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Feasibility study for thermal coal quality management in small-scale open cast coal mines in the conditions of the Far North

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Abstract

Relevance. The use of local coals instead of imported ones is relevant for the eastern and northern regions of Russia. Such problems are true for the Kirov open-cast mine, which is involved in providing thermal coal to the western group of regions of the Republic of Sakha (Yakutia), where imported coal products are also delivered, the quality of which exceeds the local one, but at the same time, due to complex seasonal logistics, there is a decrease in quantitative and qualitative loss of the finished product, as well as a higher price. Thus, it becomes necessary to justify geotechnological measures for obtaining graded coal in local open-cast mines, which will improve the qualitative and quantitative indicators and increase the efficiency of its use instead of imported, more expensive coals. For enterprises located in remote, transport and energy isolated regions of the Far North, the problems of improving the quality of using local coal resources instead of imported ones have now gone beyond the purely technological concept, but are important in terms of the energy security of the population, the socio-economic development of the region.

The purpose of the research is to substantiate technological solutions for managing the quality of thermal coal in small-scale open cast coal mines in the Far North to improve the efficiency of supplies to remote areas and evaluate the effectiveness of the proposed measures.

Methods – scientific generalization, systematization and analysis of scientific and technical literature, method of analogy on the choice of geotechnology to improve the quality of coal shipments to consumers from small-scale open-cast coal mines in the conditions of the Far North.

Results. A geotechnological scheme for upgrading the extracted solid fuel is proposed, which is based on the concept of creating an additional production line in small-scale open-cast coal mines near consumers, instead of expensive, complex and unreliable logistics of imported coal, contributing to a technical and economic assessment of the production of coal products of the required quality. Calculations of the economic efficiency of using graded coal in bulk instead of raw coal, as well as the use of flexible containers for transporting solid fuels to end consumers.

Conclusion. This technology makes it possible to reduce the qualitative and quantitative losses of coal, which makes it possible for end consumers in the Nyurba region to use local coal instead of imported coal. The active development of local coal deposits is one of the ways to increase the stability of the solid fuel supply chain to consumers, as well as the energy security of hard-to-reach areas of Yakutia and support their economic and social development.

***Keywords*:** brown coal, small-scale open cast coal mine, quality, sorting, packing, granulometric composition, efficiency, Far North.

Introduction

For enterprises located in remote areas of the Far North, the problems of increasing the efficiency of using local coal reserves instead of imported ones have now gone beyond the purely economic concept, but are important in terms of the energy security of the population and the socio-economic development of the region. For many regions, including the Far North, coal remains a vital fuel and energy resource, the importance of which is only increasing for remote and hard-to-reach regions [1].

Currently, for the needs of housing and communal services in the Vilyui group of districts of the Republic of Sakha (Yakutia), both imported coal from deposits (Dzhebariko-Khaiskoye, Belogorskoye) and local (Kirovskoye, Kempendyayskoye deposits) are used (fig. 1, table 1) [2]. Total

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Table 1. Specification comparison of the geographical, geological and mining conditions of coal deposits used for housing and communal services in the Vilyui group of districts of the Republic of Sakha (Yakutia)
Таблица 1. Сравнительная характеристика географических, геологических и горно-технологических условий месторождений угля, используемого для нужд ЖКХ в Вилюйской группе районов РС (Я)

