilers with overall capacity of 40 kcal/h. It is also planned to repurpose one more boiler plant.

Coal gasification allows air emission reduction at the stage of production and reduces carbon footprint of products. The products are: heat and semicoke. Emission of one of them is zero, thus, the technology can be assumed to be clean, which improves eco-friendliness of coal production.

At bottom, semicoke is a smokeless fuel used as a sorbent in industry. It facilitates removal of heavy metals and organic matter from air, which enables removal almost of all impurities in waste water. The use of this innovation can stimulate the demand for coal in ferrous metallurgy worldwide due to decreased expenditures connected with purchase of expensive coking coal.

In 2023 a series of fruitful industrial-scale tests of semicoke briquettes was implemented at metallurgical plants in the Ural and in Kuzbass. The results that prove commercial efficiency of the technology are described below.

Coal gasification performance on a commercial scale

Market price of semicoke, Rub/t	*4000–6000*
Output of semicoke, t/yr	*1000*
Sales revenue of semicoke, ths Rub	*5000*
Expenditures connected with coal, ths Rub	*3000*
Expenditures connected with gas, Rub	*1000*
Total production expenditures, ths Rub	*3001*
Profit, ths Rub	*1999*
Profitability, %	*66.6*

The data point at the expediency of the commercial-scale application of the advanced coal gasification technology. Still, the most critical role of the technology is the environmental effects. It reduces air emission of sulfur, nitrogen oxide and particulates. The new way of coal gasification allows combining coal with other sources of energy such as biomass or waste, which also improves ecological properties of production. Efficient management of coal waste through their conversion in useful products contributes to the objectives of low-carbon economy, as well.

Let us discuss the influence of the partial coal gasification technology on the environmental properties of final products.

In the above example, in conventional combustion of coal with sulfur content of 1% per 1 t, sulfur emission is 0.01 t SO_2.

With the coal gasification technology, sulfur content can be decreased to 0.5% [17]. Then emission can be 0.005 t SO_2.

Reduced sulfur emission per 1000 t of coal: (0.001–0.005) t SO·1000 = 5 t SO_2.

Emission of nitrogen oxide (NO_x). In conventional coal combustion, emission of NO_x is 0.8% of the mass of coal: 0.008 t NO_x per 1 t of coal. In coal gasification, this index can be lowered to 0.004%. Reduction of emission of NO_x per 1000 t of coal is: (0.004–0.008) t NO_x 1000 = = 4 t NO_x.

Emission of particulates. In conventional coal combustion, emission of particulates is 0.02%. In coal gasification, this index is decreased to 0.01%. Emission of particulates per 1000 t of coal: (0.0001–0.0002) t of particulates·1000 = 0.1 t of particulates.

Carbon footprint. In the use of 1000 t of coal in combination with 200 t f biomass, carbon footprint is reduced; coal (carbon footprint 2.5 t CO_2 per 1 t of coal): 1000·2.5 CO_2/t of coal = 2500 t CO_2.

Biomass (carbon footprint 0 t CO_2 as it is assumed to be carbon-neutral) [18]: 200 t of biomass.

Total carbon footprint: 2500 t CO_2 – 0 = 2500 t CO_2.

In case of using only coal, carbon footprint is 2500 t CO_2, and the use of biomass allows reducing carbon footprint to 2000 t CO_2.

Another effect consists in decrease in coal waste of conventional combustion. Conventional combustion generates waste in amount of 20% of the total coal volume. Combustion of 1000 t of coal: 1000 t of coal·0.2 = 200 t of waste. Coal gasification reduces waste to 10%: 1000 t of coal·0.1 = 100 t of waste. Waste reduction: 200 – 100 = = 100 t of waste.

These calculations are systematized in **Table 3**.

Total reduction in emission of pollutants and waste per 1000 t of coal in coal gasification is:

Table 3. Environmental performance of new coal gasification technology, t

Parameter	Conventional coal combustion	Coal gasification	Difference (reduction)
Emission of sulfur per 1 t of coal	0.01	0.005	0.005
Emission of sulfur per 1000 t of coal	10	5	5
Emission of NO_x per 1 t of coal	0.008	0.004	0.004
Emission of NO_x per 1000 t of coal	8	4	4
Emission of particulates per 1 t of coal	0.0002	0.0001	0.0001
Emission of particulates per 1000 r of coal	0.2	0.1	0.1 т
Carbon footprint per 1 t of coal	2.5 т	0	2.5
Carbon footprint per 1000 t of coal	2500	0	2500
Waste per 1 t of coal	20*	10*	10*
Waste per 1000 t of coal	200	100	100
*Volume of waste per 1 t of coal is in percent			

5 t SO_2 + 4 t NO_x + 0.1 t of particulates + 2500 t CO_2 + 100 t of waste = 2609.1 t.

This proves the positive effect of the coal gasification technology on the environmental properties of production.

To sum up, the coal industry has a bad time at the moment, which dictates implementation of innovative technologies of coal gasification. These technologies appreciably improve the environmental properties of production, which is the main path of development of low-carbon economy. Such approach can cut down coal mining cost and also promote production of new commodities to be in demand in metallurgy both in Russia and in the world. Eventually, this will allow the maximum effective concept of coal export, help create new productions and spur technological transformation of the coal-related industries, preserve coal mines and enable high-quality utilization of coal resources in the future.

Conclusion

The accomplished research proves the presence of many challenging problems in the coal industry. In the conditions of globalization, digitalization and green technology trend on the world market, the coal demand declines.

Meanwhile, many innovative solutions are being developed in the area of coal mining and processing; they make the processes environmentally safe, reduce expenses and improve eco-friendliness of coal. For this reason, the Russian mining companies should introduce new technologies of coal gasification. This can cut down expenditures, optimize production processes and upgrade product quality.

The study also shows that all innovations should be accompanied with value engineering to confirm their efficiency and advisability. The calculations prove the significance of innovations and their effect on coal cost in case of coal gasification. Altogether, this can bring possibilities to reduce production expenses and to cut down costs of final products.

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