Characteristic	Nizhne-Lena coal basin			
	Dzhebariki-Khaya	Belogorsk	Kempendyayskoye	Kirovskoe
	Imported coal		Local coal	
Area, km^2	0,6	–	0,4	6,0
Reserves, mt	(A + B + C_1) – 9,4; C_2 – 1,2	(A + B + C_1) – 4,9	(A + B + C_1) – 4	(A + B + C_1) – 7,1
Type and grade of coal	Hard, D	Brown, B3; Hard D, G	Brown, B2	Brown, B2
Penetrating depth, m	1,5–30	11–16	12–17	5–17
Stripping ratio, m^3/t	7,3	1,7; 1,3–3,3	2	1–2
Average seam thickness, m	3,3	12–18	17–21	21–26,3
Nearby settlements	Dzhebariki-Khaya, Tomponsky district	Sangar, Kobyaysky district	Suntar, Suntar district	Nyurba, Nyurbinsky district
Nearby rivers	Aldan	Lena	Vilyuy	Markha
Import volume, thousand tons	65 thousand tons – until 2021 47 thousand tons – from 2021	18 thousand tons from 2021	20 thousand tons	30 thousand tons

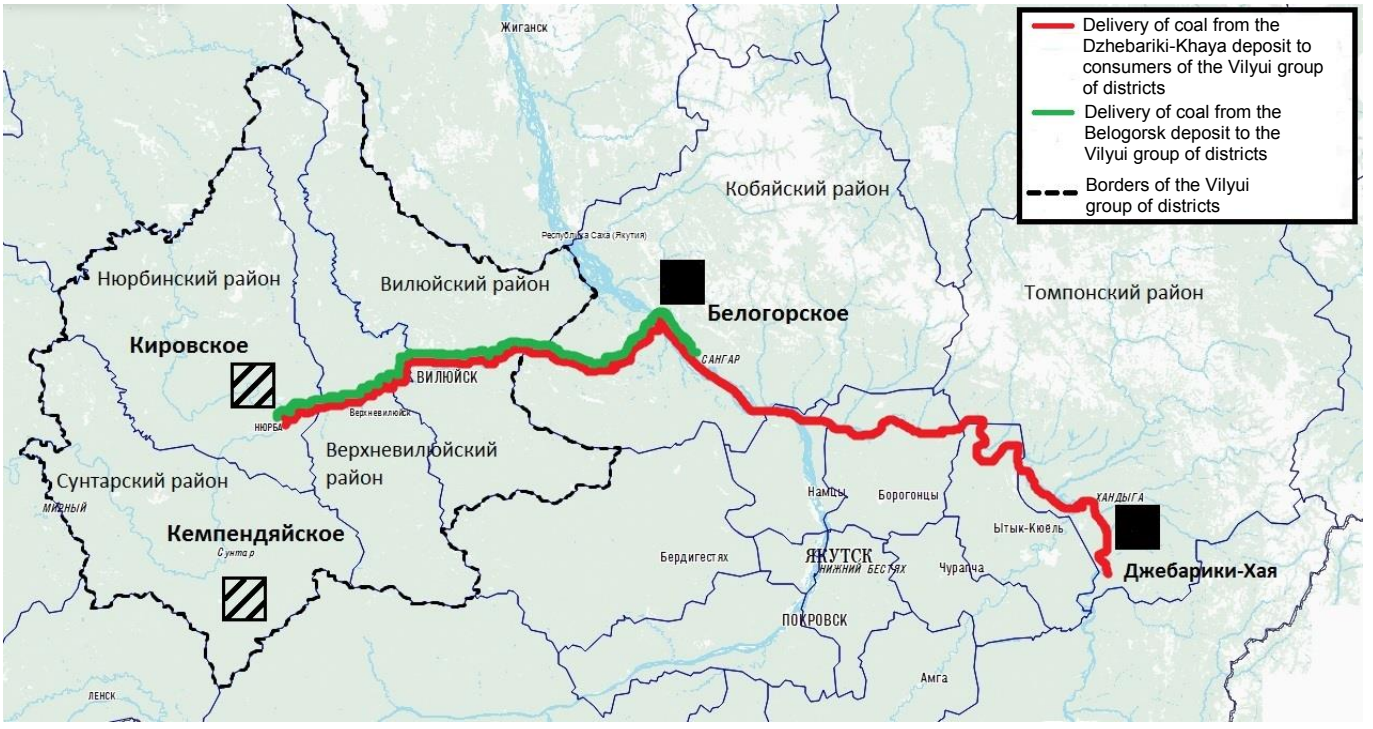

Figure 1. Thermal Coal Supply Scheme of the Nyurbinsky and Suntar regions of the Republic of Sakha (Yakutia)
Рисунок 1. Схема обеспечения энергетическим углем Нюрбинского и Сунтарского районов РС(Я)

coal consumed is about 120 thousand tons, and the share of imported coal is the largest and amounts to about 70%.

Coals from local deposits (Kirovskoye and Kempendyayskoye) also participate in the coal supply of their regions, the annual capacity of the Kirov open-cast mine is within 30 thousand tons. The quality characteristics of imported and local coal show the low quality of the latter (table 2) [3]. And although imported coal from other regions has a multiple higher cost, heat supply companies prefer to import a multiple more expensive (2.5 times), but high-quality fuel of the highest degree of coalification.

Until 2021, most of the required volume of coal (65 thousand tons) for the needs of the State Unitary Enterprise "Housing and Communal Services of the Republic of Sakha (Yakutia)" in the western regions was provided by the Yakutugol company from the Dzhebariki-Khaya open-cast mine, where coal in ordinary and often diluted form was shipped from coastal warehouses in river transport for delivery to consumers along three navigable rivers: Aldan, Lena, Vilyui. Since 2021, coal has been supplied from the Belogorskoye deposit, the quality of which is practically not inferior to coal from

Table 2. Quality of imported and local coal
Таблица 2. Качество завозимых и местных углей

Deposit, type and grade of coal	Mass fraction of as-fired moisture average/limit, %	Ash content average, %	Volatile content, %	Heat of combustion higher/lower, kcal/kg	Mass fraction of sulfur, %
		Imported until 2021			
Dzhebariki-Khaya, Hard, D	10,0	17,0	41,3	7500/5200	0,3
		Imported from 2021			
Belogorskoye, Brown, B3; Hard, D, G	15,8	11,5	41,3	7064/5323	0,24
		Local			
Kirovskoe, Brown, 2B	40	19,5	34,5	5262,3/3210,1	3,0
Kempendyayskoye, Brown, 2B	30,0	7,5	–	5430/3463,2	1,5

Dzhebariki-Khaya (table 2). The change in the supplier of coal products did not lead to an increase in their safety and quality, as well as to a decrease in the cost of the final product.

High losses in the technological supply chains of coal for the needs of remote areas of Yakutia are made up of a number of main components. Design losses during coal mining, depending on the thickness and proximity of the seams, their dip angles, the type of mining equipment used and the selected development systems, are 3–10% according to operating experience for open-cast mines. Higher losses of coal occur during transportation, transshipment and storage in open warehouses, and, as a rule, exceed the standard [4, 5]. When burning this type of fuel, due to the inconsistency of the quality of coal with the technical specifications and state standards of boilers in terms of ash content, humidity, heat of combustion or lump size, losses reach 30% [6, 7]. This problem becomes especially acute in the conditions of the Far North when developing deposits that are more than 1000 km away from consumers with complex logistics [8]. The terms of deliveries along such a route reach 12 months, during this period the fuel loses its quantity and quality. At the same time, in the open air, especially brown coals quickly weather, lose moisture, crack and crumble with the formation of more fines [9–10].

An assessment of changes in the properties of low-grade coals, performed using the example of brown grade BR2 from the Kangalasskoye deposit, showed that storage conditions and its duration affect the quality of coal. First of all, this refers to its granulometric composition, which, in general, changes in dynamics towards an increase in small grain-size classes. When raw coal is stored in bulk and in graded form in an open area, the granulometric composition of fuel actively changes with a significant increase in the grain-size class up to 30% (0–10 mm) [11].

On the basis of the experiments carried out on the storage of brown coal from the Kirovskoye deposit in the natural conditions of the Far North, it was found that during storage from April 29 to May 30, the working humidity W^r decreased by 3 times and amounted to no more than 12%, in the lower grain-size classes the ash content A^d exceed the average values by 7%. At the same time, samples of natural disintegration show a high yield of small grain-size classes of –5 mm after crushing (more than 70%), which is explained by high self-dispersion [12].

Analyzes of previous studies have shown that particles less than 8 mm do not actually participate in the combustion process, since they fall into the ash compartment and fly out into the chimney with the air draft, and the sludge remaining in the furnace reduces the efficiency of the boiler. It has also been established that for the production of the same amount of thermal energy, raw coal is needed 1.5–2 times more in volume than graded coal when burned in boilers with a grate [13].

Based on observations in this area of research on the variability of the qualitative characteristics of coal during its extraction, storage and transportation, it can be assumed that coal, undergoing all the processes of mining and the technological chain in the conditions of the Far North, significantly loses its properties.

The rational use of coal as an energy raw material is largely associated with ensuring the safety and release of coal products in an open-cast mine, the best quality that meets the technical requirements of thermal and mechanical equipment. One of the options for implementing such a strategy for consumers in the western regions of Yakutia could be the production of graded coal in bulk and in soft containers (FIBCs). The solution of this issue will improve the technology of production, transportation and storage of graded coal in terms of resource saving and energy security of the population.

The main part

For municipal needs of the Nyurbinsky district, coal from the Kirovskoye deposit is the most suitable (table 2), taking into account the fact that long-term expensive transportation is not required, provided that the quality of the mined coal is improved (upgraded). One of the less costly and at the same time effective ways to improve the quality of BR2 coal in the Kirovsky open-cast mine is sorting into grain-size classes [14, 15].

Options for the extraction and sale of coal from the Kirovskoye deposit were considered:

The current technological scheme: Extraction and shipment of coal in ordinary form (the existing scheme for the delivery of coal for public utilities and the population);

Option 1: Release of coal in graded form in bulk;

Option 2: Release of graded coal in bulk and in flexible containers.

Current scheme: The existing geotechnology of the Kirovsky open-cast mine includes a cyclical technology for excavating overburden and coal by a bulldozer method without drilling and blasting. The deposit is developed by a combined mining method, using T-35.01 and ShanTui SD32 bulldozers for overburden and mining operations, designed to develop

pre-loosened rocky and frozen soils. Transportation of overburden rocks into the mined-out area is also carried out by bulldozers, and with the participation of the KAMaz 65115 transport in conjunction with the Amkador 342V loader. Loading of coal is carried out by a ZL50GN wheel loader with a bucket capacity of 3m^3. Delivery of coal in ordinary form to the warehouse is carried out by FAW dump trucks with a carrying capacity of 40 tons. Consumers are supplied with BR2 grade coal from the coal warehouse and partially from the open-cast mine. The accepted operating mode of the open-cast mine is one shift of 8 hours, a five-day working week. The average annual volume of coal production is 27,000 tons, overburden is 42,820 m^3, with such small volumes, the cost of 1 ton of raw coal sales is 1,767 rubles, the shipping price is 2,030 rubles/ton (excluding VAT).

The proposed options for the production of graded coal in bulk and in flexible containers provide for an increase in the production of solid fuel by 30,424 tons, due to the replacement of imported coal from the Belogorskoye deposit. The work schedule of the sorting and packing line is being accepted.

	April	May	June	July	August	September	October
Productivity, thousand tons							
Sorting ……	7000	20,160	20,160	19,099			
Packing ……..	6720	6720	6720	6720	6720	6720	6680

Based on a preliminary assessment and calculations for the selected machinery and equipment, a production line is proposed for the release of coal products in graded form in bulk (***Option 1***) and graded coal in FIBCs (***Option 2***) (fig. 2).

***Option 1 (Sorting)*:** The crushing and screening plant carries out the processes of crushing and sorting raw coal according to grain-size classes. The technological scheme at the Kirovsky open-cast mine is a cyclic type of coal reception in ordinary form with a volume of 57,424 tons, followed by division into grain-size classes and in-line formation of stacks of 47000 tons of graded fuel and 9570 tons of fine coal. The technology includes: a ZL50GN wheel loader, which ships raw coal to a DVZ-2/500 toothed roll crusher, where it is crushed up to 150 mm, then the coal passes through a GIS 51 throw screen, which is equipped with a 150 mm grate to eliminate lumps, and a mesh with a 10mm cell for dividing into two classes –150+10 mm; –10+0 mm. Graded coal of grain-size class –150+10 mm is a coal product supplied to the consumer in bulk.

Option 2 (Sorting + packing): This option includes two technological lines: a line for the production of graded fuel (***Option 1***) and a line for packing into flexible containers (FIBCs). Cyclic-flow packing technology implies a storage hopper with the release of graded coal into soft containers (FIBCs) of 1 ton. Graded coal of class –150+10 mm passes through the BIG PL 900/GR semi-automatic equipment of the packaging line into soft containers, coal in bags forms a temporary storage area. Further, the packaged coal is delivered to warehouses for the sale of thermal coal in the Nyurbinsky district.

An economic effectiveness assessment of using local coals in graded form instead of imported ones showed the following. To introduce a new technology for producing graded coal

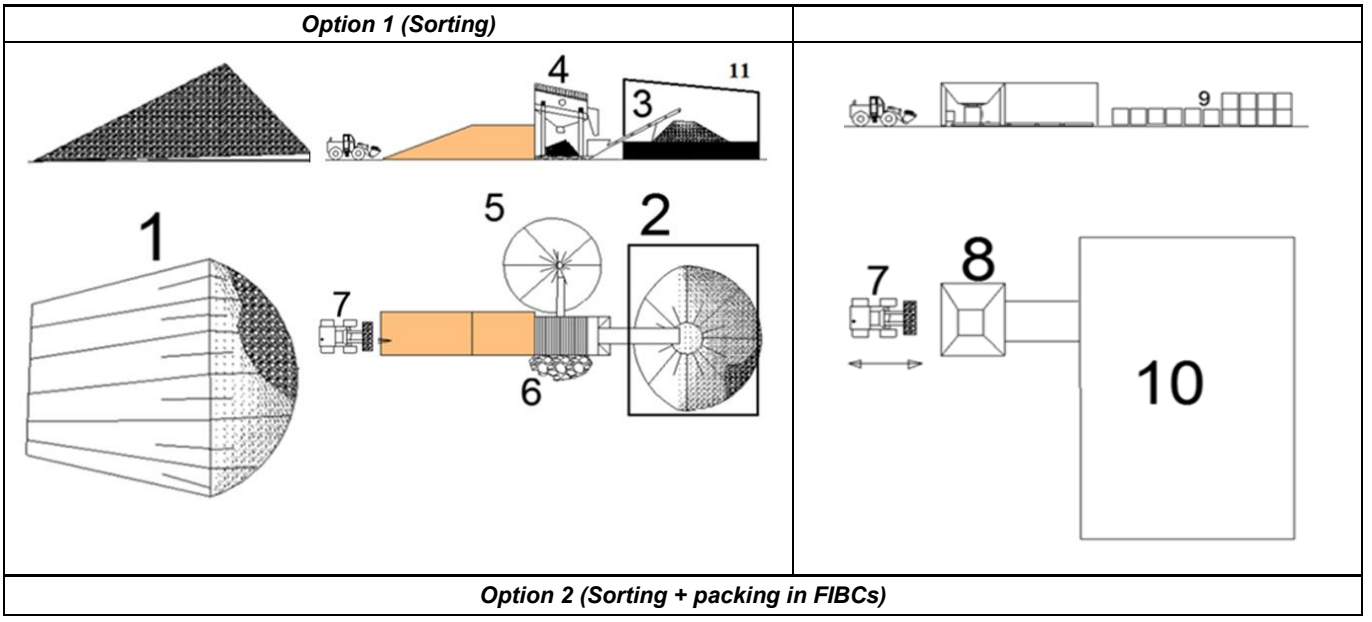

Figure 2. Scheme for production of graded coal in bulk and in flexible containers: *1* – Dump of raw coal; *2* – Dump of graded coal –150+10 mm; *3* – Belt conveyor DS.KSh-800; *4* – Crushing and screening plant; *5* – Coal dump, grain-size class –10+0 mm; *6* – Dump of coal +150 mm; *7* – Load haul dumper; *8* – BIG PL 900/GR packaging line in flexible containers; *9* – 1 t flexible containers; *10* – Warehouse-platform for temporary storage of packaged graded coal; *11* – Shielding canopy

Рисунок 2. Технологическая схема производства сортового угля навалом и в мягких контейнерах: *1* – отвал рядового угля; *2* – отвал сортового угля, –150+10 мм; *3* – ленточный конвейер ДС.КШ-800; *4* – дробильно-сортировочная установка; *5* – отвал угля, класс крупности –10+0 мм; *6* – отвал угля +150 мм; *7* – погрузочно-доставочная машина; *8* – линия упаковки BIG PL 900/GR в мягкие контейнеры; *9* – мягкие контейнеры 1 т; *10* – склад-площадка временного хранения упакованного сортового угля; *11* – экранирующий навес

Table 3. Comparative economic effectiveness assessment of using local coal instead of imported
Таблица 3. Сравнительная оценка экономической эффективности использования местного угля взамен привозного

Indicators	Local coal (Kirovsky open-cast mine)			Imported coal
	Option 1	Option 2	The current option	
	Sorting in bulk	Sorting + Packing		
Volume of raw coal processing, t	47,000	47,000	27,000	15,000
Capital expenditures, thousand rubles	4710	6210	–	–
Additional unit costs for the operation, rub./t	67	896	–	–
Cost of production and sale of 1 ton of coal, rub.	1839	2628	1767	2103
Cost of mining 1 ton of coal (without VAT), rub./t	2102	2891	2030	2303
Transportation costs for 1 ton of coal, rub./t		89		4200
Total cost of coal delivery to settlements, rub./t	2191	2980	2119	6503

Table 4. Qualitative characteristics of coal with existing and proposed technologies for managing coal quality
Таблица 4. Качественные характеристики угля при существующей и предлагаемых технологиях управления качеством угля

Indicators	Existing technology for shipment of coal in raw form	Option 1	Option 2
Ash content, %	11,6	7,2	7,2
Humidity, %	36,6	10–25	11
Volatile content, %	48,7	–	–
Average net calorific value Q_{ai}, kcal/kg	4205	> 4205	> 4205
Sieve composition, mm	–300+0	–150+10	–150+10

(***Option 1***) and graded coal in big bags (***Option 2***), capital expenditures are required in the amount of 4,710 thousand rubles and 6,210 thousand rubles respectively (table 3).

With the introduction of a new technology for producing graded coal (***Option 1***) and graded coal in big bags (***Option 2***), the cost of graded coal increases by 67 rubles/ton or by 3.5% compared to the cost of raw coal produced using the current technology, when sorting and packing coal in big bags – the growth is 42%, which is associated with the high cost of packaging material.

The calculations show that when imported coal (from the Belogorskoye deposit) is replaced with local (Kirovskoye) coal, the price of solid fuel will decrease by 2.2–3 times compared to the existing one for imported coal (from 6500 rubles/ton to 2191–2980 rubles) taking into account the caloric component and transport tariffs for transportation.

The proposed ***options*** for the release of coal products in graded form in bulk and in FIBCs contribute to reducing losses and improving quality (Table 4).

Saving when replacing imported coal with local for all consumers of the Nyurba region can amount to 53 million rubles (when using graded coal in bulk) and 37.9 million rubles (when using coal in flexible containers). At the same time, according to the authors, the energy security of the population comes to the fore, which is significantly increased due to a significant improvement in the transport accessibility of fuel and energy resources for consumers.

Conclusion

At present, the current situation with the supply of coal to the Vilyui group of regions of the Republic of Sakha (Yakutia) indicates the need to improve the efficiency of using local coal, since imported coal from other regions has a multiple (2.5–3 times) higher cost due to transportation costs.

It is proposed to increase the volume of production in the Kirovsky brown coal open-cast mine instead of using imported coal from the Belogorskoye deposit. The current scheme of shipment of coal in raw form, production of graded coal in bulk and production of graded coal in bulk in flexible containers are considered. In the conditions of the Far North, the technological scheme for the production of graded coal in bulk and in flexible containers in the Kirovsky micro-open-cast mine makes it possible to provide consumers in the Nyurba region with solid fuel of the appropriate volume and quality.

A feasibility study for producing graded thermal coal in raw form and in flexible containers confirmed the economic effectiveness of the proposed measures.

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Технико-экономические обоснование управлением качества энергетического угля на разрезах сверхмалой мощности в условиях Крайнего Севера

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Аннотация

Актуальность. Использование местных углей взамен привозных актуально для восточных и северных регионов нашей страны. Такие проблемы хорошо заметны на Кировском разрезе, который участвует в обеспечении энергетическим углем западной группы районов Республики Саха (Якутия), куда также доставляется привозная угольная продукция. Ее качество превышает местное, но при этом за счет сложной сезонной логистики имеют место снижение количественных и качественных потерь готового продукта и более высокая цена. Таким образом, становится необходимым обосновать геотехнологические меры получения сортового угля на местных разрезах, что позволит улучшить качественные и количественные показатели и повысить эффективность его использования взамен привозных, более дорогостоящих углей. Для предприятий, которые находятся в удаленных транспортно- и энергоизолированных районах Крайнего Севера, проблемы повышения качества использования местных ресурсов угля взамен привозных в настоящее время вышли за рамки исключительно технологического понятия, а имеют важное значение в рамках энергобезопасности населения, социально-экономического развития региона.

Цель работы – обосновать технологические решения по управлению качеством энергетического угля на сверхмалом угольном разрезе на Крайнем Севере для повышения эффективности поставок в удаленные районы и дать оценку эффективности предлагаемых мероприятий.

Методы исследований – научное обобщение, систематизация и анализ научно-технической литературы, метод аналогии по выбору геотехнологии для улучшения качества отгружаемого угля для потребителей с микроразреза в условиях Крайнего Севера.

Результаты исследований. Предлагается геотехнологическая схема по облагораживанию добытого твердого топлива, которая основана на концепции создания дополнительной технологической линии на разрезах сверхмалой мощности вблизи потребителей взамен дорогостоящей, сложной и ненадежной логистики завозимых углей. Она способствует технико-экономической оценке выпуска угольной продукции требуемого качества, расчетам экономической эффективности использования сортового угля навалом взамен рядового, а также использованию мягких контейнеров для транспортировки твердого топлива конечным потребителям.

Заключение. Данная технология позволяет снизить качественные и количественные потери угля, что позволяет использовать местный уголь взамен привозного конечным потребителям Нюрбинского района. Активная разработка местных угольных месторождений является одним из направлений повышения стабильности работы цепи поставок твердого топлива потребителям, а также энергетической безопасности труднодоступных районов Якутии и поддержки их экономического и социального развития.

***Ключевые слова*:** бурый уголь, разрез сверхмалой мощности, качество, сортировка, упаковка, гранулометрический состав, эффективность, Крайний Север.

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